VOLUME 17 SEPTEMBER, 1929 NUMBER 9

PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers

Forthcoming Meetings

BUFFALO-NIAGARA SECTION
Buffalo, N. Y., September 17, 1929

CHICAGO SECTION
Chicago, Ill., September 20, 1929

CLEVELAND SECTION
Cleveland, Ohio, September 18, 1929

DETROIT SECTION
Detroit, Mich., September 19, 1929

EASTERN GREAT LAKES DISTRICT CONVENTION
Rochester, N. Y., November 18-19, 1929

LOS ANGELES SECTION
Los Angeles, Calif., September 16, 1929

NEW YORK MEETING
New York, N. Y., October 2, 1929

PHILADELPHIA SECTION
Philadelphia, Penna., October 3, 1929

PITTSBURGH SECTION
Pittsburgh, Penna., September 17, 1929

SAN FRANCISCO SECTION
San Francisco, Calif., September 18, 1929

TORONTO SECTION
Toronto, Canada, September 16, 1929

WASHINGTON SECTION
Washington, D. C., September 12, 1929

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 17 September, 1929 Number 9

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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, 1923, 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, 1923, 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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EDWARD V. APPLETON

Recipient of 1929 Morris Liebmann Memorial Prize

Edward V. Appleton was born at Bradford, Yorkshire, England, in 1892. He studied at St. John's College, Cambridge, and Cavendish Laboratory, Cambridge, receiving the M.A. and D.Sc. degrees. During the period of the World War from 1914 to 1920 he was Captain in the Royal Engineers. In 1920 he joined the Cavendish Laboratory, Cambridge, as a demonstrator in physics, in which capacity he served until 1924. From 1924 to date he has been Professor of Physics, Wheatstone Laboratory, King's College, London, and a member of the Radio Research Board.

Professor Appleton was awarded the 1929 Morris Liebmann Memorial Prize for his investigations in the field of wave propagation phenomena. He was appointed to membership on the Committee on Meetings and Papers of the Institute in 1929 and has been an Associate member of the Institute since 1926.

INSTITUTE NEWS AND RADIO NOTES

Eastern Great Lakes District Convention

The tentative program for the Eastern Great Lakes District Convention, to be held in Rochester, N. Y., on November 18–19, 1929, is as follows:

Nov. 17—	4 P.M.–6 P.M.	—Registration
Nov. 18—	8:30 A.M.	—Registration
	10:00 A.M.	—Opening Session and Technical Talks
	12:00 M.	—Luncheon
	1:00 P.M.	—Inspection Trip
	8:00 P.M.	—Technical Session
Nov. 19—	9:00 A.M.	—Technical Session
	12:00 M.	—Luncheon
	1:00 P.M.	—Inspection Trip
	6:30 P.M.	—Banquet

The executive committee of the Convention is composed of the following members: Virgil M. Graham, chairman; L. Grant Hector, vice chairman; L. E. Hayslett, secretary; H. J. Klumb, treasurer.

The Convention is to be sponsored by the Buffalo-Niagara, Cleveland, Rochester, and Toronto sections. All members of the Institute are invited to take part in the two-day program which is being arranged.

Appointment of Assistant Secretary

The Board of Direction of the Institute of Radio Engineers at its June 5th meeting authorized the Secretary to secure the services of Harold P. Westman, of Hartford, Connecticut, as Assistant Secretary. Mr. Westman joined the office staff on July 15th. He will be actively associated with the several standardization projects which the Institute fosters, and will have charge of the general correspondence in the Institute office. He comes to the Institute from the American Radio Relay League of Hartford, Connecticut, where he has been employed as technical editor of the magazine *QST* for the past several years.

H. B. Richmond Elected President of R. M. A.

H. B. Richmond, treasurer of General Radio Company, has been elected president of the Radio Manufacturers' Association for 1929–1930. Mr. Richmond for a number of years has been prominent in the Radio Manufacturers' Association as chairman of its Engineering Division. In that capacity he is succeeded by Walter E. Holland, of the Philadelphia Storage Battery Company. R. H. Manson, of Stromberg-Carlson Manufacturing Company, is to be in charge of the standardization activities of the R. M. A.

All of these gentlemen are well known to Institute members. Each has taken an active part in the work of the Institute's Committee on Standardization.

Books Received

Under this heading it is proposed, from time to time, to publish in the PROCEEDINGS brief announcements of new books received at the Institute's editorial office. Such an announcement will be found in the present issue. More extended reviews of books will also be offered as heretofore, although of necessity their preparation entails some delay.

Associate Application Form

It has been decided that the advertising section of each issue of the PROCEEDINGS will contain a condensed application form for Associate membership in the Institute. This form is placed in the PROCEEDINGS for the benefit of members who desire to have eligible non-members enrolled in this grade of membership.

The attention of the membership is again called to the fact that the names of non-member business associates may be used as references for Associate membership in the Institute if the applicant does not personally know five Associates, Members, or Fellows.

U. S. Civil Service Examinations

The United States Civil Service Commission announces open competitive examinations for the positions of physicist, ($3,800 per year), associate physicist, ($3,200 per year), and assistant physicist ($2,600 per year). Vacancies in the Bureau of Standards and Bureau of Mines, Department of Commerce, under the National Advisory Committee for Aeronautics and in positions requiring similar qualifications in other branches of the service will be filled from these examinations.

Applicants will not be required to report for examination at any place, but will be rated on education and experience (70 per cent) and writing, such as publications, reports or theses which are to be filed by the applicant, (30 per cent).

Members of the Institute interested in any of these positions should communicate with the U. S. Civil Service Commission, Washington, D. C. requesting Form No. 2600 and stating the exact title of the examination desired, referring to announcement No. 180.

1928 Standardization Report

There are still available a few copies of the reprint of the 1928 Standardization Report which appeared in the 1929 Year Book. One copy of this reprint is available free of charge to each member of the Institute upon request to the Secretary. To non-members the price is one dollar each.

World Engineering Congress

F. B. Jewett, vice president of the American Telephone and Telegraph Company, and C. W. Latimer, of the Radio Corporation of America, New York City, have been appointed the official representatives of the Institute of Radio Engineers at the World Engineering Congress to be held in Tokio in October of 1929.

Mr. Latimer is to present the paper, "Technical Achievements in Broadcasting and Their Relation to National and International Solidarity" which has been prepared by a Symposium Committee of the Institute. This paper is to be published in the November, 1929, issue of the PROCEEDINGS.

Incorrect Addresses

On pages XXI and XXII of the advertising section of this issue will be found the names of one hundred and twelve members of the Institute whose correct addresses are not known. It will be appreciated if members of the Institute having any imformation concerning the present addresses of any of the persons listed will communicate with the Secretary of the Institute.

Proceedings Binders

For the past several years the Institute has made available at cost a binder for copies of the PROCEEDINGS. Several hundred of these have been distributed to the membership.

These binders serve as a very convenient means of preserving current issues of the PROCEEDINGS, since each individual issue is held in place by a wire strap without damaging the copy.

The binders are available at one dollar and fifty cents each, postpaid, from the Secretary.

Institute Meetings

JUNE NEW YORK MEETING

It was erroneously announced in a previous issue of the PROCEEDINGS that J. O. McNally presented the paper, "A Study of the Output Power Obtained from Vacuum Tubes of Different Types," at the June 5th meeting of the Institute in New York City. This paper was presented by the co-author, H. A. Pidgeon, of Bell Telephone Laboratories.

CONNECTICUT VALLEY SECTION

A meeting of the Connecticut Valley section was held in the auditorium of the Hartford Electric Light Company, Hartford, Conn., on July 11th.

E. A. Laport, of the Westinghouse Electric and Manufacturing Company, presented a talk on "The Installation of Three Radio Telephone and Telegraph Stations in China." Twenty-six members of the Institute were present.

SEATTLE SECTION

On June 4th a meeting of the Seattle section was held jointly with the Seattle section of the American Institute of Electrical Engineers in Eagles Auditorium, Seattle. A. V. Eastman, chairman of the section, presided.

S. P. Grace, assistant vice president of the Bell Telephone Laboratories of New York, presented a lecture and demonstration. The operation of many of the modern electrical marvels pertaining to sound transmission, including the following, were explained: the artificial larynx in use, the mechanical lung in use, the electric brain functioning, the electric ear functioning, the record of a heart beat, the evolution of telephony, a victrola playing a picture, the law of gravitation defied, delayed speech, scrambled speech.

Due to the unusual interest in this program, the desire of a great many people to attend, and the limited seating capacity of the auditorium, admission was by ticket only. One hundred and sixty members of the two societies and their guests attended.

Committee Work

Committee on Admissions

A meeting of the Committee on Admissions was held in the office of the Institute on July 10, 1929 at 9:30 A.M. The following members were present: R. A. Heising, chairman; H. F. Dart, Arthur Batcheller, and E. R. Shute.

The committee considered a number of recommendations of the Committee on Membership for transfer of members to the higher grades of membership in the Institute.

Standardization Committee

Dr. Taylor has appointed the following chairmen of the subcommittees of the Committee on Standardization: C. B. Jolliffe, vacuum tubes; Haraden Pratt, transmitters; E. T. Dickey, receivers; H. A. Frederick, electro-acoustic devices.

1930 Convention

President Taylor has appointed a small subcommittee to arrange the technical program for the 1930 Convention. The membership of this Committee is as follows: K. S. Van Dyke, chairman; W. Wilson, H. M. Turner, and V. G. Smith.

The first meeting of the Committee was held on July 24th in the office of the Institute. Preliminary plans for the technical program were drawn up. Tentatively, the Committee plans a symposium, a lecture of popular interest, and two sessions of individual papers. It is expected that between twelve and fourteen papers will be presented at these four sessions.

Personal Mention

Harry R. Lubcke has recently become assistant director of research with the Crocker Research Laboratory of San Francisco.

Leroy Moffett, Jr., a recent graduate of the University of Oklahoma, is now student engineer with the Southwestern Bell Telephone Company at Oklahoma City, Okla.

Ray E. Stauffer has become associated with the General Electric Company at Schenectady, N. Y. in the radio engineering department. Mr. Stauffer was formerly a student of the University of Iowa.

Arthur V. Baldwin is now associated with the Johnsburg (Pennsylvania) Radio Corporation as radio engineer. Mr. Baldwin was formerly assistant engineer at the Canadian Westinghouse Company, Ltd., Hamilton, Ontario.

William H. Doherty, formerly research associate, Radio Laboratory of Bureau of Standards at Washington, D. C., has recently joined the staff of the Bell Telephone Laboratories at New York City as radio engineer.

W. S. Duttera, of Gettysburg College, has become associated with the General Electric Company at Schenectady in the Radio Development Department.

Edward J. Fielding, formerly movietone engineer, Major Laboratories at New York City, has become assistant engineer with the Madison Square Broadcasting Corporation in New York City.

Frederick A. Holborn, until recently radio engineer with Federal Brandes Corporation at Newark, N. J., has joined the Gold Seal Electric Company of Newark, N. J., as chief engineer.

Sidney G. Knight is now associated with Les Laboratories Standard at Paris, France, having formerly been with the International Standard Electric Corporation at London.

D. Blair Mirk, until recently in London, England, with the International Standard Electric Corporation as radio engineer, has joined Les Laboratories Standard at Paris.

Glen R. Ogg, formerly chief radio electrician on the USS *California*, is now officer in charge of the U.S. Naval Radio Station at Brownsville, Texas.

Henry Tanck is now on the engineering staff of the Federal Telegraph Company at Palo Alto, Cal.

David G. Wyles, until recently radio engineer with National Electric and Engineering Company, Ltd., of Wellington, New Zealand, has become technical manager of Philipps Lamps, at Melbourne, Australia.

L. C. F. Horle, for a number of years chief engineer of the Federal Telephone Manufacturing Company at Buffalo, N. Y., is now located in New York City where he is practicing consulting radio engineering in radio design and development, and patent matters at the Hudson Terminal Building. Since the organization of the Buffalo-Niagara section of the Institute, Mr. Horle has served as its chairman.

H. H. Friend, Physics Department, Lehigh University, is now located in the Research Department of the Radio Corporation of America, New York City.

F. T. Brewer has joined the engineering staff of the Bremer-Tully Manufacturing Co. of Chicago as radio engineer. Mr. Brewer is a recent graduate of the University of Illinois.

L. W. Howard, a graduate of the University of California in the class of 1929, has become associated with the Federal Telegraph Co., Palo Alto, California, in the Engineering Department.

Ray A. Montford, formerly assistant operator at Station WDAF at Kansas City, Mo., is now associated with the Western Electric Co. at Kearney, N. J., as equipment engineer.

William W. Waltz, formerly with the Electric Storage Battery Co. of Philadelphia, is now employed as installation engineer at the Electrical Research Products, Inc., New York City.

Edward N. Dingley, Jr., until recently asociated with the Bureau of Engineering, Navy Dept., as radio engineer at Washington, has joined the engineering staff of the Mackay Radio and Telegraph Co. at New York City.

Paul A. Kober is now associated with the Claud Neon National Laboratories of Long Island City. Mr. Kober was formerly connected with the Daven Corporation of Newark, N. J., on television problems.

Theodore H. Mann, formerly factory manager of Theodore Mann and Co. at Bielefeld, Germany, is now employed as laboratory assistant in the Sound Department of William Fox Studios at Hollywood, Calif.

W. B. Moorehouse, until recently associated with Westinghouse Lamp Co. as radio development engineer, is now employed as research engineer with the Bell Telephone Laboratories, Inc., New York City.

Walter F. Lanterman has resigned from the radio engineering department of the General Electric Company at Schenectady to become development engineer of the Universal Wireless Communications with headquarters at Chicago.

John B. Hawkins has recently become resident manager at United Reproducers Corporation, St. Charles, Ill.

John F. Farrington has resigned from the telephone engineering staff of the Bell Telephone Laboratories at New York to become radio engineer with the International Communications Laboratories, Inc., New York City.

H. R. Butler, for some time employed in the radio engineering department of the General Electric Company, has joined the staff at Wired Radio, Inc., as radio engineer.

Carl E. Welcher, formerly manager of Station WKEN at Buffalo, is now installation engineer with Electrical Research Products, Inc., New York City.

Thomas S. McCaleb, for several years electrical engineer with the Liberian government at Monrovia, W. Africa, has recently become associated with the Pan-American Airways, Inc., in the capacity of assistant communication engineer of the Mexican Division.

M. G. McCarroll has left the General Electric Company at Schenectady to become sound technician with Paramount News in New York City.

E. G. Ports, until recently research engineer with the Bell Telephone Laboratories, Inc., is now employed by International Communication Laboratories, Inc., at New York City as communication engineer.

G. Edwin Stewart resigned from the National Broadcasting Co. and has become chief recording engineer of Paramount Famous Lasky Corporation at New York City.

Paul M. Segal, for a number of years attorney in the District Attorney's Office, Denver, Colorado, has joined the staff of the Federal Radio Commission as assistant general counsel.

John L. Weston, for some time associated with the General Electric Co. at Schenectady in the radio engineering department, has recently joined the Engineering Staff of Wired Radio Inc., at Newark, N. J.

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED

August 7, 1929

Transferred to the Member grade

Dist. of Columbia	Washington, c/o Federal Radio Commission	Segal, Paul M.
	Washington, 3314 Newark St.	Mirick, C. B.

Elected to the Member grade

California	San Francisco, Signal Office, Presidio of San Francisco	Winner, William Lane, Jr.
Dist. of Columbia	Washington, Dept. of Commerce, Radio Division	Barron, J. H., Jr.
Illinois	Alton, 1124 Washington St.	d'Adrian, A. L. Duval
	Chicago, 1400 Union Trust Bldg.	Caldwell, Louis G.
Massachusetts	Waban, 100 Devon Road	Replogle, Delbert E.
Montana	Bozeman, c/o Montana State College	West, Glenn Edwin
New Jersey	Boonton, Radio Frequency Laboratories, Inc.	Wilmotte, R. M.
	Maplewood, 26 Berkeley Road	Pidgeon, Howard A.
New York	New York City, USS *Bridge*, c/o Postmaster	Johnson, C. M.
	New York City, 711 Fifth Ave., Room 1223	McElrath, George
Pennsylvania	State College, 234 West Fairmont Ave.	Woodruff, Eugene C.
Canada	Toronto, Ont., Windsor Arms Apts., St. Thomas and Sultan Sts.	Schwarz, Bertram A.
England	Leeds, Yorks, 35 Reginald Terrace, Chapeltown	Harvey, Lionel
	Leeds, 6 Blenheim Terrace, Northeastern School of Wireless	Russell, M. W. G.
	Manchester, British Broadcasting Corp.	Bird, R. J.
	Norbury, SW, 119 Headcorn Road	Shaw, A. C.
Germany	Berlin, Fritschestrasse 41, I, Charlottenburg	Roder, Hans
Italy	Milan, Corso Italia, 13, c/o S.I.R.A.C.	Osiatinsky, L.
New Zealand	Christchurch, Canterbury University College, Elec. Dept.	McLellan, Roderick Arthur
	Wellington, G. P. O. Box 638	Thow, Keith H.
Scotland	Dundee, 1 Lochee Road	Lyne, R. H.
	Edinburgh, "Dunelm," 8 Cluny Drive	Beveridge, John A.
Spain	Cartagena, Calle de Ignacio Garcia No. 3	Ramirez Eduardo Garcia

Elected to the Associate grade

Alabama	Birmingham, 1315 Woodland Ave., W. E.	Giglio, James A.
Arkansas	Little Rock, c/o Marine Hotel, Room 850	Beem, Arthur W.
	North Little Rock, 1301 W. 9th St.	McDonald, A. H.
	Little Rock, 1311 Commer St.	Minor, Robert Lee
California	Glendale, 1341 5th St.	Bockoven, Lewis Murray
	Hollywood, 814 No. Vista St.	Schiefer, C. Vreeland
	Los Angeles, New City Hall, Room 317	Chapple, James M.
	Los Angeles, 2848 Westview St.	Gronoff. Harry
Colorado	Denver, 3839 Yates	McClimans, Abner E.
	Denver, 1536 South Acoma St.	Strelesky, H. J.
Dist. of Columbia	Washington, 4201 9th St., N. W.	Fugazzi, Frank J.
	Washington, 1722 19th St., Apt. 706	Hudiburg, Rea S.
	Washington, 917 North Carolina Ave., S. E.	Monar, Fred B.
	Washington, 5806 Colorado Ave.	Murray, Philip J.
	Washington, 3308 14th St., N. W.	Zinnecker, H. K.
Florida	Orlando, 30 E. Pine St.	Shreve, A. French
Illinois	Chicago, 6038 Calumet Ave.	Hellman, Milton E.
	Chicago, 4865 North Hermitage	Hukle, R. M.
	Chicago, 1541 East 65th St.	Johnson, E. O.
	Chicago, 4250 W. North Ave.	Lagasse, Albert
Indiana	Indianapolis, 2136 North De Quincey St.	Chapel, I. C.
Kentucky	Ashland, c/o General Office, American Rolling Mill Co.	Carr, Edward Mayes
	Newport, 43 16th Street Clifton	Preuss, Arthur C.
Louisiana	Slagle	Hayes, Fred D.
Massachusetts	Belmont, 33 Willow St.	Sykes, Roger Allen
	Chicopee Falls, 121 East St.	Winstead, Theodore Bernard
	Great Barrington, 24 Silver St.	Parrish, Robert R.
	Salem, 27 Chestnut St.	Poor, Walter E.
	Sommerville, 46 Francesca Ave.	Dillaby, Edwin F.
	Springfield, 1283 Carew St.	Morehouse, Dayton J.
	Walton, 42 Brookfield Road	Clark, R. W. 3rd

Michigan	Detroit, 10401 Jefferson Ave., E.	Harding, Lawrence Merle
	Detroit, 324 Hendrie Ave.	Schaefer, Richard J.
	East Lansing, Hermian House	Moore, Harold A.
	Jackson, Sparks-Withington Co.	Obright, C. Alvin
	Jackson, Sparks-Withington Co.	Strait, Clarence L.
	Kalamazoo, 216 Rose Place	Goldsmith, O. Brude
	Marshall, 301 N. Liberty St.	Faulkner, Douglas
	Ypsilanti, 406 Florence St.	Augustus, Lee M.
Minnesota	Minneapolis, 4912 41st Ave., S.	Roth, Harold B.
	St. Paul KSTP, St. Paul Hotel	Mills, H. Lawrence
Missouri	Independence, 109 Bowen St.	Beck, Ray
	Kansas City, 4707 Grand Ave.	Fouts, Avery L.
	Kansas City, 2904 Forest Ave.	Gundy, Clarence Van
	Kansas City, Federal Building, Room 231	McDonell, William J.
	Kansas City, 4211 Wabash Ave.	Swett, J. P.
New Jersey	Cliffwood, Bell Telephone Labs.	Crawford, Arthur B.
	Fort Monmouth	Hoppough, Clay I.
	Lawrenceville, A. T. and T. Co. Radio Station	Gilman, George William
	Long Branch, 165 Garfield Ave.	Herson, Jacob S.
	Roselle Park, 216 Filbert St.	Robinson, James W.
	Rutherford, 1 Erie Ave.	Wattson, Harry B.
New York	Brooklyn, 521 Monroe St.	Grainger, Maurice J.
	Brooklyn, 269 Fifteenth St.	Levine, Harry
	Brooklyn, 330 Bambridge St.	Perrin, Arthur G.
	Candor	Williams, Warren R.
	Elmira, P. O. Box 402	Downing, Richard E.
	Jackson Heights, L. I., 78 84th St.	Stotler, Albert
	Long Island City, 50-65 40th St.	Asch, Marcus
	New York City, 618 W. 136th St.	Carazo, Louis
	New York City, c/o Lexington Hardware and Radio Co., 1633 Lexington Ave.	Kaplan, Benjamin G.
	New York City, 583 Riverside Drive	Knight, J. B., Jr.
	New York City, 24 Walker St., Room 203.	Nichols, Eldon
	New York City, 3063 Godwin Terrace	Rosenfield, Melville J.
	New York City, Radiomarine Corp. of Amer., 326 Broadway	Venner, E. G.
	Port Jefferson, 238 E. Broadway	Carter, Philip Staats
	Rochester, 200 Central Trust Bldg.	Burns, Robert G.
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	Syracuse, 230 Roxford Road	Martin, George L.
Ohio	Canton, 137 Columbus Ave., N. W.	Faulstich, C. J.
	Cincinnati, 3120 Montana Ave.	Felix, Clarence George
	Cincinnati, Crosley Radio Corp.	Hunter, Theodore A.
	Cleveland, 2309 Roanoke Ave.	Burkhardt, Karl R.
	Cleveland, Research Labs., National Carbon Co.	Filgate, John T.
	Cleveland, 5800 Broadway	Martin, Frank J.
	Columbus, 2205 Summit St.	Stringfellow, William
	Springfield, 2103 Elmwood Ave.	Downey, William C.
	Springfield, 556 S. Limestone St.	Stolzenbach, R. W.
	Wooster, 408 W. Grant St.	Specht, Miles
Oregon	Portland, 901 E. Yamhill	Neubauer, Edwin William
Pennsylvania	Bethlehem, 520 W. Broad St.	Hottel, H. W.
	Bradford, 21 Thompson Ave.	Gimera, George
	Harrisburg, 401 Wiconisco St.	Heckman, J. W.
	Harrisburg, 1722 Boas St.	Poorman, Arthur E.
	Lansdale, 122 E. 5th St.	Schieber, Leonard B.
	Oil City, Box 514	Paca, William S.
	Philadelphia, 2924 Poplar St.	Greathead, Arthur W.
	Philadelphia, Moore School of Elec. Engr., U. of P.	Jen, C. K.
	Philadelphia, 6814 N. 16th St.	Lowe, Carr E.
	Pittsburgh, 1216 Chelton Ave.	Ostermeier, C. H.
	Sharon Hill, 32 Bonsall Ave.	Travis, Irven A.
	Swissvale, 7442 Washington St.	Stanton, J. S.
South Carolina	Columbia, c/o Perry-Mann Electric Co.	Buggel, William Edward Rose
Tennessee	Memphis, 505 South Main St.	Randolph, George T.
Texas	Houston, 1620 Main St.	Carter, William H., Jr.
	San Angelo, 16 South Milton St.	Jones, Frank M.
Australia	Strathfield, "Glenroy," 19 Concord Road	McIntyre, Daniel G.
Canada	Halifax, N. S., 69 Dublin St.	Crowell, A. M.
	Montreal, Que., c/o Northern Electric Co., Ltd.	Catton, W. R.
	Montreal, Que., Northern Electric Co., 637 Craig St. W.	Comach, Stanley I.
	Toronto 8, Ont., 34 Belhaven Road	Kitchen, C. P.
	Toronto 4, Ont., 7 Delaware Ave.	Nichols, W. A.
	Victoria, B. C. 1518 Cook St.	Murdoch, G.
	Weston, Ont.	Hollinsworth, V. E.
England	London SW1, 52 Eaton Terrace, Westminster	Troutbeck, Wilfrid H.
	Surrey, Sutton, "Gateside," Sutton Common Road	Howard, C. G.
	Wigan, Lancs., 4 Springfield St.	Evans, Alfred
India	Bombay, Indian Radio Telegraph Office	Enon, Ernest R.
Philippine Islands	Manila, 306 San Antonio Paco	Aglugub, Zacarias G.
South Africa	Johannesburg, P. O. Box 6461	Archer, C.

South Rhodesia	Salisbury, P. O. Box 34, c/o Messrs. Hubert Davies & Co., Ltd.	Morison, Bruce

Elected to the Junior grade

Illinois	North Chicago, 1510 Sheridan Road	Taylor, H. S.
Kansas	Lawrence, 1024 Alabama St.	Wheeler, Frederick
Minnesota	Northfield	Griffith, Paul E.
Missouri	St. Louis, 2615 St. Vincent Ave.	Duffy, Charles A.
New York	Brooklyn, 825 DeKalb Ave.	Dlugatch, Irwin
	Yonkers, 448 North Broadway	Seitz, Frank A., Jr.
Washington	Vancouver, 1210 Harney St.	Ryan, Lloyd F.

APPLICATIONS FOR MEMBERSHIP

Applications for 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 election of any of these applicants should communicate with the Secretary on or before September 30th. These applicants will be elected by the Board of Direction at its October 2nd meeting.

For Transfer to the Member grade

California	Palo Alto, Federal Telegraph Company	Suydam, Clinton H.
Illinois	Chicago, 5746 Drexel Blvd.	Deeley, Paul McK.
	Chicago, 2022 The Engineering Bldg.	Hayes, H. D.
	Chicago, 6222 Woodlawn Ave.	Keselton, Chas. C.
Massachusetts	Tufts College	Kenrick, Gleason W.
New Jersey	Westfield, 519 Alden Ave.	Baukat, Henry W.
New York	Baldwin, L. I., 17 Brookwold Ave.	Hoernel, Paul C.

For Election 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.

For Election 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 East 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 So. 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.
	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.
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Maine	Portland, 67 Bradley St.	Ryall, Henry
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	Mattapan, 55 Goodale Road	Parnes, Henry
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	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 West 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
	Jamesport	Seaman, James Corwin
	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.
	New York City, Bell Tel. Labs., 463 West St.	Bousquet, Arthur G.
	New York City, 502 W. 152nd St.	Buckler, John J.
	New York City, Int. Com. Lab., Research Dept., 67 Broad St.	Cahill, William J.
	New York City, Bell Tel. Labs., 463 West St.	Carlton, Roger C.
	New York City, c/o E. T. Cunningham, Inc., 370 7th Ave.	Carroll, Michael J.
	New York City, Bell Tel. Labs., 463 West St.	Decino, Alfred
	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
	New York City, 1130 Anderson Ave., Bronx	Levy, Lester
	New York City, 132 E. 36th St.	McSweeny, Roger
	New York City, E. R. P. I., 250 W. 57th St.	Nickerson, Fred W.
	New York City, Bell Tel. Labs., 463 West St.	Nimmcke, Frederick E.
	New York City, 100 Morningside Drive	Shelby, R. E.
	New York City, c/o National Broadcasting Co., 711 Fifth Ave.	Smith, William Wallace
	New York City, 1065 Lexington Ave.	Taussig, Wm. S.
	New York City, 43 W. 12th St.	Whitmer, Robert M.
	Pelham Manor, 1465 Roosevelt Ave.	Kelly, Dale
	Riverhead, c/o R. C. A.	Schoenborn, Ferd.
	Schenectady, General Electric Co., Research Lab.	De Walt, K. C.
	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, Herbert William
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 E.
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.
	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, Manue 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.	Linnstt, Douglas N.

For Election 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 Jersey	Sea Side Park, 118 E St.	Slattery, John J.
New York	New York City, 3164 Grand Concourse	Linde, James E.
Pennsylvania	Philadelphia, 224 E. Sharpnack St.	Bosco, Joseph F.
South Dakota	Humboldt	Tilgner, Shelton R.
India	Benares City, 56 Luxa	Ghosh, B. N.

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PART II

TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 17, Number 9 *September, 1929*

STUDIES OF ECHO SIGNALS*

By
A. Hoyt Taylor and L. C. Young
(Naval Research Laboratory, Bellevue, Anacostia, D. C.)

Summary—*This paper is a continuation of work reported in the Proceedings of the Institute of Radio Engineers for May 1928 by the same authors. A more extended study of echo signals with particular reference to directional characteristics and to diurnal variations has been carried out. Attention has also been given to the question of the relations between the echo signal and the frequency. Distortions, probably due to echo signals, have been recorded on long distance transmission. The relation between the echo signal and effective height of the Kennelly-Heaviside layer has been discussed.*

ALTHOUGH this paper is not primarily concerned with around-the-world signals which are not truly echo signals, it is nevertheless a continuation of the studies of high-frequency radio wave propagation published previously,[1] and therefore it will be proper to mention at the outset that one of the predictions in regard to the nature of round-the-world signals has since the publication of the earlier paper been found to be correct. In discussing the above mentioned reference it was stated that South American stations had not so far shown round-the-world signals, but that they might possibly be expected to do so in the high-frequency bands during the equinoctial periods and only at those times. Since it has a bearing on the general correctness of the analysis of conditions producing round-the-world signals previously given, it is interesting for us to be able to state that since the earlier paper was written round-the-world signals have been recorded on 21,500 kc from Buenos Aires operating then under the call LP2. These round-the-world signals were repeatedly noticed during the equinoctial periods of fall and spring, but have been noted at no other times, thus substantially verifying the prediction made in the earlier paper. A typical record of such conditions is shown in Fig. 1. The top line on the figure is the timing line produced by a 200-cycle tuning fork. The next line shows overlapping signals and echoes so that the signal was unreadable. The next line is again the timing line followed by a record, reading from left to right, which shows the tail end of the signal followed by a round-the-world echo, whose timing difference corresponds to approximately 0.14 second for a trip around the world. The next line is again the timing line followed by a record,

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[1] Taylor and Young, Proc. I. R. E., 16, 561; May, 1928.

reading from left to right, which shows the letter *A* with weak round-the-world signals of both the dot and dash. By measuring from the end of the round-the-world signal corresponding to the dash back to the end of the dash itself, we again find a timing interval corresponding to a trip around the world of 0.14 of a second. A similar measurement can be obtained by measuring from the beginning of the dot to the beginning of the round-the-world signal following the dot and which is overlapped by the dash. Round-the-world signals from southern stations are then, as previously predicted, only ordinarily to be found close to the equinoctial period and not by any means every day even at that time.

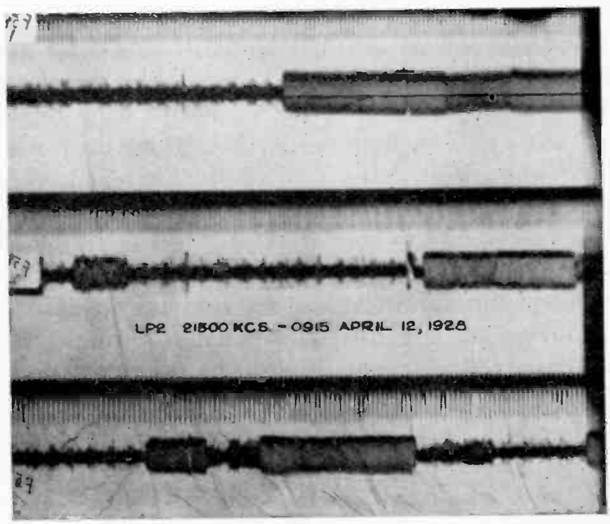

Fig. 1

It will be recalled that in the earlier paper simultaneous measurements were made on Rocky Point stations on the fundamental and the sub-harmonic of frequencies in the 18 mc band. It has been found that at certain hours of the day, depending somewhat on the season of the year, similar measurements can be made on South American stations excepting that in this case we are recording the transmitted signal and its harmonic instead of the sub-harmonic. It is, of course, understood that the sub-harmonic came from imperfectly shielded intermediate stages in the transmitter which were operating on one-half the frequency of the output and which coupled a small amount of energy in the antenna, which was nevertheless sufficient for recording.

In the case of the South American records shown in Fig. 2 on LP1, also at Buenos Aires, we have to do here with simultaneous transmissions, one of which is a real harmonic of the other. The upper line represents the transmission on 8500 kc and the lower one the harmonic on 17,000 kc. This record was taken at the hour 1745 on March 17, 1928. At this hour the Kennelly-Heaviside layer has not risen high enough to eliminate the upper frequency, but is high enough to permit good signals on both frequencies. It is assumed from the nature of the traffic that the station at this time was actually operating on 8500 kc. It is difficult to see, however, how the signals could have been read in this country on 8500 kc on account of prolongations of the signal due undoubtedly to short-time echoes, whereas the signal was extremely clear-cut and well defined on the harmonic frequency of 17,000 kc. It was thought at first that the tailing out or prolongation of the 8500 kc signals could be explained in the following way: If the layer were at an effective height of, say, 280 to 320 km, it would at this hour of the day permit both fairly low-angle and fairly high-angle rays to enter

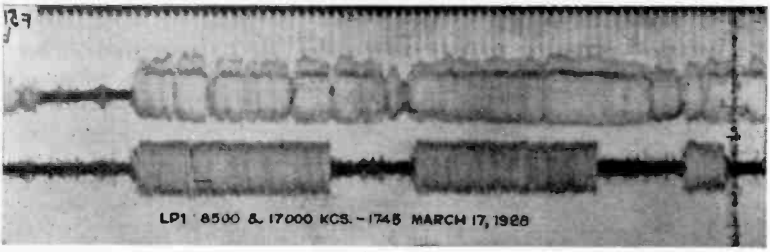

Fig. 2

into the reception at Washington. The low-angle rays would make only a few alternate reflections on the layer and earth on the way up from South America, whereas the high-angle rays would make a good many reflections and therefore would arrive later, thus prolonging the signal. That this effect actually does frequently occur we are well convinced. Indeed, it probably normally occurs except where the high-angle rays are prohibited either from too great a layer height or too great an absorption. But in this particular instance the overlap from 0.04 to 0.05 of a second is too great to permit this explanation to hold for it. Neither does the overlap seem to be of the proper magnitude to be accounted for at all by round-the-world signals. Indeed, there is no other indication, either in the pictures or by ear, of the existence of round-the-world signals at 8500 kc. This record is not only interesting because it cannot be readily explained, but is of practical importance as showing how this prolongation of the signal can practically limit the communication to very low speeds indeed. It should be clear from the record that the speed of communication at the time it was taken was not more than ordinary hand speed, and yet it was too fast for a clear and legible record to come through on 8500 kc on account of the above mentioned prolongations. On the other hand, the signals received at the same time on harmonic frequency could readily have been perfectly legible at high speeds as they were remarkably clear-cut.

Fig. 3 shows some records taken on Bogata, formerly called HJG, simultaneously on 13,700 and 27,400 kc. These records were taken in the daytime, and it will be noted that the 27,400 signal either arrives at the same time as the 13,700 signal or a little earlier. This probably indicates that the signal on the higher frequency is arriving by means of principally low-angle paths with less reflections than is the case on the lower frequency. This is in general accord with the idea that very high frequencies are restricted to relatively low angles except under conditions involving rather unusual electron distribution in the layer.

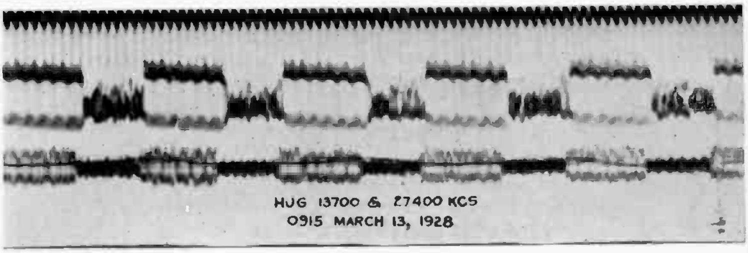

Fig. 3

The interval of lag on the front of the dots and dashes varies from 0 to 0.003 second; on the rear of the dots and dashes this interval varies from 0.00185 to 0.0035. These figures are based on a number of different photographs, only one of which is illustrated. This type of time lag or hang-over can probably be readily explained by the above explanation of different wave paths. These observations also show a sharper delineation of dots and dashes on the higher frequency, as they should if the explanation is adequate. It will be clear then that while the results shown in Fig. 3 just discussed are susceptible of explanation without reference to echo signals, the results in Fig. 2 must be interpreted as due to some kind of echo effect.

In order to carry out studies of short time echoes in such a way as to throw some light on the direction from which they come, it was decided to locate an observing center at some point out in the country where directive antenna structures could be effectively used and where interference would be at a minimum. The U. S. Coast and Geodetic

Survey very kindly offered the Naval Research Laboratory the use of such a location at the Cheltenham Magnetic Observatory, which lies just off the Crane Highway at a point some eleven miles in an air line slightly south of east from the Naval Research Laboratory. It was found at this point that the ground wave which furnishes the timing basis for observations from our own transmitters could be received with sufficient strength to make an excellent record. There are absolutely no power lines, telephone wires, or other distorting and disturbing influences on this location, and we were therefore able to set up four long low, single-wire antennas to the four cardinal points of the compass, grounding the ends of them through resistances. A rather sensitive receiver was used for the work which had a stage of shield-grid radio-frequency amplification preceding the detector. A Westinghouse oscillograph was used for recording. The transmitters at the Naval Research Laboratory were provided with a contacting arrangement which permitted transmission of extremely brief dots so spaced that round-the-world signals would rarely be confused with short-time echoes.

Preliminary studies of the directivity of the four receiving wires were made by observing long distance stations and their general directive properties were found to be excellent. With very few exceptions western stations were invariably received more than three times stronger on the west wire than they were on the north and south wire, and were received scarcely at all on the east wire. The South American stations showed the same behavior with reference to the south wire. European stations, on the other hand, being from the northeast, came in almost equally well on the north and east wires, but very poorly on the south and west wires. There were two exceptions to this check on the directivity of the receiving wires. Occasionally European stations would come in phenomenally well at certain hours late in the evening on the south wire, but these were clearly exceptional cases for which we have no adequate explanation. Another exception was that our own station which should have sent its ground wave in with the greatest strength on the west wire was in fact received much better on the north wire. Since, however, the frequencies used were rather high and the country in between was extremely rough and hilly, it is quite easy to see that violent distortions of the ground wave pattern could readily account for this result, and the general action on long distance signals gave us reason to expect that the directional results obtained on echo signals would be sufficiently reliable. In our earlier paper we made the suggestion that the short time echoes were largely due to reflection from rough or hilly country, and when we went to work at Cheltenham we naturally expected to find the strongest and most numerous echoes coming from the west and north. While we did observe plenty of echoes from these directions we were surprised to find that the most numerous and the strongest echoes almost invariably came from the south and east, in both of which directions lies the sea. It would appear to us apparent, after a careful study of this matter and an examination of hundreds of echoes, that the surface of the sea is an excellent medium (possibly due to its high refractive index) for throwing back these echo signals. We are not yet able to say whether this action differs in stormy weather from the action in calm weather.

TABLE I

NKF 18.5 Megacycles April 30, 1928

Time	EAST		SOUTH		WEST		NORTH	
	1st Group	2nd and 3rd Groups	1st Group	2nd and 3rd Groups	1st Group	2nd and 3rd Groups	1st Gr u	2nd and 3rd Groups
1600	0.0107		0.0094 0.0107		0.0115 0.0123		0.0104 0.0120	
1700	0.0110 0.0116 0.0125	0.0257 0.0276	0.0098 0.0118		0.0108			
1730	0.0102 0.0118	0.0230 0.0238	0.0144		0.0111			
1830				0.0174 0.0190	0.0106		0.0101 0.0110	
1900	0.0115 0.0122	0.0236 0.0261 0.0360 0.0370	0.0106 0.0112	0.0186 0.0255 0.0294 0.0345	0.0112		0.0116 0.0125	
1930	0.0120 0.0125 0.0141	0.0282 0.0306 0.0370 0.0410	0.0123		0.0148		0.0119	0.0286 0.0299
2000	0.0130 0.0130	0.0291 0.0334	0.0136 0.0143		0.0112 0.0115		0.0133 0.0147	
2030	0.0122 0.0125 0.0151	0.0288	0.0140		0.0120 0.0120		0.0152 0.0178	
2100	0.0187 0.0190	0.0293 0.0309	0.0189 0.0196		0.0148 0.0175	0.0258 0.0260	0.0195 0.0197	
2130	0.0181 0.0184 0.0188	0.0326 0.0330 0.0345	0.0198		0.0182 0.0198	0.0296 0.0342	0.0188 0.0201	
2200			0.0220 0.0246	0.0370 0.0392	0.0184 0.0190		0.0188 0.0196	0.0301
2230	0.0181 0.0187 0.0188 0.0205	0.0335 0.0370	0.0202 0.0245		0.0204 0.0217		0.0184	
2300	0.0152 0.0171 0.0182 0.0185 0.0190 0.0210	0.0351 0.0355 0.0361	0.0207 0.0208 0.0240	0.0291 0.0312	0.0189 0.0197		0.0200 0.0210	

The first test at Cheltenham was made with a high power transmitter at the Naval Research Laboratory set on 18,500 kc. Table I summarizes the results of the observations on 18,500 kc taken on May 18, 1928. It will be seen that if one considers the results for any given wire there is a general tendency for the echo time to lengthen out as one passes from afternoon to evening with the longest time echoes much more numerous late in the evening. This record was begun at 1600 zone plus five time and completed at 2300, at which time echoes were still being received. The record also shows that more echoes were received from the south and east than from the west and north, and the film shows that these echoes were also averaging better

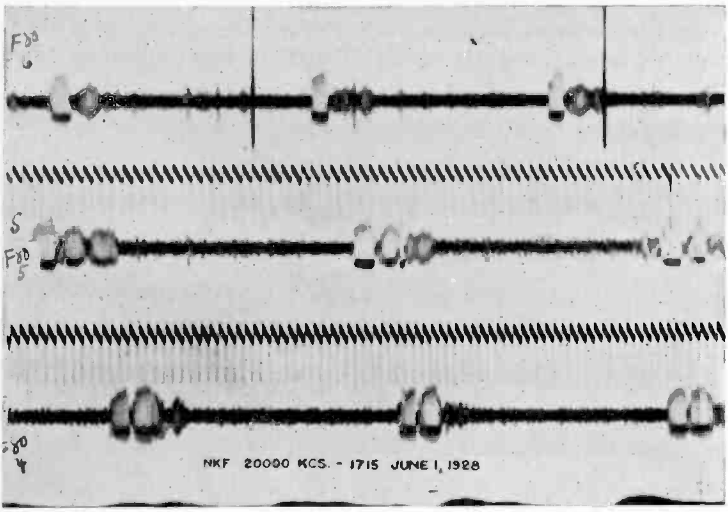

Fig. 4

intensity. We interpret those echoes whose times lie between 0.01 and 0.016 second to be, in general, signals returned from the first zone of reception which immediately follows the skip distance region. Since these echoes can be returned from either edge of this first zone of reception, it follows that they will be spread over a considerable time interval. At the same time there is no doubt but that, as the evening wears on and the effective height of the Kennelly-Heaviside layer becomes greater, this zone of reception moves outward, which tends to lengthen the echoes. Thus, we see zone 2 echoes, obtained earlier in the evening, falling at time intervals which would probably correspond to zone 1 at a later hour. From a consideration of the very shortest time echoes, which we assume to be reflected from the inner edge of the first zone of reception, we may deduce, for instance, that between the hours 1700 and 1800 the skip distance on this frequency was of the order of 1600 km.

If we refer this to the curves published by one of us,[2] we see that the effective height of the Kennelly-Heaviside layer at this hour as measured from the east wire observations was approximately 240 km. The west and north wires give about the same average result, but the south wire determinations would give us a lower figure; namely, about 200 km. This is a reasonable result. The early evening observations on various wires between timing intervals of 0.016 and 0.022 should probably be interpreted as reflected from the second zone of reception, whereas in the later observations, at least later than 2100, they are probably first zone reflections since few, if any, reflections of shorter intervals are simultaneously noted. The much less numerous reflections

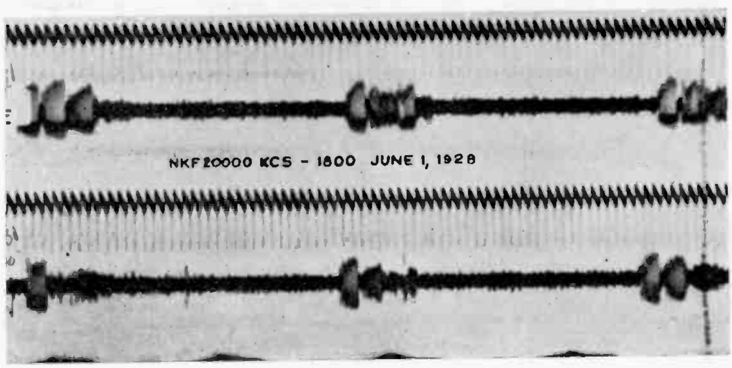

Fig. 5

of longer time intervals, extending in some cases out to over 0.04 of a second, are not readily explainable unless we assume that they are from zones beyond the second, some of which are sufficiently distant to give this time. The main thing, of course, is that an echo signal has to be of sufficient intensity to return to us after a round trip of over 12,000 km. If these echoes of the order of 0.03 to 0.045 second were always of very weak intensity one might be satisfied with this explanation, but the fact that they are sometimes extremely strong renders the tentative explanation we have given somewhat doubtful. While the general trend of the echoes is to come in from longer and longer time intervals as the evening wears on, this trend is decidedly not without its fluctuations, some of which will be spoken of later.

[2] Hoyt Taylor, Proc. I. R. E., 14, 521; April, 1926.

The next observations were made on the same transmitter at the Naval Research Laboratory tuned to 20,000 kc. These observations were made on June 1, 1928 and are summarized in Table II. Figs. 4, 5, and 6 are reproduced from records made on 20,000 kc. They were

TABLE II
ECHO TIME
NKF 20 MEGACYCLES JUNE 1, 1928

Time	EAST		SOUTH		WEST		NORTH	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
1400	0.0204	0.0172 0.0196						
1500					0.0225	0.0190		
1600	0.0166	0.0166	0.0166	0.0166				
1700	0.0141 0.0148	0.0154 0.0156 0.0330*	0.0291*	0.0146 0.0310*			0.0179	0.0175
1800	0.0127 0.0132 0.0134	0.0134 0.0139 0.0146 0.0154 0.0270* 0.0280*			0.0161 0.0200	0.0161 0.0200 0.0335*	0.0132 0.0160 0.0300*	0.0132 0.0290*
1930	0.0172 0.0180 0.0186 0.0196 0.0315* 0.0360*	0.0204 0.0212 0.0216 0.0230 0.0385* 0.0390*	0.0198 0.0178 0.0198	0.0206 0.0201	0.0210	0.0212 0.0212	0.0176	0.0215
2000	0.0225 0.0410*	0.0233 0.0420*	0.0172		0.0188 0.0201 0.0391*	0.0400*	0.0177 0.0195	0.0196 0.0120
2100	0.0216 0.0234	0.0238 0.0246			0.0216	0.0250	0.0195	0.0207

* Second group echoes.

taken at 1715, 1800, and 2005 hours, and are herewith presented to show the way the time interval between signal and echo increases as the hour gets later.

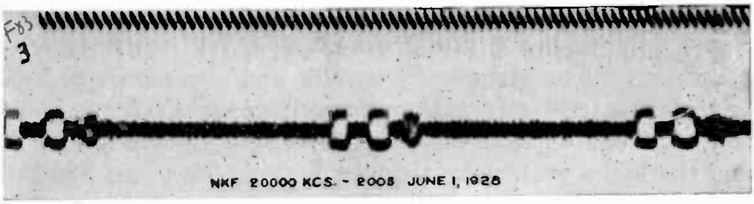

Fig. 6

In Fig. 4 we see the echoes almost overlapping the signal. In Fig. 5 the echoes overlap each other but are spread further out from the signal, and in Fig. 6 the signal with its two distinct echoes, one strong and one feeble and both of short time duration, is plainly distinguishable. The results of the observations on 20,000 kc are shown in Table II. We find again a great predominance of echoes on the east wire. One curious thing about the record is that the Kennelly-Heaviside layer appeared to drop in effective height between 1400 and 1800, after which it rose rapidly. The skip distance determinations for the hour 1800 would show a distance of 1900 km, which would correspond to an effective layer height of approximately 225 km, which is of the same order of magnitude as previously determined for 18,500 kc. This observation is based on the east wire. The north wire would give about the same height, but the west wire would give a skip distance of 2400 km corresponding to an effective layer height of approximately 250 km. This is contrary to what one would expect as the layer should be lower in effective height to the westward than to the eastward, at this hour of the day. However, there were very few observations on the west wire and possibly the reflection upon which the calculation was based was not the nearest possible reflection to obtain from the first zone westward. The reflections from the westward at that time were very weak besides being few. There is only one measurable reflection on the south wire upon which to base an observation, and this reflection would give somewhat greater height than on the east wire but not as great as on the west. The general tendency for the time intervals to increase as the day wears on is contradicted between 1400 and 1800, but is plainly in evidence from 1800 to 2100. This peculiar inversion in the apparent movement of the layer is evidenced in nearly all of our observations. The time at which it occurs is shifted towards later hours as we go from spring to summer. During the spring months reflections, especially on the north wire, would sometimes disappear late in the evening but during the summer months reflections even on as high as 20,000 kc would not disappear as late as 2300. Some of the longer time reflections would disappear very frequently late in the evening. Curiously enough, the afternoon reflections are usually weaker and less numerous besides being of shorter time interval than the average night reflection, and on several occasions we have been unable to find any reflections at all around the hours during the morning between 0900 and 1300. The explanation of this is not wholly obvious. It is true, however, that these short time echo signals are not of very great intensity, and that the absorption may be expected to be heavier in the daytime than it is in the evening. Normally we would expect echoes, although of weaker intensity, during the entire daylight period and lasting into the night until the Kennelly-Heaviside layer became high enough to cut these frequencies off entirely. It was noticed during the summer observations that whenever we got persistent echoes on the east wire late at night on the high frequencies it was generally possible to hear European stations on these same high frequencies whether we received them on fundamental or harmonics. Thus, when our local observations indicated a persistence of a moderately low layer level, the transatlantic observations indicated in general the same thing.

TABLE III
ECHO TIME
NKF 20 MEGACYCLES JULY 18, 1928

Time	EAST		SOUTH		WEST		NORTH	
	Front	Rear	Front	Rear	Front	Rear	Front	Rear
1545	0.0158 0.0174	0.0190 0.0206	0.0158	0.0167 0.0177				
1630			0.0175	0.0175				
1700	0.0177 0.0178	0.0207						
1730	0.0166 0.0167	0.0186 0.0187						
1745	0.0154 0.0175	0.0177 0.0204 0.0318*	0.0179					
1815	0.0169 0.0169	0.0181 0.0182			0.0152 0.0156	0.0177 0.0179	0.0167	0.0187 0.0188
1915	0.0156 0.0175 0.0177	0.0207 0.0215 0.0221 0.0368* 0.0380*	0.0164	0.0190 0.0295*				
2000	0.0185	0.0222	0.0155 0.0156	0.0191 0.0192 0.0375*				
2045	0.0188 0.0211	0.0217 0.0225					0.0157 0.0165	0.0208 0.0225
2100			0.0158	0.0208 0.0355*				
2130	0.0171 0.0177 0.0178	0.0188 0.0199 0.0203	0.0173 0.0175 0.0179	0.0172 0.0175 0.0176 0.0365*				
2145			0.0181 0.0185 0.0188	0.0191 0.0194 0.0197	0.0172			

* Second group echoes.

At this point in the investigation it was thought that possibly the nature of the antenna structure at the transmitter might have something to do with the echoes and to the fact that they were stronger from certain directions than others. The horizontal doublet was therefore replaced by a vertical half-wave doublet coupled to a feed line, but again the observations showed the same general distribution of echoes, the east wire being the favorite both by number and intensity, and following that the south wire. We conclude, therefore, that directivity from the transmitter has no particular influence on the number and strength of the echo signals, and in particular has no bearing on the fact that echoes were received better from over the sea than elsewhere.

About this time steps were taken to shorten the dot impulses at the transmitter to permit a sharper discrimination and measurement of the echo timing. Table III presents the results of the observations also on

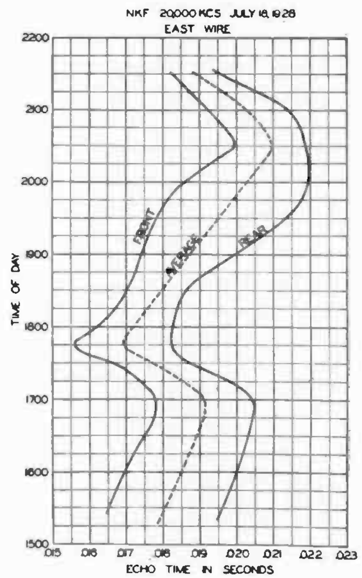

Fig. 7

20,000 kc obtained on July 18, 1928. Fig. 7 presents graphically the results on the east wire in which the echo signals can be presented in the form of two curves corresponding to measurements made on the front of the dot and the rear of the dot, respectively. From the very nature of it the echo signal has a tendency to spatter out a good bit so that it was thought wise to get measurements in both ways. It was thought that if a medium line was drawn between these two curves it would represent the variation in the skip distance and therefore the variation in effective layer height between the hours of 1530 and 2200. This curve shows again a diminution in skip distance and effective layer height in the early evening for this observation taken in the summer, coming somewhat earlier than for observations taken earlier in the year. A second apparent surge in layer height is evident in this case around the hour 2030. Effects of this nature were so persistent in our records (only part of which are reproduced in this paper) that it is perhaps worth while to present a summary of results in the form of the curves shown in Fig. 8. This figure plots the average time interval observed against the hour of the day. This average time interval is related to certain distances which would be double the skip distance.

Curve 1 taken on 18,500 kc on April 30th shows the first knee or bend in the curve at the time 1830. Curve 2 taken on June 1st at 20,000 kc, of course, shows greater skip distances, but it also shows the knee in the curve occurring at 1800, whereas curve 3 taken on 20,000 kc on July 18th shows greater initial skip distances, less variation in the signal throughout the night, and the knee of the curve occurring at

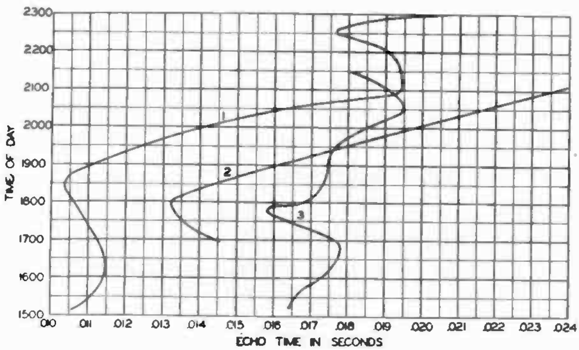

Fig. 8

about 1745. It is evident that this apparent preliminary drop in the effective layer height or decrease in the skip distance from afternoon to early evening is a real effect occurring for both the frequencies observed but differing insofar as it occurs earlier in midsummer than in spring, and is therefore probably related to sunset effects. The subsequent variations which occur in curve 1 and curve 3 are probably due to some turbulence in the layer, the mechanism of which is at present entirely in the dark.

On July 26th observations on short dots on 20,000 kc were taken at Cheltenham from 1000 on. No reflections were observed on any of the wires until 1500, and then on the south and east wires, but too weak to photograph properly. At about 2000 the echoes began to be of normal strength and at the same time extremely good round-the-world signals were noted. Fig. 9 shows the type of record obtained earlier in the day when neither round-the-world nor echo signals were present.

Fig. 10 shows this sort of record obtained after 2000. The signals marked S_1, S_2, S_3, and S_4 are the ground waves. R_1, R_2, R_3, and R_4 are short time echoes. AS_1 and AS_2 are round-the-world signals showing the typical timing interval of 0.14 of a second, and A_2S_1 is a signal which has made two trips around the world, being 0.28 of a second behind the signal S_1. It is plainly not a short time echo, and equally plainly the timing interval is not at all right for it to have made one trip around the world. This rather unusual record shows these three types of phantom signals very well.

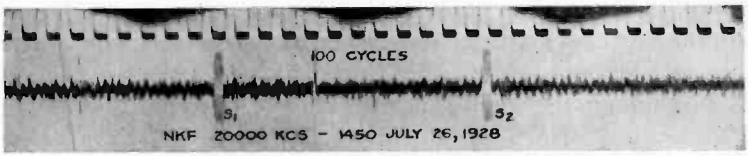

Fig. 9

From a series of observations on the front and rear of the dots on round-the-world signals, the average time interval measured on the front of the dot is 0.1386 second and on the rear of the dot 0.1391 second, giving an average time interval of 0.1389 which checks well with the average round-the-world timing intervals in the earlier paper already referred to. The twice around-the-world signal shows a timing

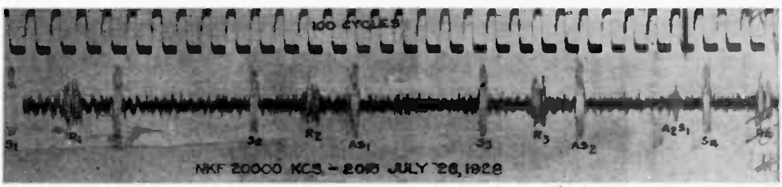

Fig. 10

interval of 0.2772. Based on this timing interval we can calculate an effective average layer height of 265 km. Table IV shows the echo signals as observed on this rather unusual night. We may conclude from a study of these echoes that the center of the first zone of reception was distant about 3600 km, and that the inner edge of the zone was approximately 3300 km distant, which would lead to an effective layer height in the neighborhood of 280 km, practically the height which cuts off permanently the use of the frequency 20,000 kc. In other words, both the absence of echoes and the extremely long time interval of the shortest echoes indicate the same thing; namely, an unusually high layer. Since this condition was apparently present also during the daylight hours it must be considered, at this time of the year especially, as decidedly abnormal. It is noteworthy that during the hours 0900 to 1400, when we ordinarily hear without difficulty the Rocky Point group of the R.C.A. by means of their echo signals, they

TABLE IV
ECHO SIGNALS 1000–2200
NKF 20 MEGACYCLES JULY 26, 1928

Time	EAST WIRE	
	Front	Rear
1700	0.0248 0.0240	0.0262 0.0253
2015	0.0220 0.0221 0.0228	0.0258 0.0254 0.0257
2145	0.0229	0.0245

Note: Echoes received only on east wire, and not strong enough to photograph until 1700.

were conspicuously absent. Some European stations in the high-frequency band were received with excessive fading. The first signals from the R.C.A. group at Rocky Point by echo were heard at 1400 very weakly. All indications therefore point to a decidedly abnormal day, the effect holding over into the night. During the evening the Rocky Point group came in at more than normal signal strength, and European stations were of excellent intensity. Nevertheless, it can be inferred that the layer remained higher than normally during the evening hours.

Some attempts were made to study echoes on still higher frequencies, but at the time this work was being carried on suitable transmitters and receivers were not available. It is highly advisable in this work that the transmitter be of extremely constant frequency and the receiver of more than ordinary stability. Since that time a different type of study has been carried out which shows that echo signals during the daylight hours exist on frequencies up to 30,000 kc and possibly higher. The upper limit is not yet known. Photographic studies have not yet been completed, so that the exact timing of these signals is also not yet known. It is known, however, that the skip distance increases with the frequency more or less as might be expected. It is also perfectly clear that it is not quite safe to extrapolate the general theory in order to forecast what may happen on frequencies above 25,000 kc until we have more detailed information as to the electron concentration in the layer and the distribution thereof. In other words, we find inconsistencies between effective heights of the layer as measured, say on 20,000 kc and as deduced from the frequency at which all echoes disappear. The effective layer height deduced from observations made in the 20,000 kc band might indicate a height which ought to cut off completely 28,000 kc, but actually at the same time we are able to observe certain echoes on 28,000 kc, indicating that it is not completely cut off although it has a very long skip distance. This clearly indicates that certain corrections and additions based on new information as to layer structure must be taken into account before we can definitely describe what has happened in these extremely high-frequency bands.

We see nothing in our latest observations to cause us to change our opinion that short time echo signals are returned not from a point in space away from the earth, but are thrown back from the surface of the land or sea by way, of course, of an intermediate reflection from the layer.

As previously pointed out, the echo signals showing relatively large retardations may be explained as signals returned from zones of reception beyond the first, except that their extraordinary intensity at times makes us feel that this explanation cannot be accepted without at least giving consideration to the mathematical possibility of their being of such an electron distribution that abnormal retardations of velocity may occur, so that even these longer time echoes could still be returned from the first zone although by rather abnormal paths in the layer and not at all unless certain conditions as to electron distribution in the layer are fulfilled. At present there seems to be no way, experimentally, of deciding between these two possible explanations.

Concerning the drop in effective height near the sunset hours, something further may be said. The first and immediate effect of approaching sunset will be to cool the atmosphere, causing a general drop in the layer height. A little later all ultra violet radiation will be cut off from the high layers and re-combination will set in causing the layer, which is always normally lower after sunset, to show a greater effective height because of the reduced number of electrons. It is then perfectly consistent that the approach of sunset could first bring on a small drop in the effective height of the layer due to cooling of the lower levels of the earth's atmosphere which constitute the supporting pillar upon which exists the upper layer. This would be a real drop in both effective and actual heights. Following this comes the re-combination in the absence of ultra violet in the high levels, which causes a thinning out of the electrons, leading in time to the subsequent and more normal rise in effective height, although the actual height may still remain low. This seems a reasonable explanation of the effects we have observed and their variation with the time of the year. Later on in the evening where we have to do with fairly high effective layer height, perturbations due to high atmospheric winds of unusual magnitude may cause turbulences and fluctuations such as are shown in some of our observations.

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GROUP-VELOCITY AND LONG RETARDATIONS OF RADIO ECHOES*

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Summary—*Van der Pol's hypothesis that group-velocity may account for the retardation of echoes observed by Stoermer is analyzed. It is shown that only under very special circumstances can the electron-distribution be proper. A favorable condition is obtained if the refractive index decreases exponentially with the height. It is shown that by slightly varying the electron-distribution anomalous results for skip-distances should follow. It is suggested that the echoes observed by Stoermer and van der Pol were splashes of the same echo focussed accidentally on a favorable patch of ground.*

ECHOES of signals with very long retardations up to 15 seconds have been observed by Stoermer and van der Pol. Explanations of these remarkably long retardations have been given by Stoermer, van der Pol,[1] and Appleton.[2] The explanation of van der Pol seems to be the most concrete one. His idea is that the radio wave may penetrate into the region of the atmosphere where its phase-velocity is very high and consequently the group-velocity is low. According to van der Pol, the very long retardations are, therefore, due to the group of waves constituting the dot or dash of the signal going by a path along an appreciable portion of which the velocity of the group is very small.

The implications involved in this explanation can be illustrated graphically by means of a theorem stated by Breit and Tuve. It has been proved there that if the path of the ray is ABC (see Fig. 1) then for short waves the time taken by the signal to go from a point A on the ground to another point C, also on the ground, is equal to the time which the signal would take to travel in empty space along the path constituted by the tangents AD, CD. The retarding effect of the electrons in the upper regions of the atmosphere is, therefore, such as to retard the arrival of the signal, the path ADC being always longer than ABC.

If now Stoermer's echoes are to be explained by group-velocity considerations, this simply means that the point D must be moved to a very great distance comparable in fact to the distance to the moon.

* Dewey decimal classification: R113.6. Original manuscript received by the Institute, March 26, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] *Nature*, 122, 878–879, 1928.
[2] *Nature*, 122, 879, 1928.

Supposing that the Kennelly-Heaviside layer is horizontal, the signal must leave the transmitter almost vertically and come down to the receiver also almost vertically. The electron-distributions which have been considered as likely or possible ones do not make it possible to have such paths without moving the point B up to an unreasonably large height. Thus, for instance, if the electron-density increases uniformly with the height, the path ABC is a parabola and the ratio of the height of D to the height of B is always 2. We cannot explain the very long echoes, therefore, by retardations due to small group-velocity by this electron-distribution unless we allow the signal to reach a height which is, say, half the distance to the moon. This is just as unreasonable as allowing it to go to the moon itself.

If we are to explain the long echoes as an effect of low group-velocity, we must find, therefore, electron-distributions which will make the ratio of the "effective height" of D to the actual height of B very large. We see from the above example that the electron-distribution must be of a special sort and that the simplest distributions do not answer the purpose. We proceed to investigate the relation between the effective height and the actual height as determined by the nature of the electron-distribution.

Let the refractive index at a height y above the lower boundary of the layer be $\mu(y)$. By Snell's law $\mu(y)\sin\theta=\sin\theta_0$, so that letting x be the distance traveled by the signal in a horizontal direction

$$dx=((\mu(y)\sin^{-1}\theta_0)^2-1)^{-1/2}dy \tag{1}$$

is the differential equation of the ray. In this formula θ_0 is the angle which the ray makes with a vertical line at the transmitter or at the

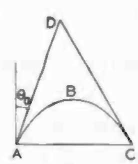

Fig. 1

receiver (see Fig. 1). Referring to the coordinates of B as X, Y, we have, letting $d\mu/dy=\mu'$,

$$X=\int_{x=0}^{\mu}[(\mu(y)\sin^{-1}\theta_0)^2-1]^{-1/2}dy=\int_{\mu=\sin\theta_0}^{1}\frac{-(\mu')^{-1}d\mu}{\sqrt{\mu^2-\sin^2\theta_0}}\sin\theta_0 \tag{2}$$

and

$$h=X\sin^{-1}\theta_0 \tag{3}$$

where X is, therefore, half the range of the signal in the reflecting layer and h is the length of AD or the effective height as observed by the retardation of the echo. In formula (2) we have transformed the expression into an integral in terms of μ, the refractive index itself. This is convenient because by so doing we fix the limits of integration as $\sin\theta_0$ and 1 and can see through the dependence of X on the form of $\mu(y)$.

In order to obtain very large effective heights we must arrange $\mu(y)$ in such a way that for a reasonable X, say, 100 or 500 miles, we should get a very small θ_0. We take, therefore, various forms for μ' as a function of μ and arrange the results in order according to powers of μ. Let

$$\mu' = -a^{-1}\mu^{-n}, \text{ i.e., } \mu = \left[1-(1-n)ya^{-1}\right]^{1/(1-n)}. \tag{4}$$

By (2)

$$X = an^{-1}\sin^{1-n}\theta_0 \int_{\sin^n\theta_0}^{1} dx/\sqrt{1-x^{2/n}} \tag{5}$$

Using (3), (4), (5) we construct the following table

n	μ	Y	X
-1	$\sqrt{1-2y/a}$	$(a/2)\cos^2\theta_0$	$a\sin\theta_0\cos\theta_0$
0	$1-y/a$	$a(1-\sin\theta_0)$	$a\sin\theta_0\log\left[(1+\cos\theta_0)/\sin\theta_0\right]$
†1/2	$(1-y/2a)^2$	$2a(1-\sin^{1/2}\theta_0)$	$2a\sqrt{\sin\theta_0}\{\sqrt{8/\pi}\Pi^2(1/4)-\sqrt{\sin\theta_0}\}$
†2/3	$(1-y/3a)^3$	$3a(1-\sin^{1/3}\theta_0)$	$(3a/2)\sqrt[3]{\sin\theta_0}\{3^{5/2}2^{-4/3}\pi^{-1}\Pi^3(1/3)-\sin^{2/3}\theta_0\}$
1	$e^{-y/a}$	$a\log\sin^{-1}\theta_0$	$a(\pi/2-\theta_0)$
2	$a/(n+a)$	$a(\sin^{-1}\theta_0-1)$	$a\cot\theta_0$

† The values for $n=\frac{1}{2}$, $n=\frac{2}{3}$ are approximate for $\theta_0 >> 1$.

A tabulation of h is not necessary, it being obtained directly from the last column and (3).

The case $n=1$ is of particular interest. For small θ_0, $h=\pi a/2\theta_0$, $Y=a\log\theta_0^{-1}$, $h/Y=(\pi/2)/(\theta_0\log\theta_0^{-1})$. If $\theta_0=10^{-5}$, $\log\theta_0^{-1}\cong 10$, $h/Y\cong 1.4\times 10^4$. Thus for directions very close to the vertical one could have retardations to a height of $1.4\times 10^4 Y$. Taking $Y=186$ miles, we would get a retardation of 28 seconds. A retardation of 3 seconds would correspond to $\theta_0=10^{-4}$, and if we should allow Y to be five times greater than we have taken it θ_0 could be as alrge as $1/2000$ radian $\cong 1/40$ of a degree. The distribution of electrons which would give a decrease of μ with height according to the law $e^{-y/a}$ makes it possible, therefore, to explain very retarded echoes provided the energy sent out nearly vertically by the antenna is sufficiently great. The requirement on the energy is rather stringent because an echo which is at all clear-cut must correspond to a sharp range of values of θ_0. The range of angles corresponding to a definite echo is, therefore, at the most 10^{-4} radian which gives at a distance of 100 km a spread of the beam of not more than 10 m. Since the wavelength used in the experiments is 31 m, the path has to be at least 300 km from the ground to the layer before we can consider such an angle as at all definite. Even though it is very difficult to imagine that at the same time the layer should be sufficiently high, the distribution of electrons just right through a height of about 800 miles and the energy sent vertically by the antenna should be sufficient, we may admit a possibility of $\mu = e^{-y/a}$ giving the very long retardations. The signals should be very erratic and very faint.

That they should be erratic can be seen further by considering other values of n. For small θ_0 and $n=2$, $Y = a\theta_0^{-1}$ and $h = a\theta_0^{-2}$; $h/Y = \theta_0^{-1}$. However, if $\theta_0 \leqq 10^{-4}$, then $a = 10^{-4}Y$. Thus if $Y = 300$ km, a is only 30 m. This means that the refractive index would drop from 1 to 1/2 in a wavelength so that true refraction could hardly occur. The situation can be saved by granting the possibility of larger Y which will increase θ_0 and a. This case is also a possibility but subject to the same limitations as for $n=1$.

For $n=0$, $h = a \log (2/\theta_0)$, $Y = a$. This is unfavorable since quite unreasonably small θ_0 is required. For $n=1/2$, $h = 2\sqrt{8/\pi}\Pi^2 (1/4)/\sqrt{\sin\theta_0}$, $Y = 2a$. The dependence of h on $\sqrt{\sin\theta_0}$ is unfavorable. For $n=2/3$, h is proportional to $(1/\sin\theta_0)^{2/3}$. This is better than $n=1/2$, but not as good as $n=1$ or 2. The case $n=-1$ gives even no purely mathematical possibility of getting large effective heights. This is the well-known case of the electron-density increasing uniformly with the height giving parabolic rays mentioned before. We may conclude, therefore, that the group-velocity explanation is a possible one disregarding absorption, and that it corresponds to such an electron-distribution for which $\mu = e^{-y/a}$.

The possibly detrimental effects of absorption have been considered by E. V. Appleton[2] and L. H. Thomas.[3] They undoubtedly point out a serious difficulty. It must be remarked, however, that the calculations of Thomas on the mean free-path correspond to an effective area of collision for electrons of the order of 2×10^{-5} cm, which is high compared even with atomic dimensions. It may be questioned, therefore, whether his calculation is to be interpreted as a change of phase of the forced electronic vibrations or simply as a cumulative effect in the scattering of electrons. It seems safest, therefore, to let the possibility of relatively low absorption in the high regions remain open,

[3] *Nature*, 123, 166, 1929.

particularly since the electron-distributions used above lead to reasonable energies disregarding absorption only if we let the actual height Y be large, say above 600 kilometers.

Focussing Effects

According to the observations of Stoermer and van der Pol, there is a considerable number of echoes arriving with the same retardation at Oslo and Eindhoven. If a direct path to each receiver were traced, the retardations would naturally be different. We prefer, therefore, to suppose that the observed echoes were splashes of one and the same echo heard by the two observers. This seems possible for the case $n=1$, for if the height of the lower boundary of the layer above the surface of the ground is a, all rays with small θ_0 are focussed at a distance πa as shown in Fig. 2.

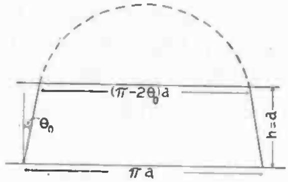

Fig. 2

Similarly for case $n=2$, the range is $2a \cot \theta_0 + 2h \tan \theta_0$. Here there is no focussing for small θ_0, and in fact if $a>h$ the range is seen to decrease with θ_0 for a considerable range of values of θ_0, the minimum being at $\tan \theta_0 = \sqrt{a/h}$ corresponding to a range of $4\sqrt{ah}$.

From the point of view of focussing, therefore, the distribution $n=1$ seems again the most likely one.

It will be observed that the variation of μ and y is not very different for $n=2/3$, $n=1$, $n=2$. We would expect, therefore, that the presence of long echoes will be connected with anomalies in general radio transmission of the same nature as is usually observed during magnetic storms. The case $n=2$ as we have seen gives smaller ranges for more oblique incidence which is just the opposite of what is usually supposed to take place. Such a condition would result in breaking up the regular transmission conditions in which oblique incidence on the layer gives larger ranges than normal incidence.

Assuming the correctness of van der Pol's explanation, we should expect changes in skip-distance to occur before or after the long echoes, and in particular we expect that at such times oblique incidence on the layer will give shorter range than normal.

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FURTHER STUDIES OF THE KENNELLY-HEAVISIDE LAYER BY THE ECHO-METHOD*

BY

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Summary—*Recent observations of the Kennelly-Heaviside layer by the echo-method are described. Multivibrator-modulation was used, giving extremely sharp "peaks" on 4,435 and 8,870 kc. Practically all of the observations were made on the former frequency, as 8,870 kc skipped over the receiver, which was very near the transmitter. Two 24-hour series of observations showed a marked diurnal-variation in the effective height of the layer and in the echo-pattern received for each transmitted "peak." The echo-pattern shows multiplicities during the day and evening, but becomes very complex at night. A few observations made during the magnetic disturbance of October 17–19, 1928, showed an unusually great effective height and a change in the echo-pattern. Daytime heights for a number of days during the autumn of 1928 are given.*

GENERAL METHOD

SOME recent experimental results obtained in studies of the Kennelly-Heaviside layer by the echo-method are reported in this paper. The method has been described in earlier publications,[1] and consists in the oscillographic recording at a receiver of the ground-wave and echo-pattern from the layer of a transmitter modulated to emit very short pulses or "peaks," separated by intervals of no emission, during which the echoes are recorded. The receiver arrangements were practically identical with those previously described,[1] and the modulation of the transmitter was accomplished by the use of unbalanced multivibrator-circuit.[2]

The transmissions, as before, were from the Naval Research Laboratory at Bellevue, Anacostia, D. C., and grateful acknowledgment is due to Captain E. G. Oberlin and to Messrs. A. H. Taylor, L. A. Gebhard, M. H. Schrenck, and others there for their continued and cordial cooperation in the carrying out of this work. We also wish to thank our colleagues, G. Breit, whose continued association with the work has contributed so largely to it, and J. A. Fleming, whose enthusiastic support has made it possible.

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, May 22, 1929. Abstract presented before joint meeting of the Institute and International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, May 15, 1929.

[1] G. Breit and M. A. Tuve, *Phys. Rev.*, **28**, 554; September, 1926.

[2] M. A. Tuve and O. Dahl, PROC. I. R. E., **16**, 794; June, 1928.

Transmitters

Two 20-kw transmitters, crystal-controlled by separate crystals and operating on 4,435 and 8,870 kc, were modulated by the same multivibrator set. Exactly simultaneous "peaks" of very short duration

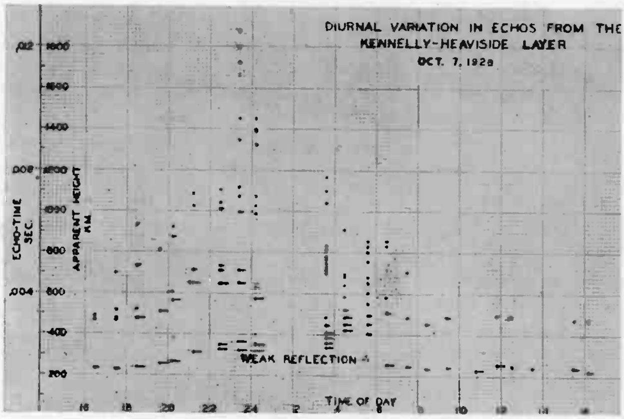

Fig. 1—Diurnal variation in echoes from layer, October 7–8, 1928.

(0.0002 sec., or less), spaced 0.1 to 0.01 sec., were consequently emitted on the two different transmission frequencies. Before the actual

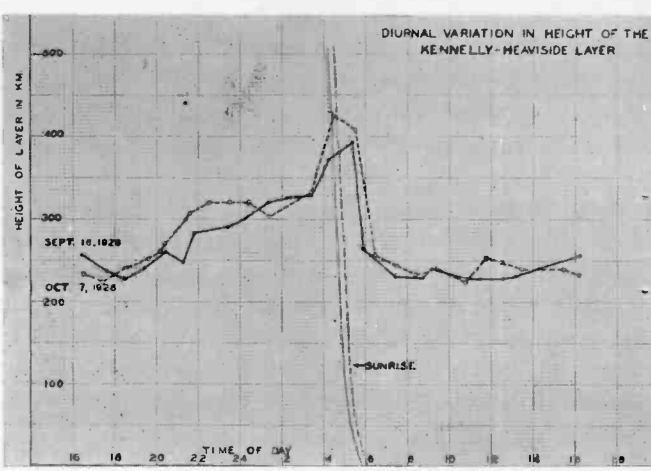

Fig. 2—Diurnal variation in height of layer, September 16–17 and October 7–8, 1928.

transmission experiments were begun, considerable time was spent at the transmitter, oscillographing the emitted wave-shape with various adjustments, to insure with certainty that no circumstances of altered voltages or other adjustments at the transmitter could give rise to secondary "peaks" or other misleading changes in emitted wave-shape. With two transmitters simultaneously modulated in this way it was hoped that simultaneous records of the effective heights of the layer for the two transmission frequencies might be obtained. Although the ground-wave on 8,870 kc is absorbed in a very few miles from the transmitting station (with this modulation it is too faint to record with our present receiver only 7 miles from the transmitter), the 4,435-kc ground-wave provides a reference point. However, it has been our experience that the 8,870-kc sky-wave "skips" over our receiver at prac-

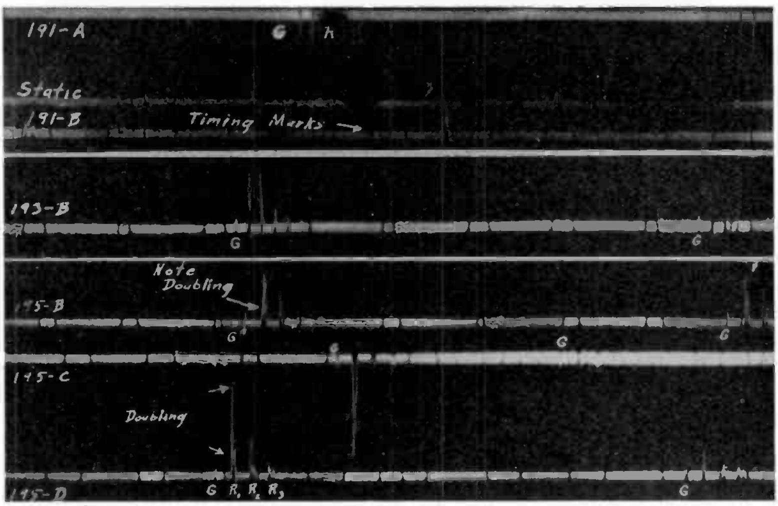

Fig. 3—Typical normal-day variation in echo-pattern, October 6–7, 1928: 191-A and 191-B daytime at 14.^{h}7 October 6; 193-B just after sunset at 18.^{h}5 October 7; 195-B, 195-C, and 195-D showing multiple reflection and scattering at 22.^{h}4 October 7.

tically all times, and a double recording receiver has not yet been set up here for this reason. The 8,870-kc wave has been received stro gly on two occasions, both times just preceding times of considerable magnetic activity (Sept. 18 and Oct. 18, 1928), but the only pictures obtained showed single "peaks," the absence of a ground-wave preventing any measurement of height. This erratic behavior is qualitatively supported by observations in previous years. These observations are being continued and extended as far as possible, however.

After the transmitters were checked as described, and the tests here reported were begun, a number of other laboratories were notified of the schedules and invited to observe the transmissions. Simultaneous observations at different points, giving data for various angles of incidence at the layer, must eventually lead to results of value to our knowledge of the electron-distribution in the upper atmosphere. Messrs. G. W. Kenrick and C. K. Jen, of the Moore School of Electrical

Fig. 4a—Record (158-A) at 3.^{h}2 September 17, 1928, showing five multiple reflections and slow-speed record (158-B) made just afterwards showing fading of separate peaks.

Engineering, University of Pennsylvania, Philadelphia, have already published their observations, made on the test of October 7–8, 1928.

24-Hour Diurnal-Variation Schedules

Some rather interesting and unexpected results were obtained when the signals were observed during two 24-hour schedules, September

Fig. 4b—Records (196-C and 196-D) at 23.^{h}5 October 7, 1928, showing four multiple reflections.

16–17, and October 7–8, 1928. Although no records could be obtained on 8,870 kc, as explained above, the 4,435-kc signals showed marked diurnal-variation in two important characteristics, echo-pattern and effective layer-height.

The echo-pattern is characteristic of the time of day at which the observation is made, and the pattern goes through a complete cycle in

24 hours. Fig. 1 shows schematically the variation in the echo-pattern (4,435 kc) during the 24-hour schedule of October 7–8. The schedule of September 16–17 showed the same patterns. The intensities of the various peaks were only roughly compared, although they were in general much stronger at night than during the daylight hours, and only three gradations of intensity are indicated in the figure. The longer lines represent peaks of amplitude three to ten times that of the ground-wave, the shorter lines represent those about equal to the ground-wave, and the dots represent the still smaller (although always definite) peaks. Since the amplitudes of the various peaks varied independently and sometimes rapidly, intensity values are of very dubious worth when taken over the comparatively brief period of one or even several film exposures. The patterns shown schematically

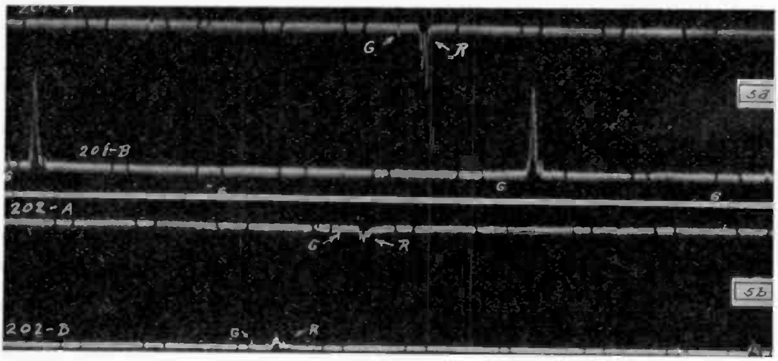

Fig. 5—Typical normal-day variation in echo-pattern October 8, 1928: 201-A and 201-B at 4.h5, reflection from a high layer with great scattering and no multiplicity; 202-A and 202-B at 5.h6, about sunrise, weak signals, echo from layer at daytime height barely visible.

in Fig. 1 are typical single patterns (due to a single "peak" at the transmitter, i.e., following a single "ground-peak" on the film at the receiver) for the different times of day; each pattern shown is typical of a considerable number of patterns recorded at the time indicated. The transmitters were operated 15–20 min. during each hour, and usually four or more full-length exposures at different receiver sensitivities were made during each transmission. The film-speed was about 200 cm per sec. and the films were about 150 cm long. These long films were found to be of great advantage in analyzing the records. The multivibrator at the transmitter was set to give from 10 to 50 "peaks" per second, so each trace recorded a number of successive signals. This made it possible to identify a repeating echo-pattern which could be associated definitely with each signal, eliminating any chance of confusion due to static or receiver noises, and also giving some indication of the amplitude variations of the various peaks. The latter variations were more or less irregular but in general were of periods greater than one sec., and show more clearly on the few slow records which were taken. (See Fig. 4*a*, trace 158-B). Typical examples of the oscillograph-records, showing various echo-patterns, are shown in Figs. 3 to 5. The accuracy of measurement is about ± 10 km, and two peaks must be separated by about 40 km (apparent height; see Fig. 1) to be completely resolved.

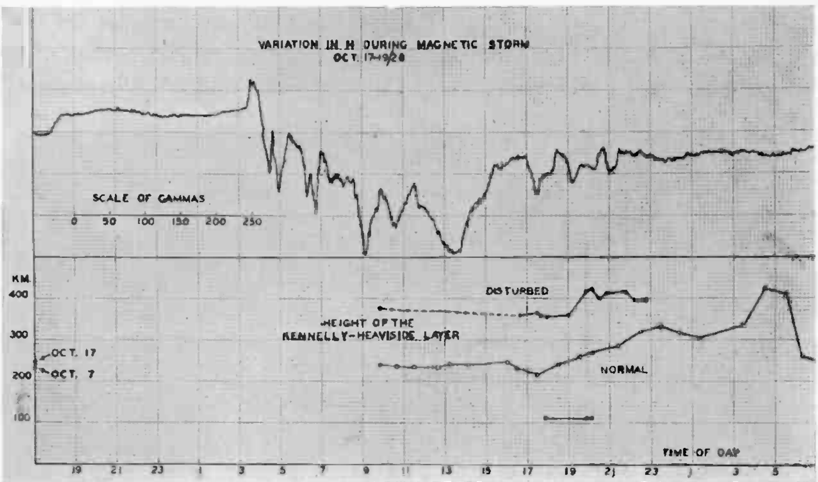

Fig. 6—Variations in horizontal intensity October 17–19, 1928, for magnetic storm recorded at the Cheltenham Magnetic Observatory and in observed height of layer for disturbed period (solid circles) October 17–18, 1928, and for normal period (open circles) October 7–9, 1928.

Several outstanding features of the results shown in Fig. 1 may be indicated. During the daylight hours there is usually at least one "reflected peak." A second often appears, although it is usually weak, and its retardation time is twice that of the first to within the errors of measurement. This multiplicity was first observed here a year ago.[3] A somewhat similar multiplicity was observed by R. A. Heising.[4] After sunset more and more echoes are observed; both this fact and the increase in amplitudes suggest decreased absorption in the layer. The peaks begin to appear in groups, each group occurring at an approximate multiple of the echo-time to the first reflected peak, although

[3] G. Breit, M. A. Tuve, and O. Dahl, Proc. I. R. E., 16, 1236; September 1928.
[4] Proc. I. R. E., 16, 75; January, 1928.

multiplicities for separate peaks are usually not exact. The separation of the peaks is greater and the amplitude of individual peaks smaller for the higher order "reflections." The grouping suggests multiple reflection between the layer and the earth, and the "splitting" in each group may possibly represent successive splitting on each reflection into separate polarized components, but this can hardly explain the very great splitting which occurs in the early morning hours. From midnight on this "splitting" becomes more and more pronounced, the peaks occur in unresolved groups, the higher-order reflections become too weak to record, and the multiplicity is gradually lost. At sunrise the

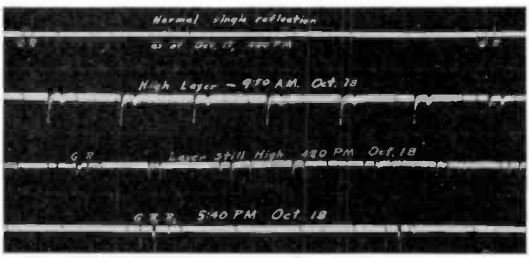

Fig. 7—Typical echo-patterns, October 18, 1928.

echo-pattern changes rapidly back to that typical of the daytime hours. An interesting feature was that a weak echo was observed from a layer at approximately the daytime height even before the echoes from the higher layer ceased. Since these heights are not multiples, it suggests that a layer at the daytime height is being formed below that from which the principal reflections occur during the night. The sunrise

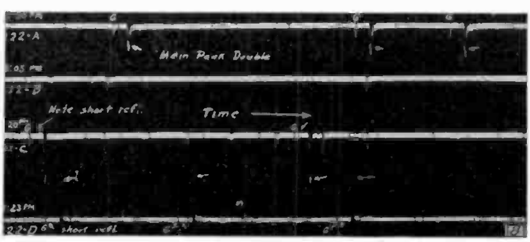

Fig. 8—Typical echo-patterns, October 18, 1928.

period will be subjected to intensive study before conclusions are drawn on the basis of such observations. Observations on various frequencies should show if there is an actual stratification of the layer.

The approximate multiplicity of the echo-time for the first, second, and higher-order reflections leads naturally to the picture of wave-groups traveling up and down a number of times between the layer and the earth's surface, although as yet we do not commit ourselves definitely to this view. However, if the echo-time to the first reflected peak be taken as a measure of the effective height of the layer, this quantity shows the diurnal variation illustrated in Fig. 2, where the values for the two 24-hour schedules are plotted. The steady day values, the slow rise during the evening, and the very sudden drop at sunrise are perhaps the most significant features. The time at which the sun's rays first appear (tangential) at different heights above the surface of the earth is roughly indicated by the transverse curves.

Magnetic Storm Observations

It may be of interest to include here a brief mention of some observations obtained on the day of a severe magnetic disturbance, October 18,

Fig. 9—Typical echo-patterns, October 18, 1928.

1928, although these observations are also reported elsewhere.[5] The measurements of height obtained on this day are shown in Fig. 6, with the diurnal curve of October 7 for comparison. The magnetogram for the day is also shown (courtesy of U. S. Coast and Geodetic Survey, Cheltenham, Md., magnetic observatory). The layer height was again normal on the morning of October 19. Typical echo-patterns (not retouched) are shown in Figs. 7, 8, and 9.

The observations obtained during the disturbance of October 17–19 were notably different in three respects from the "normal" ones obtained previously on undisturbed days: (1) the layer was abnormally high, as shown in Fig. 6; (2) an unusual short-time echo was observed (Figs. 6 and 8); and (3) the echo-pattern during the evening did not show the many groups of echoes otherwise observed at this time of day. Reflections from a height of about 100 km have been observed before,[6]

[5] L. R. Hafstad and M. A. Tuve, *Terr. Mag.*, 34, 39–44, 1929.
[6] G. Breit, M. A. Tuve, and O. Dahl, Proc. I. R. E., 16, 1236; September, 1928. O. Dahl and L. A. Gebhard, Proc. I. R. E., 16, 290; March, 1928.

but this was the only time they were observed by us during the autumn of 1928. The echo-patterns during the evening of October 18 resembled those of the "normal" early morning hours, when the layer-height was similar, as illustrated by Fig. 10.

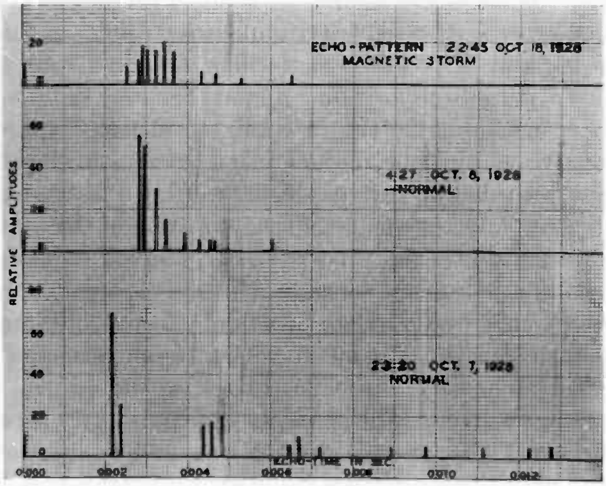

Fig. 10—Specimen echo-patterns during magnetic storm October 18, 1928, and during normal days October 7 and 8, 1928.

TABLE I

Effective Daytime Layer-Heights, Autumn 1928

Date	Time		Effective heights
1928	h	m	km
Jul. 14	11	00	229
Jul. 16	10	15	235
Sep. 12	13	50	246
Sep. 16	16	20	241
Sep. 26	16	35	235
Sep. 27	10	00	234
Sep. 28	14	18	245
Oct. 1	9	40	252
Oct. 3	9	52	245
Oct. 3	14	44	245
Oct. 6	9	53	252
Oct. 16	14	33	253
Oct. 16	16	15	243
Oct. 17	9	40	375
Oct. 19	9	55	252
Oct. 20	14	30	235
Oct. 26	9	55	225
Oct. 26	14	59	232
Oct. 29	10	00	225
Nov. 4	10	00	232
Nov. 5	10	00	220
Nov. 7	10	00	225
Nov. 10	9	40	226
Nov. 17	9	50	232

Discussion

This paper is published as a report of experimental results. The writers prefer to postpone any extensive discussion of the significance or interpretation of these results in terms of electron-distribution and other characteristics of the ionized layer until further data are available, particularly observations at frequencies differing considerably from 4,435 kc, and, if possible, at various distances from the transmitter. Such observations are being undertaken here as far as facilities permit. It seems probable that a complete series of approximately simultaneous tests by this method using various transmission frequencies and recorded at various distances from the transmitter will give a fairly complete knowledge of the ionization of the upper atmosphere. However, the varied echo-patterns received indicate that the reflection (and refraction) processes at the layer are not simple. Complex echoes of course would have a profound effect on other methods of measurement of layer-height, but for other frequencies and distances than those of this work the reflections may be simple, although certainly not in all cases.[4] The possibility of complexity is to be borne in mind, however. Discussion of such points, and comparison of these layer-heights with those obtained by other investigators will be postponed pending further observations, particularly on other frequencies.

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IONIZATION IN THE ATMOSPHERE OF MARS*

By
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(Naval Research Laboratory, Bellevue, Anacostia, D. C.)

Summary—*Assuming that the atmosphere at the surface of Mars consists of 1/5 oxygen and 4/5 other gases, as nitrogen, etc., the composition of the atmosphere to great heights is calculated, just as was done for the earth, from the actions of gas diffusion and gravity. The electron density in the atmosphere of Mars due to the ultraviolet light of the sun is found to have a maximum value of* 1.1×10^5 *at a height of 440 km above the surface on a summer day, and* 0.55×10^5 *at 310 km on a winter day. On a summer day the skip distances for 100, 80, 60 and 50-meter waves are 0, 730, 1410 and 2240 km, respectively, and the shortest wave for reliable long distance wireless communication over the surface of Mars is about 47 meters. Winter and night values of these quantities are greater. Because of the skip distances for waves below 100 meters, it would seem that conditions on Mars are not very advantageous for short-wave communication, and it may be conjectured that no wireless apparatus exists there for waves below 100 meters. Waves longer than about 100 meters will not pierce through the atmosphere of the earth. These calculations, apart from other considerations, support the conclusion that only a very optimistic experimenter would look for successful wireless communication between the earth and Mars.*

IN a recent paper[1] the ionization in the atmosphere of the earth was calculated on the assumption that the ionization was caused by the ultraviolet light of the sun. Since, among other things, the solar ultraviolet energy and the action of ultraviolet light upon the atmospheric gases were not completely known, an exact calculation was not possible. What was done was to show that the sunlight falling perpendicularly on the atmosphere might be expected to produce 2×10^8 ion pairs, i.e., electrons and positive ions, in the high atmosphere each second in a 1 cm^2 column and that this rate of production gave rise to an ionization in the Kennelly-Heaviside layer in agreement with that inferred from the facts of wireless telegraphy. In the present paper a similar calculation has been made of the ionization in the atmosphere of Mars, and this has led to some rough estimates about wireless wave propagation on Mars.

Gravity at the surface of Mars is $0.38 \times 980 = 372$ cm sec^{-2}, and therefore Mars could retain an atmosphere of oxygen, nitrogen, water

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, March 29, 1929. Published with the permission of the Navy Department. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

[1] Hulburt, *Phys. Rev.*, 31, 1018; 1928.

[2] Russell, Dugan, and Stewart, "Astronomy," Vol. 1, 341; 1926.

vapor, and heavier gases, but probably not hydrogen and helium.[2] Water vapor and oxygen are detected spectroscopically in the atmosphere of Mars, but the presence of other gases as nitrogen, carbon dioxide, etc., can only be guessed. The pressure of the atmosphere at the surface of Mars appears to be roughly from 0.1 to 0.5 of that at the surface of the earth; we shall take the value 0.3. We shall assume that the atmosphere at the surface of Mars, like that of the earth, contains about $\frac{1}{5}$ part oxygen, the rest being nitrogen and other gases. Since the total molecular density of the earth's atmosphere at sea level and at 0 deg. C is 2.56×10^{19}, the total number n_0 of molecules at the surface of Mars is $0.3 \times 2.56 \times 10^{19} = 7.7 \times 10^{18}$ and of oxygen molecules n_0' is 1.5×10^{18}.

Assuming isothermal gravity equilibrium[3] the molecular density n at any height z cm above the surface is approximately

$$n = n_0 \, e^{-pz}, \tag{1}$$

where $p = mg/kT$. g is the acceleration of gravity at the surface of Mars, m the mass of the average molecule, k the molecular gas constant, and T the temperature of the atmosphere. With $g = 372$ cm sec^{-2}, $m = 4.8 \times 10^{-20}$ grams, $k = 1.372 \times 10^{-16}$ erg deg^{-1} and $T = 300°$ Kelvin, p is 4.35×10^{-7}. With this value of p and with $n_0 = 7.7 \times 10^{18}$ formula (1) is assumed to give the total molecular density of the Martian atmosphere to great heights for a summer day, i.e., the sun directly overhead. The period of rotation of Mars on his axis is 24.6 hours and the axis is tilted at an angle of 25.2 deg. to the plane of the ecliptic. These quantities are much the same as those for the earth and therefore we assume that the Martian diurnal and seasonal temperature changes and wind currents are roughly similar to those of the earth. Maris[4] has discussed the wind currents in the high atmosphere of the earth, and has shown that they will keep the various gases thoroughly mixed up to a level known as the "diffusion level," which is at about 160 km for a summer day; at this level n is of the order of 10^{11}. The diffusion level is lower in winter and at night. Above the diffusion level the various gases separate out under the action of gravity, their densities being given by the gravity equilibrium equation (1), the lighter gases floating above the heavier ones. The diffusion level is of course not sharply marked, the transition from the region of complete mixing to the region of gravitational separation being a gradual one. In the atmosphere of Mars n is of the order of 10^{11} at 400 km and therefore 400 km is taken to be roughly the diffusion level.

[3] Jeans "Dynamical Theory of Gases," page 309, 1904.
[4] Maris, *Terr. Mag. and Atmos. Elec.*, 33, 233; 1928

Accordingly, the density n' of the oxygen molecules is $n/5$ for heights up to 400 km; above 400 km n' is given by $n' = n_1' \exp. [-p'(z-400)]$, where n_1' is 4.16×10^{10} the value of n' at 400 km, and p' is 4.80×10^{-7}, the value of p for the oxygen molecule.

We may now use exactly the same physics and methods to calculate the ionization in the atmosphere of Mars as were used in the case of the earth. Namely, the equation was solved which expressed the condition that in each element of volume of the atmosphere the rate of supply of the electrons and ions was equal to the rate of loss, the loss being due to three causes, (a) the diffusion of the electrons and ions, (b) the recombination of the electrons with positive ions, and (c) the attachment of the electrons to neutral oxygen molecules thereby to form negative oxygen ions. The equation and the methods of solution were exactly as described in (18) and pages 1027 to 1029 of reference 1, and there is no need to give further details here. Since the distances from

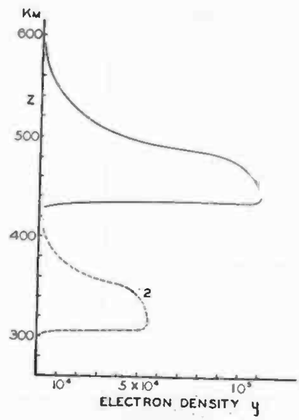

Fig. 1—Calculated electron density curves for the atmosphere of Mars; curve 1, summer day; curve 2, winter day.

the sun to Mars and to the earth are 227.7×10^6 and 149×10^6 km, respectively, the rate of production q of electrons per second in a 1 cm² column of the atmosphere of Mars is $2 \times 10^8 \div (227.7/149.5)^2 = 8.6 \times 10^7$; q for the earth is 2×10^8. The values of the recombination and the oxygen attachment coefficients were the same as those worked out for the case of the earth. The electron density, given in curve 1, Fig. 1, was found to have a maximum value of 1.1×10^5 at a height of 440 km for the conditions of a summer day. Following out the change from summer to winter for a temperate zone, as was done for the earth, the winter day electron density curve is given in curve 2, Fig. 1. Below their maxima the curves drop quickly to low values, and as pointed out for the case of the earth they probably do not represent correctly the ionization below the maxima. The ionization in this region is undoubtedly greater than that given by the curves, but in spite of this the curves serve fairly well as first approximations and are used to derive some conclusions about the propagation of wireless waves. If the atmospheric pressure, and particularly the oxygen pressure (because the oxygen attachment term is an important one in the electron density equation), is an order of magnitude greater or less than the value which has been used the electron density curves of Fig. 1 will be raised or lowered, respectively, some 50 km.

Assuming that the wireless waves are sharply reflected from the summer day electron layer of curve 1, Fig. 1, and assuming no magnetic field, the limiting wave, defined as the shortest wave which can be used for reliable long distance communication, is 47 meters; see reference 1, equation (26) for the calculation. The skip distances were calculated[5] and are given in Fig. 2. The values of the skip distances

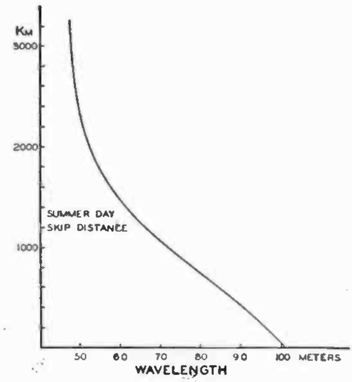

Fig. 2—Calculated skip distance curve for a summer day on Mars.

and the limiting wave thus determined may be as much as 40 per cent too large because there may be appreciable ionization below the 400-km level which has been neglected. The summer night values and the winter day and night values are greater than the summer day values. The skip distances on Mars occur for longer waves than on the earth, because the maximum density of ionization is less and is at a greater height than in the case of the earth, and because the radius of Mars is 3370 km, which is smaller than the 6370-km radius of the earth. Since the skip distances are fairly great for waves less than 50 meters, we may conjecture that commercial wireless circuits on Mars would

[5] Taylor and Hulburt. *Phys. Rev*, **27**, 189, (1926), equation (8).

hardly use wavelengths below 50 meters and that short-wave communication would be mainly in the 60 to 120-meter band. The advantages of long distance low-power transmission peculiar to the short waves below 30 meters on the earth are, however, not so pronounced for waves longer than 60 meters, and on the whole one might suppose that the conditions on Mars are more suited to long waves, 1,000 meters or greater, than to the short waves. These conclusions might be modified if there were a magnetic field on Mars.

The longest wave λ_1 which can penetrate through an electron layer of maximum electron density y_1 is obtained by putting $\mu=0$ and solving for λ in the expression for the refractive index $\mu=1-y\,e^2\lambda/\pi m$, where e and m are the electronic charge and mass; this is the expression for the refractive index with no magnetic field. For a summer day on Mars $y_1=1.1\times 10^5$ and $\lambda_1=100$ meters. Waves longer than 100 meters will be reflected (refracted) back from the electron layer, and waves a little shorter than 100 meters, although they will pierce through the layer, will suffer considerable loss in intensity by partial reflection and possibly by absorption, the loss due to these causes decreasing with the wavelength. For summer night and for winter conditions y_1 is less than 1.1×10^5 and waves longer than 100 meters may pass through the layer; for example, on a winter day $y_1=0.55\times 10^{15}$ and $\lambda_1=140$ meters. In the atmosphere of the earth on a summer day $y_1=3\times 10^5$ and $\lambda_1=61$ meters; on a winter day $y_1=1.5\times 10^6$ and $\lambda_1=85$ meters, and in the late hours of the night when y_1 may be as low as 8×10^4, λ_1 is 137 meters. For wireless communication between Mars and the earth one should perhaps use waves well below 100 meters in length in order to penetrate our own atmosphere. But in view of the suggested poor conditions on Mars for the utilization of these waves, it may be that there are no short-wave receiving stations on Mars, except possibly those for experimental or research purposes. The polarized wave longer than 214 meters (discussed in reference 5, equation (2), and pages 209 and 215) which might pierce our atmosphere, is of speculative utility depending as it does on the intensity of magnetization of the electron atmosphere. From the present calculations, quite apart from other considerations it is concluded that only a very optimistic experimenter would look for successful wireless communication between the earth and Mars.

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NOTES ON THE EFFECT OF SOLAR DISTURBANCES ON TRANSATLANTIC RADIO TRANSMISSION*

By
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In 1923 when the relation between abnormal long-wave radio transmission and solar disturbances was first noted, the outstanding abnormality was the great decrease in night time signal field strength accompanying storms in the earth's magnetic field. There was a slight increase in daylight signal field but this was distinctly secondary to the effect upon night field. Previous to 1927, data on signal fields were limited to one set of measurements a week, and although daylight signal field strengths were higher during periods of increased magnetic activity, it was somewhat difficult to determine the effect of individual storms. The present notes show the effects of individual storms of 60-kc transatlantic radio transmission and also give some indication as to their effect on short-wave radio transmission.

It should be borne in mind that it is not felt that disturbances in the earth's field are in themselves responsible for the abnormal radio transmission, but that these two phenomena along with earth currents, aurora, etc., result from some cause or causes, attributable to the sun. In a previous paper, radio transmission was correlated with all these phenomena. In these notes disturbances in the earth's magnetic field alone will be taken as the criterion of the solar state.

The results are in general as follows:

1. The higher daylight signal field strengths on 60 kc obtaining during periods of increased solar disturbances are associated more with general magnetic activity than with individual storms.
2. Individual storms do tend to increase 60 kc daylight signal fields, however. For the more severe storms during 1927 and 1928, the result was an increase of about 30 per cent on the day the storm began to about 75 per cent for the four or five days following. The effects of individual storms vary greatly, however.
3. The day-to-day signal fluctuations on 60 kc are much greater during periods of greater magnetic activity and are greater during the winter months than during the summer months.

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4. Magnetic disturbances are accompanied by a large decrease in short-wave signal field strength on the day of maximum activity. Even mild magnetic storms may be accompanied by a reduction of signal field to or below the measurement limit. The recovery is a matter of one to seven or eight days depending on the severity.
5. Within a narrow range, an approximate linear relation is found between daily short-wave radio field strengths expressed in decibels above or below 1*uv* per meter and the daily average of the horizontal component of earth's field.

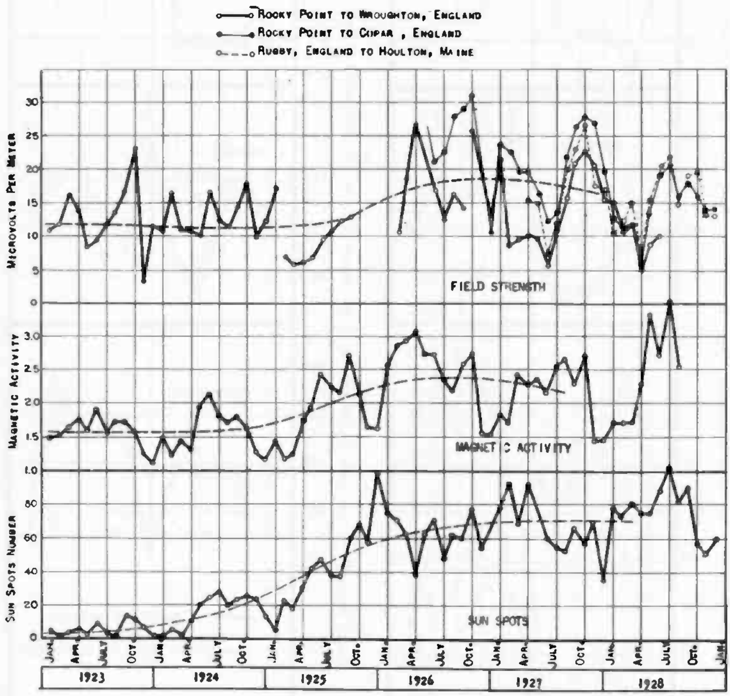

Fig. 1—Monthly average of daylight radio signal fields. Compared with monthly averages of magnetic activity and sun spots. Signal fields corrected to 5000 km distance, 3000 meter amperes, and 60 kc transmission frequency.

Effect on Long-wave (60 kc) Transmission

Fig. 1 shows the general variation in the trends of long-wave daylight radio transmission and activity of the earth's magnetism and sun spots. The increase in field strength with increase in the above activities is quite apparent. A large part of this gain in signal field is realized as a gain in signal-to-noise ratio as, in general, noise appears to be quite unaffected. This may be due to the fact that the transmission path of noise—chiefly from east, south and southwest—lies to a great extent outside the auroral zone.

Figs. 2 and 3 represent the variation in signal field strength for a number of days preceding and succeeding a number of individual

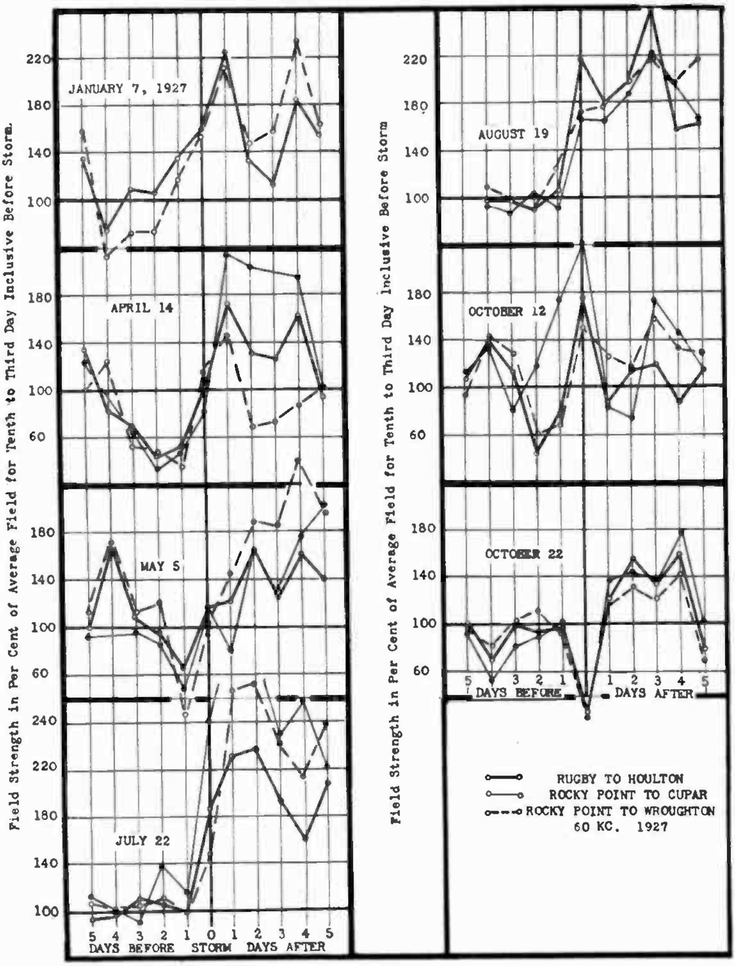

Fig. 2—Effect of solar disturbances on 60-kc daylight radio transmission.

severe disturbances in the earth's magnetic field. The day of the magnetic storm is taken as the first day that daylight signal fields could be affected after the appearance of the effect on the earth's field. For example, if the effect in the earth's field was first noted at 7 P.M., the first daylight fields which could be affected would be the next day; if the effect was first noted at 7 A.M., the same day was taken as the day of the storm.

It will be noted that although on the whole the effect accompanying the storms is an increase in the fields of approximately 30 per

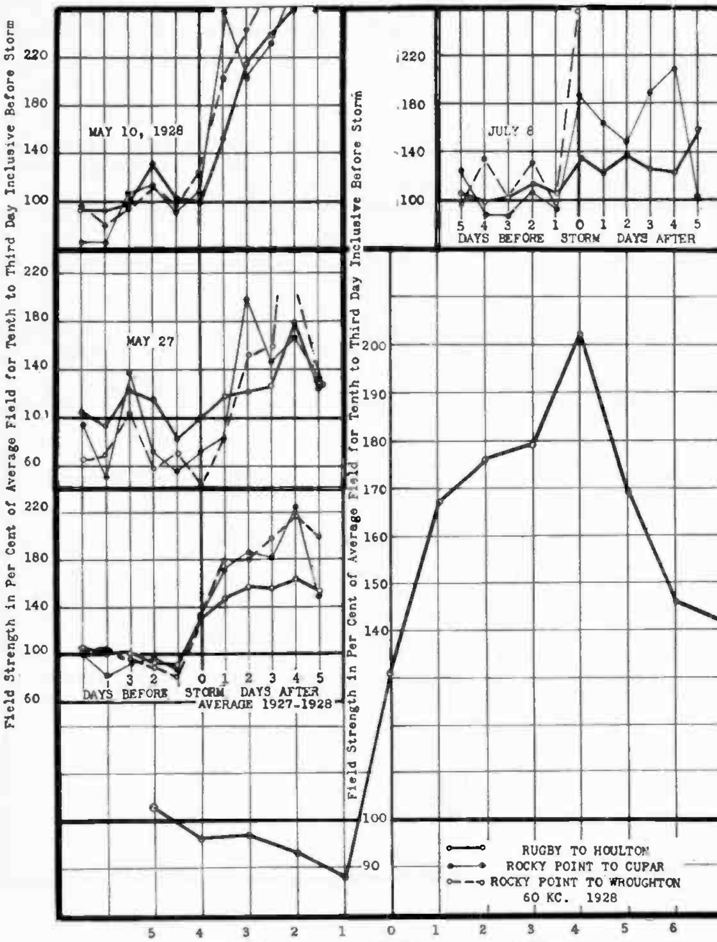

Fig. 3—Effect of solar disturbances on 60-kc daylight radio transmission.

cent on the day of the storm and 75 per cent for the four or five days following, the effect varies greatly with different storms. Although on the average curve of Fig. 3 there is a slight decrease in signal field on the few days preceding the day of maximum magnetic disturbance, a decided effect of this kind was noted on only one-half the individual storms. On October 22 (storm began in the earth's field at 1:30 A.M., E.S.T., October 22) the field dropped to 20 per cent of its value. In the storm beginning on October 12, 1928, the field was back to about average on the day after the storm, although it came up again on the third day. It is seen that from the first to the fourth or fifth day the fields do not follow a well defined characteristic. In the case of the storm of April 14, the results for Cupar, Wroughton, and Houlton are distinctly different.

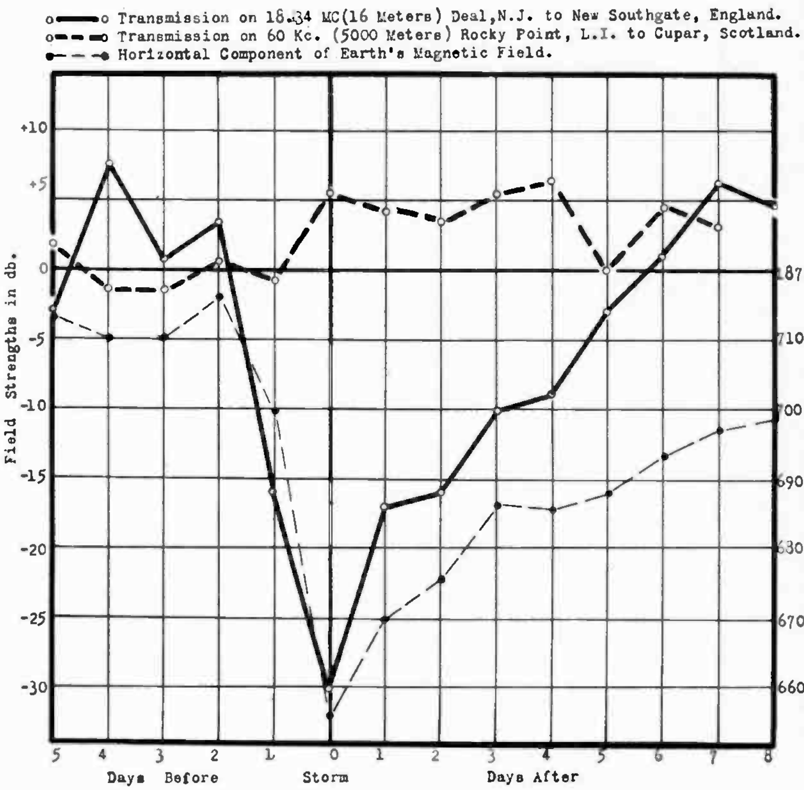

Fig. 4—Variation in radio transmission before and after solar disturbance, July 8, 1928.

The storms noted above were considered quite severe. For storms of less severity, the general effect is much less marked.

As to the significance of a 75 per cent change in field strength, it is of interest to consider the day-to-day change in field strength. For 1927 and 1928 the average day-to-day change in fields as measured at Houlton, was 30 per cent of the average yearly field, varying from 40 to 50 per cent in the winter time to 15 to 20 per cent in the summer. Such high percentages necessarily mean that there is considerable fluctuation in addition to that accompanying actual magnetic storms.

Daily data were not available previous to 1927 but similar figures for week-end measurements in England of transmission from Rocky Point, Long Island, give some idea of the change from year to year.

Such fluctuations consist not merely in an increase in field strength during storms and then a return to normal but also in decreases in field strengths to abnormally low values. The latter cases are most prevalent in the winter months; October to April, inclusive.

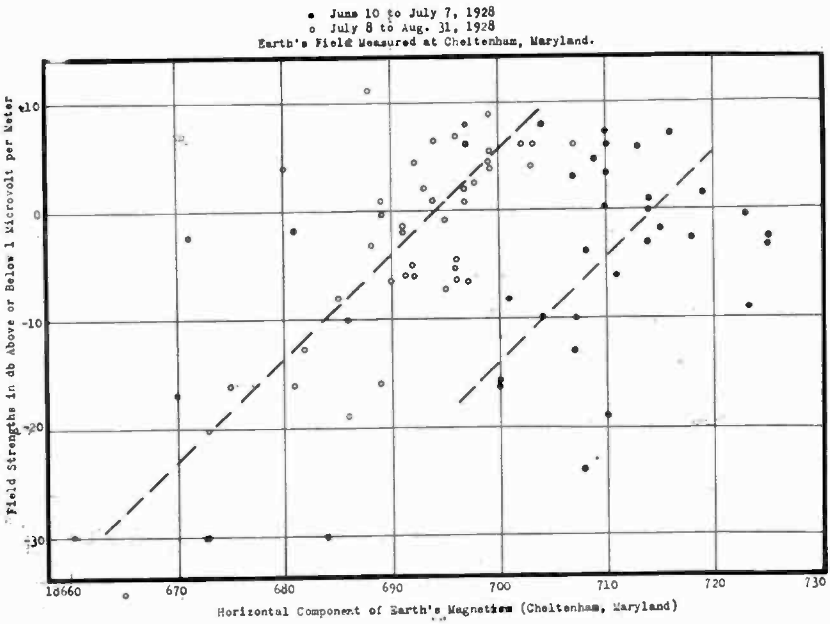

Fig. 5—Variation in field strengths with horizontal component of earth's magnetism. Transmission from Deal, N. J. to New Southgate, England. Frequency 18.34 megacycles (16 meters).

Year	Average Fluctuation / Average Field	Average Fluctuation / Average Monthly Field (Summer)	Average Fluctuation / Average Monthly Field (Winter)
1923	27 per cent	8 per cent	50 per cent
1924	25 " "	15 " "	50 " "
1925	26 " "	10 " "	60 " "
1926	31 " "	25 " "	60 " "
1927	43 " "	30 " "	75 " "
1928	55 " "	40 " "	80 " "

In view of the fact that 1923 was near the minimum of a sunspot cycle, and 1927 and 1928 near the maximum, it is seen that transmission is much less stable during periods of increased solar disturbances and is not confined only to such severe cases which actually result in magnetic storms.

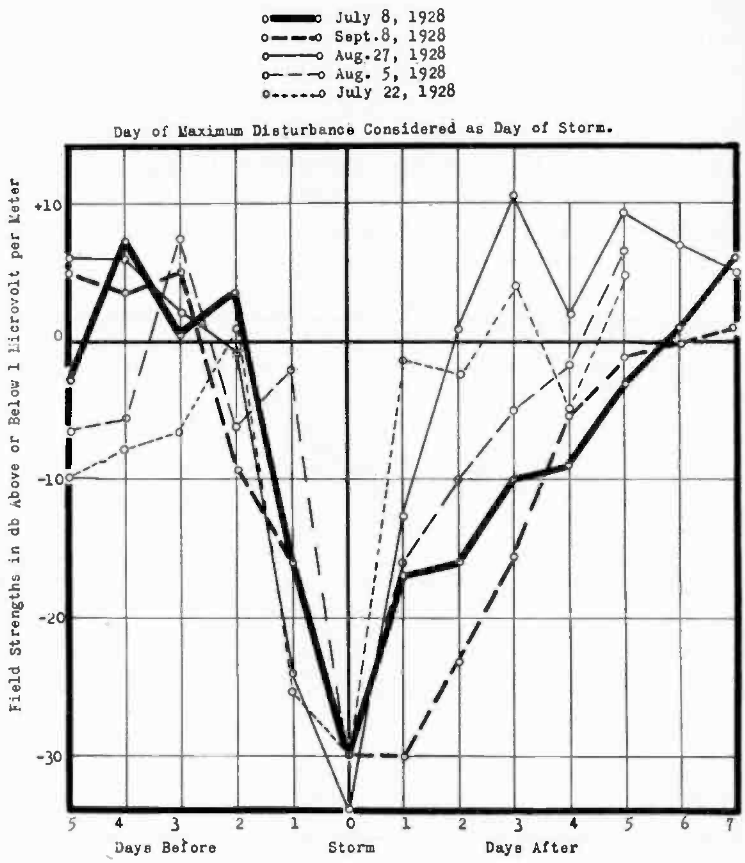

Fig. 6—Variation in field strength before and after a solar disturbance. Transmission from Deal, N. J., to New Southgate, England. 18.34 megacyles (16 meters).

Effect on Short-Wave (18.34 megacycles; 16 meters) Transmission

The effect accompanying magnetic storms in the case of short-wave radio transmission is the reduction of the field strengths almost to, or below, the measurement limits. Fig. 4 compares the effect upon long and short-wave fields for the storm July 7–10, 1928. The storm was first noticeable in the earth's magnetic field at about 2300 G.M.T. July 7, but was most active July 8, which is considered as the day of the storm. The long waves (60 kc) were not particularly affected before the storm began, but upon its advent the field strength increased 80 per cent and continued high for several days. At short waves (18.34 megacycles; 16 meters) the field strength went down considerably before the storm began and reached a minimum of 1/30 (or less) of normal value (30 db below 1 μv per meter) on the day the storm was most active. From then on there was a slow recovery reaching normal values some six or seven days later. In addition to low field strength, transmission during this period was subject to considerable fading signifying, as it were, unstable conditions.

In the same figure is plotted the variation of the daily average of the horizontal component of the earth's magnetic field. The agreement with the 16-meter fields suggests a possible relationship.

Fig. 5 shows radio fields plotted as a function of the daily average of the horizontal component of the earth's magnetic field from the first part of June, 1928, to the end of August, 1928. Taking all the points as a whole there does not appear to be any significant relation. In plotting the data, however, it was noted that the data points fell quite definitely into two groups, one before the magnetic storm of July 8 and one after. Within each of these groups, the distribution of the points suggests the possibility of some relation such as indicated by the dotted lines.

Fig. 6 shows short-wave radio transmission during periods of several magnetic storms in the summer of 1928. In general the decrease in fields preceding the day of maximum activity is about the same for all storms. The recovery is, however, much more rapid for the less severe storms. Of the storms in question only one was really severe and one—that of July 22—was hardly severe enough to be called a storm.

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IMAGE TRANSMISSION BY RADIO WAVES*

By
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THE purpose of this paper is to introduce a series of papers in which are described specific methods whereby transmission by radio of stationary images or moving pictures can be effectively carried out. Accordingly it has seemed desirable to establish the position of image transmission by radio in the general engineering technique of this field rather than to discuss individual methods or specialized apparatus.

All radio engineers are well acquainted with the transmission of intelligence by modulated radio waves. The simplest mode of modulation corresponds to telegraphy and is generally carried on at slow or moderate speeds and with one hundred per cent modulation. More elaborate and difficult to both the transmitter and receiver, and more critical in its electrical requirements on the intervening medium, is the transmission of speech or music, which involves modulation at higher frequencies than are generally required for telegraphy, and which similarly aims at complete modulation at peaks of sound amplitude, though with a comparatively small *average* modulation. Stationary image transmission at speeds now regarded as normal falls between ordinary telegraphy and telephone transmission in its general difficulty and physical characteristics. On the other hand, television, or the transmission of moving pictures, is by far the most difficult method of radio transmission so far seriously proposed or accomplished. The modulation frequencies are considerably higher than are required for the transmission of speech or music, the average modulation is low, but complete modulation is also desired for peaks of light or shade. Television therefore requires powerful transmitters having long and linear modulation characteristics, both as regards frequency and amplitude, receivers having similar radio and intermediate frequency characteristics indicating accurate proportionality of response, and a high quality radio circuit between transmitter and receiver. By "high quality" is meant a circuit essentially free from fading or any form of selective absorption of the radio wave.

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1. Comparison of Facsimile Transmission and Telegraph Transmission

Facsimile transmission is the transmission of stationary images. Its purpose in general is to avoid the human or variable element in transmission and reception and to enable the transmission of material which is not of simple alphabetic nature as, for example, drawings, writing or the like. It is not in itself the most rapid method for the transmission of intelligence. Certain of the five-element letter codes used in ordinary telegraphy are considerably the superior of facsimile transmission in this regard. They lack, however, the capability of carrying with any facility the special material which facsimile transmission can handle (such as pictures and the like). It is necessary to keep in mind the importance of the human element and the scope of subject matter which can be handled. In appraising the relative values of telegraphic and facsimile methods of transmission (for the same number of words per minute), facsimile transmission in general requires a more perfect circuit than does telegraphic transmission. While suitable facsimile terminal apparatus has been thoroughly developed and is amply capable of handling facsimile transmission and reception at any reasonable speed, yet radio circuits (while giving much promise of ultimate satisfactory performance for facsimile purposes), are not yet at a stage where extremely high speeds of transmission are consistently feasible over certain transmission distances or paths.

The practical conclusion is drawn that the improvement of the radio circuit, and the increasing importance of sending highly personal or graphic material without the necessity for skilled operators at each point of the circuit, will be the elements of most importance in any further study of the place of facsimile transmission in the communication field.

2. The Relation of Facsimile to Television Transmission

Television transmission is a method of communication of intelligence far transcending in its requirements any form of facsimile transmission so far developed. On the average, the transmission of an excellent facsimile picture of considerable size *at television speeds* would correspond to the transmission of a total number of dot-elements requiring but a few seconds. The actual facsimile picture sent *at facsimile speeds* may require almost as many tens of minutes for its transmission. The speed of picture element transmission is therefore in the approximate ratio of 100 to 1 or more for television as compared to facsimile transmission.

Television is therefore found to be more susceptible to disturbance by eccentricities in the transmission path than is facsimile transmission. Extremely objectionable effects in the form of blurred or multiple images, or "explosive pictures," are obtainable under conditions when telephony or telegraphy could be carried out over the corresponding circuit with little, if any, noticeable deterioration of quality.

The limitation of the service range of television stations resulting from this feature is not generally appreciated. It is, however, a factor of importance, and it is to be anticipated that the ratio of the "service range" to the "heterodyne range" of a television station will be considerably less than for telephony, facsimile, or telegraphy. This is an unpleasant feature when contemplated in the light of future Federal assignments of television frequencies to individual stations and the repetition of such frequencies at various points in the United States. Despite considerable experimentation final data on this subject are not available.

3. The Relation of Television to Telephone Broadcasting

There are certain marked differences between television and telephone broadcasting which require consideration by the radio engineer and designer. Essentially a radio telephone signal is a single modulation of the carrier wave. A television signal, in general, will necessarily include two modulations, one corresponding to the picture, and the other (directly or indirectly) to the synchronizing means. Certain general considerations indicate that the average modulation frequencies for the picture and the modulation frequency for the synchronizing signal should not be widely dissimilar if effective and accurate framing is required. The omission of synchronizing signals implies an unusually high degree of precision in the speed controls at the transmitter and receiver and, while a possibility, does not appear at present to be the most readily available method of framing the picture, (unless occasional manual adjustment is acceptable).

As previously indicated, television requires a much wider frequency band (because of the high frequencies of modulation) than does telephony. It is accordingly more open to interference, both man-made and natural, to fading, and to selective attenuation. As a secondary result of the wide frequency band occupied, the national syndication of television programs by wire lines presents a new series of problems which, so far as one can judge from the available literature, have not yet been solved.

Furthermore, the high modulation frequencies for television make transmitter and receiver design impracticable unless the shorter wavelengths (higher frequencies) are used for the transmission. This imposes further difficulties, namely, the considerable attenuation of the short wave, particularly in its passage over urban areas, and the generally diminished service area as compared to telephone broadcasting stations of equivalent power.

No doubt the considerations just mentioned have contributed substantially to the more leisurely progress of commercial television as compared to telephone broadcasting and have prompted caution on the part of responsible radio engineers interested in television service to the public.

4. Future Television Standardization

It is clear also that more definite and elaborate standardization will be required in the television broadcasting field than in the telephone broadcasting field. In order effectively and conveniently to receive a television transmission, the receiver must have certain constants and characteristics determined by the transmitter. It must be arranged to handle the same number of horizontal and vertical elements in the picture, the same number of pictures per second, must be arranged for the same scanning method (as to direction and mode), must follow the same antenna current versus picture light-and-shade correspondence relationship, must have the same synchronizing means, and presumably must be adapted to receive the transmitted arrangement of television and synchronizing signal in one or more frequency bands.

In other words, while a telephone broadcasting receiver will in general receive almost any sort of telephone transmission (excluding only such rarely used methods as single sideband transmission and "modulation by frequency variation"), a television broadcast receiver will receive satisfactorily only the highly individual transmissions emanating from a specific type of transmitter of definite design. The conclusion to be drawn from this state of affairs is an obvious one. Clearly the establishment of unusual constants in a television transmitting station by any organization not having a wide knowledge of the broadcasting and television fields and of the probable effect of such a choice of constants on the entire television service to the public, is prejudicial to the orderly and rapid development of the television broadcasting art.

After this brief introduction, it becomes timely to place before the membership of the Institute the individual papers dealing with various phases of image transmission by radio waves.

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THE ELECTRICAL TRANSMISSION OF PICTURES AND IMAGES*

By

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Summary—*The objective of this paper is a discussion of some of the important principles underlying the electrical transmission of pictures rather than a description of detailed methods by which such transmission may be effected. The subject, which includes both still pictures and television, is treated as a special form of electrical communication, differing from other forms primarily in the nature of the information conveyed.*

The necessity for reducing the information represented by a picture or scene to a form where it may be expressed as a single-valued function of time is considered. This function is used as a basis for comparing picture transmission systems with the more familiar telephone and telegraph systems, and for evaluating the amount of information carried by each. The dependence of the rate at which information is train mitted upon the frequency range occupied by the signal is shown to be of fundamental importance.

The major portion of the paper is concerned with a study of the relations between the original picture and the transmitted signal as it appears in the several parts of the system. Since the excellence of any system for the transmission of intelligence is measured by the fidelity with which it reproduces the original information, the effect upon the final picture of deviations from ideal performance on the part of each element is examined. Attention is given to the conditions governing the use of modulated waves for the particular forms of signal encountered in picture transmission. The relations between the more important transmission characteristics and the appearance of the reproduced picture are considered briefly.

On the basis of the above study a number of conclusions are reached as to the performance characteristics to be sought in the several elements to be used in picture transmission systems.

THE transmission of pictures is concerned with two general fields of application. One involves the reproduction of a single still picture in permanent form. In the other, the objective is the reproduction of a succession of images at such a rate that they appear to the eye as an uninterrupted image. Phrased in this manner it is evident that what is known as television may be considered as a particular kind of picture transmission.

For many years the processes required for the electrical transmission of pictures have been known; the comparatively recent accomplishment of such transmission is due entirely to the fact that physical means for adequately carrying out these processes have only lately become available. It is significant that the required elements have been

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developed largely through the study of other methods of electrical communication, emphasizing as it does that the electrical transmission of pictures is actually an extension of principles already well understood to an additional form of information. A review of some of the factors involved in the application of the basic methods of electrical communication in this new field calls attention to many problems of importance in its further development.

The fundamental principle underlying the telegraph, the telephone, picture transmission systems, or television is that complex electric waves, which are controlled at the sending station by the sound or the image which is to be sent, are used at the receiving station to control some devices whereby the sound or the image is reproduced. In television one does not see the person at the other end of line, nor in telephony does one hear his voice. In one case, the distant person is represented by an image produced by an optical system; in the other, his voice is represented by sounds produced by an acoustical system. The only thing which is ever transmitted over the wires or through the ether is an electric wave. In any method for communicating intelligence by means of the transmission of electric energy, three major functions are always involved. At the sending end, means must be provided for imparting to an electric wave characteristics determined by the information to be conveyed. Next, means must be provided for transmitting this electric wave without injury to these identifying characteristics. Finally, at the receiving end, means are required which, under the control of the transmitted wave, reproduce the desired information.

In the case of sound the problem is relatively simple, due to inherent similarities between acoustic waves as they exist in air, and electric waves as they exist in wires; each of these may be described in terms of a quantity which varies with respect to time. In a sound wave, the air pressure at a given point varies from instant to instant; in an electric wave the current-driving force at a given point in the conductor varies from instant to instant. It is not difficult, therefore, to devise a system in which the electric force driving the current is at each instant proportional to the pressure of the acoustic wave falling on the controlling device. This has been successfully accomplished by the familiar telephone transmitter and by the radio broadcast microphone. Similarly, any apparatus by which variations in the amplitude of an electric current cause corresponding variations in air pressure may be used at the receiving end to reproduce sounds resembling those existing at the sending end. Such means are found in the electromagnetic receiver.

In other systems of electrical communication no such convenient analogy exists between the electric wave and the information to which it must be related. In these cases it is necessary to translate the information into the form of a time variation before it is suitable for identification with the characteristics of an electric wave. With written information this translation may be accomplished by means of the Morse code. Here each letter of the alphabet is represented by a quantity which alternates between two assigned values in a specified manner. This code may, of course, be represented as a variation in one displacement with respect to another. Our familiar script may be similarly described, but unfortunately it is not a single-valued function, and consequently cannot be directly identified with a single time variation.

It is interesting to note how the telautograph solves this part of the problem. Here a point is moved as in writing. Two communication channels are employed; one carrying information as to the time variation of horizontal displacement; the other, similar information as to vertical displacement. By causing a point at the receiving end to follow these two time variations of displacement simultaneously its motion is made to duplicate that of the moving point at the sending end. The trace of its motion is all that concerns the recipient of the information; the rate at which it moves is of interest to the communication engineer, since it furnishes him with his necessary time function. In this case, time appears temporarily as a parameter common to two related displacements.

These examples have been noted to emphasize the fundamental fact that in every electrical communication system the information to be conveyed must be put into the form of a time variation. The various types of picture-transmission system are no exception. To accomplish this necessary translation in these systems there have been devised numerous scanning and distributing devices. By means of these, information regarding the tone value of each elementary area comprising a picture or subject is transmitted over a single channel individually; the several areas being dealt with in some predetermined order and at some definite rate.

Although there are many variations possible in the arrangement of the scanning and distributing means, our present purpose will be served if our attention is confined to a representative method. Imagine a given picture divided into a series of narrow parallel strips, and these strips into small sections which may be considered as elementary areas of the picture. If the image of an illuminated aperture is formed on one of these elementary areas and then moved so as to pass along all of the parallel strips in turn, the light passing through the picture—or reflected from it—will at any instant be determined by the tone value of the area which happens to be covered by the image of the aperture. Inasmuch as the location of the portion of the picture selected in this manner changes from instant to instant, the intensity of the light must change correspondingly, and the desired translation from a variation which can be defined in terms of space only, to one which can be defined in terms of time, has been effected. A similar procedure may be used to effect the complementary distribution at the other end where these time variations in light intensity are duplicated by the controlled variations of some suitable light source. If this light is used to illuminate uniformly an aperture, the image of which is moved over a surface in a manner identical with that of the image at the transmitting end, the light falling on any point is thus determined by the intensity of the local source at the instant when the area is exposed. As the exposed area moves from point to point, the various tone values are distributed over the illuminated surface, and the retranslation from a variation which can be defined in terms of time only, to one which can be defined in terms of space, has been effected.

Although we have secured the desired variation in tone value with respect to position, we have not yet secured a complete image, as the variation with time has not been eliminated. It is necessary, therefore, to provide further means to enable us to combine a series of successively illuminated areas into a complete picture. If we move the image of the variably illuminated aperture over a photographically sensitized surface, the tone values corresponding to each position will be recorded. During one complete distributing operation each elementary area will be exposed, and the surface will, on development, exhibit simultaneously the desired space variations in tone value. In other words, information about each separate area has been stored up until the entire message has been completed, in order that it might be examined as a whole. If, instead of making a photographic record, we observe the light as it is directed to successive portions of the image area, we will see a complete image, provided the eye receives impressions from the last areas while those received from the first are still retained by the retina. Further, if repeated images thus formed follow each other in rapid succession, any motion of the object or image at the transmitting end will be accompanied by a corresponding change in the image at the receiving end, and the effect of motion will be obtained. Thus the apparently moving image seen in television may be thought of as made up of a succession of individual still pictures exactly as in the projection of motion pictures.

By means of these scanning and distributing devices, and image-storing processes, it is possible to overcome the lack of a common characteristic between a visual image and an electric wave, and to express one in terms of the other quite as readily as in the case of a sound wave and an electric wave. To complete the picture transmission or television system, therefore, it is necessary simply to combine these functions with those of the three elements which we have already found to be present in every electrical communication system, namely, a device for controlling the current, an electrical transmission medium, and a device controlled by the current.

In any of the various electrical communication systems the most important part of the problem of the design of the system has to do with the amount of information which is to be carried. It is apparent that in any picture-transmission system the amount of information is related to the number of discrete elementary areas which are to be recognized. In order to reproduce an exact duplicate of the original picture it would be necessary to make infinitesimal both the width of the parallel strips into which it is divided for scanning and the elementary lengths of these strips. Since this would involve an infinite number of elementary areas, and consequently an infinite amount of information, it is necessary to examine with some care the magnitude which the individual areas may be permitted to have.

In the original picture each of the strips into which it is divided may be crossed by lines of varying tone value. If we assume that light is collected from an infinitesimal elementary length of strip, its value represents the average tone value of the element. In the reproduced picture, again assuming that the trace is made by an aperture of infinitesimal length, the individual strips are built up of cross bars of uniform tone value, all of which must lie at right angles to the strip. Each of these elementary lengths in the reproduced picture has, in the ideal case, a tone value proportional to the average tone value across the corresponding elementary length in the original picture. This failure to reproduce the actual distribution of tone value along each elementary bar results in distortion which appears as a definite structure in the picture.

If the width of a single strip is so small that the eye is unable to distinguish any change in tone value which may occur across it, the reproduced picture will appear to be as free from structure as the original. It has been found that this condition is approximated by using one hundred scanning paths across a picture one inch wide. As the strips are made narrower there is a slight improvement. With two hundred strips per inch the structure would rarely be detectable by ordinary inspection. If the strips are made wider, however, the deterioration in the appearance of the picture is very rapid, the structure with seventy-five lines per inch being so marked as to be objectionable. Although the nature of the structure in picture transmission is quite different from that used in the halftone printing process, there is a close correspondence between the number of structural elements per inch in the two cases for a given picture quality. The above distortion is inherent in the method used for reproducing the picture. It is fixed by the design of the apparatus and the limit to which it is reduced is set largely by economic considerations.

Our chief concern in building apparatus for the transmission of any information is the fidelity with which the system reproduces the original information. To investigate the effect on the final picture of deviations from ideal performance on the part of each of the several major functional elements, we must study in some detail the phenomena which take place in transmitting information as to the variations in tone value along the several strips constituting the entire picture surface.

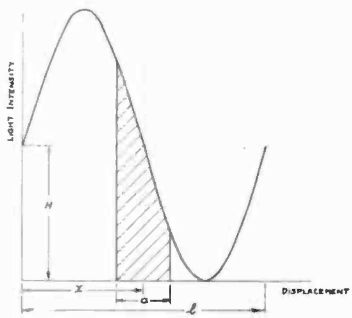

Fig. 1—Amount of light transmitted through a rectangular aperture moving along a path having a sinusoidal variation in density.

We have first to consider the nature of the variations in intensity as the light is collected from a small area moving along this strip. Let us take a sinusoidal variation in tone value and determine the relative amounts of the variation in light as apertures of different length are moved along it. The condition is represented in Fig. 1. The variation is drawn as taking place about an average value, such that the minimum intensity is exactly zero. The results would be unaltered if larger average values were used. Smaller average values are physically impossible. In the figure, a equals the aperture length and l equals the length of a cyclical variation. The average value is represented by H.

The amount of light passing through the area defined by the aperture image is shown as the shaded portion of the figure. The expression for this area is

$$
\begin{aligned}
A &= \int_{x-a/2}^{x+a/2} \left(H + H \sin \frac{2\pi x}{l} \right) dx \\
&= Ha + \frac{lH}{\pi} \left(\sin \frac{\pi a}{l} \right) \left(\sin \frac{2\pi x}{l} \right).
\end{aligned}
\tag{1}
$$

If the aperture length is expressed as a fraction of the length of a cycle, that is, if $a = kl$, the above expression becomes

$$
A = klH + \frac{lH}{\pi} \left(\sin \frac{2\pi x}{l} \right) (\sin k\pi). \tag{2}
$$

It is evident that the maximum amount of light should be obtained when the center of the aperture is at the position $x_1 = l/4$, and the minimum amount when it is at $x_2 = 3l/4$. The relations between maximum, minimum, and average value have been computed for a number of ratios of aperture length to cycle length. In Fig. 2 the ratio

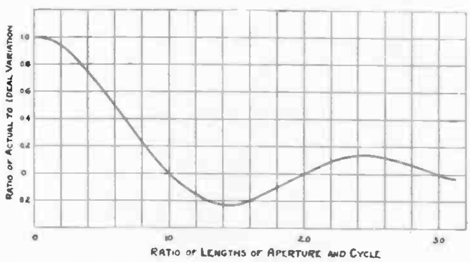

Fig. 2—Performance of an actual aperture relative to an ideal aperture as a function of the ratio of the aperture length to the length of a cyclical variation in picture density along the aperture path.

of the actual amplitude of the variation to the ideal amplitude has been plotted as a function of the ratio of these lengths. From this it is seen that when a single cyclical variation of the picture has a length equal to that of the aperture the observed variation becomes zero. Beyond this point, that is, with cycle lengths less than the length of the aperture, the variation reappears. Now, however, the variation in light intensity is exactly out of phase with the variations which would be given by an ideal aperture located at the center of the actual aperture. In other words, when the center line of the real aperture lies on the element of maximum density we receive maximum light instead of minimum light. When the cycle lengths become less than one-half the aperture length the variations again appear in their correct phase.

It is seen from an examination of the curve given in Fig. 2 that in order to secure light variations having amplitudes reasonably proportional to those which would be obtained by an ideal aperture—that is, one of infinitesimal length—it is necessary that the length of the aperture be less than about one-third the length of the minimum cyclical variation which is to be transmitted. A complete analysis of the effect of finite aperture dimensions is contained in a previously published paper.[1]

For convenience in discussing the performance of the several functional elements of the transmission system it is desirable to express the complex variation in light intensity in terms of the frequencies of its sinusoidal components. If some cyclical variation in picture density is repeated in a length l of aperture path, and if the aperture moves a the velocity v, the frequency of the resulting cyclical variation in light intensity will be v/l. It is possible, therefore, to determine at once the frequency range of the variations which are encountered during the transmission of the picture and which, consequently, must be taken into account in the design of the system.

The first important fact is that the light intensity always has a positive value. It differs in this respect from an acoustic wave which has alternate positive and negative values. In describing in terms of its several sinusoidal variations the light obtained when a picture is scanned, we must, therefore, include a component of fixed amplitude; that is, of zero frequency. It is this component which is related to the average tone value of the picture. For example, a picture made up of alternate strips of black and dark gray exhibits changes in tone value which are identical with those obtained from a picture made up of alternate strips of light gray and white. The difference between the two pictures lies wholly in the average value of the light intensity. It is imperative, therefore, that information as to the amplitude of this zero frequency component be transmitted if we are to distinguish at the receiving end between these two pictures. Inasmuch as variations in average picture density may occur slowly throughout the entire transmission operation, it is apparent that there will be also present components of extremely low frequency.

To establish a definite upper limit to which the system must be made to respond, let us assume that each picture strip is divided into elementary lengths equal to the width of the strip. This condition approximates equivalent resolutions along the strip and at right angles to it. On this basis, the maximum frequency at which recognizable

[1] Gray, Horton, and Mathes, "The Production and Utilization of Television Signal," *Trans.* A. I. E. E., 46, 918–934, 1927; *Bell System Tech Jour.*, October, 1927.

variations occur is $v/2d$, where d is the assigned elementary length. If n is the number of picture elements per unit area and A is the area transmitted per second, this limiting frequency may be expressed as $nA/2$ cycles per second. On the basis of 10,000-unit areas per square inch we must have, if this area is to be transmitted in one second, a frequency range extending from 0 to 5,000 cycles per second.

In picture transmission it is possible to choose the rate of transmission to fit the frequency range of the available communication channel. In television, however, the time allotted to a single scanning operation is fixed by the necessity of completing the operation in a time less than that required for the image to pass from the retina of the eye. It is not the intention to recommend here a desirable value to adopt for this scanning interval. For our present discussion we may use the convenient value of twenty scanning cycles per second. Working backward, therefore, from the frequency range of the communication channel we may find, by assuming a frequency range of 20,000 cycles per second which is near the upper limit obtainable on available wire circuits and also over present day radio channels, that it is possible to transmit information regarding approximately 40,000-unit areas per second. On the basis of twenty pictures per second, therefore, the original image may be divided into 2,000 elementary areas. This division may be accomplished by crossing the image with approximately forty-five parallel paths. The number 48 is being extensively used because of convenience, since it is commensurate with the graduations on the dividing heads used in laying out the scanning disks.

The preceding considerations apply to a particular example of a fundamental proposition of communication engineering which states that the amount of information to be transmitted fixes the product of the frequency range employed by the time required.[2] For our purpose it is perhaps more convenient to say that the frequency range occupied by a signal is directly proportional to the rate at which information is to be transmitted. In the case of picture transmission the number of elementary areas serves as a measure of the amount of information.

Since it is possible to express various forms of information in common terms, namely, those of time variations, it is interesting to compare the amounts of information involved in several methods of electrical communication.

In the case of telegraphy the several letters are made up of a number of units, each of which may have either of two values. Taking the

[2] R. V. L. Hartley, "Transmission of Information," *Bell System Tech. Jour.*, 535–563; July, 1928.

dot as a fundamental unit length the dash is commonly equal to three unit lengths. The space between letters is also equal to three unit lengths, and the space between words is equal to five unit lengths. On this basis each letter, including the space between it and the succeeding letter, requires on the average ten unit lengths. If we assume an average of five letters for each word, there are in the neighborhood of fifty elementary units required for each word. Actually, it is found that in order to preserve the signal shape reasonably well it is necessary to transmit frequencies corresponding to the third and fifth harmonics of the unit frequency. This is equivalent to recognizing 250 elementary units per word.

In telephony, studies of speech and music have yielded information as to the range of frequencies involved. With speech it has been found that commercial telephone circuits give intelligible reproduction when limited to the frequency range between 250 and 3,500 cycles per second. On high-grade transmission channels used for broadcasting musical programs it is desirable that the frequency range extend from 60 cycles per second, or even lower, to somewhere in the neighborhood of 8,000 cycles per second. If we assume, as in picture transmission and television, that each cyclical variation is made up of two time units, we find that for speech each minute of time should be divided roughly into 400,000 such units. Then whenever someone speaks at the rate of, say, one hundred words a minute, he requires 4,000 of what may be called information units per word. On the basis of the many values which have been arbitrarily assumed in making the above estimates we find that one square inch of picture, containing 10,000 units, is equivalent to only two or three spoken words, or to forty words of telegraph code. It is interesting to note that a square inch at phonograph record contains about six or seven words, if spoken of the rate of one hundred words per minute.

It is, perhaps, unusual to compare the amount of information represented by a picture with the amount of information represented by a sequence of sounds. There are today, however, so many mechanical means for recording each of these that it is possible to find several common measures. Perhaps the most striking is the recently developed talking motion picture film. Here the sounds accompanying a given action may be conveniently recorded on a narrow strip along the edge of the film on which the action is recorded. In this case the scene requires a film width of 7/8 of an inch; the accompanying sound is allotted a width of 1/8 of an inch. It therefore appears that in this system the information delivered by the loud speaker is only about one-seventh that shown on the screen. Actually, due again to the finite dimensions of the aperture used in recording the sound, its record is less efficient in the use of space than is the visual record. Consequently, the relative amounts of information differ by much more than the figure obtained in this way.

A more significant comparison may be made by estimating the number of units necessary to give a very good television image of an extended scene. If the reproduced image were to be comparable with a 4 x 5 photograph seen at the usual viewing distance, we have $A=400$ and $n=10{,}000$, on the basis of previous assumptions. The frequency range required is, therefore, 2,000,000 cycles per second wide. Admirable reproduction of any sound may be achieved by the use of a frequency range 10,000 cycles wide. Thus it appears that the ratio of the visual to the audible information received by the spectator of some event is, as an order of magnitude, somewhere in the region of 200 to 1. This figure should be kept in mind when talking of adding a television screen to your house telephone, as it gives some idea of the increased information carrying capacity which would be demanded of the nation's wire plant.

It should be emphasized that in making the preceding estimates, as throughout this entire discussion, it is the intention to point out relative magnitudes and not to recommend or to attempt to establish desirable operating values. In television particularly, no number can be fixed as representing a required amount of information; a recognizable image may be secured by ten pictures per second, each having less than 1,000 elements; twenty pictures per second, each containing 500,000 elements is probably nearer the performance expected by the eager public. Somewhere between these widely separated limits is the region in which subsequent activity will be concentrated. It will be interesting to watch the boundaries of this territory expand.

Returning now to the behavior of our physical system, the effect of the aperture may be examined in terms of the sinusoidal components making up the complex variation in light intensity. As an aperture of fixed length is moved at some given velocity v, the frequency of any cyclical variation, as we have already seen, is v/l where l is its length. Referring to the curve of Fig. 2, we have data showing the extent to which any variation is reduced by the aperture in terms of k, the ratio between aperture length and the length in which the variation completes one cycle. This suppression may be referred to the frequency at which sinusoidal variations in light intensity occur by writing the frequency as $f=kv/a=kf_o$ where f_o is the frequency of that variation which is completely eliminated. To obtain an idea of the practical significance of this relation it has been replotted, in Fig. 3, as the equivalent attenuation of the aperture, in decibels, for an aperture length equal to 1/75,000 the distance scanned in one second. The frequency scale has been laid off logarithmically.

The preceding computations of aperture performance have all been made in terms of a rectangular aperture, the image of which completely covers a length *a* of the scanning path. In general a circular aperture exhibits similar characteristics. It should be noted, however, that the variations in light through a circular aperture are not independent of the distribution across the scanning path; this follows from the fact that a circular aperture may be considered as a group of elemen-

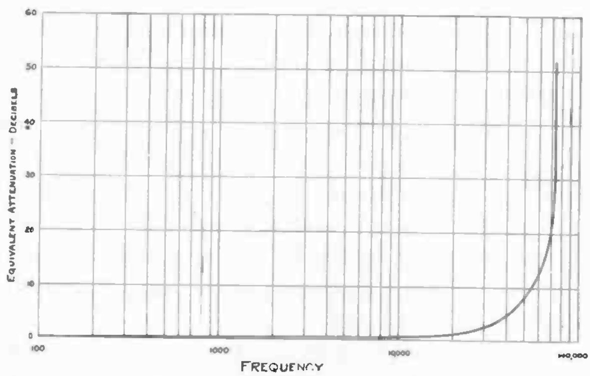

Fig. 3—Discrimination of an aperture having a length equal to 1/75,000 the length of scanning path covered in one second, plotted as equivalent attenuation against the frequency at which cyclical variations in picture density are traversed.

tary apertures of varying length. The response of each element obviously depends upon the variations encountered in its own particular path, hence the integrated response depends upon the actual arrangement of tone values in the scanning path, instead of solely upon the average value of each infinitesimal length. For practical purpose, however, these differences between circular and rectangular apertures are of secondary importance as compared with the general aperture effect.

From the curve of Fig. 3 it appears that the aperture introduces a frequency characteristic not unlike those of filter networks or similar structures. This suggests that the distortion thus produced may be compensated for, to a certain extent, by introducing a correcting network, or equalizer, into the electrical part of the system. This has been shown to be practical in tests made by the Bell Laboratories in which cyclical variations completed in less than twice the aperture length were reproduced with negligible injury due to the aperture effect.

The distortions already considered have to do with the method of reconstructing the picture and with the method of translating from space variations to time variations. It should be noted here that the effect of finite aperture dimensions appears both at the transmitting and at the receiving terminals where the above translations are necessary. The remaining elements of the system are concerned with transmitting information concerning the time variations in light secured by these translating methods. The effect of distortion occurring in this process must, however, be expressed in terms of the reproduced picture, rather than in terms of the variations in light intensity obtained at the receiving station.

It must be noted that any given signal distortion is significant only when the particular method of reconstructing the image at the receiving station is taken into account. This point is emphasized particularly by the method of transmission developed by the Radio Corporation of America in which the type of picture structure was chosen with a view towards minimizing the effect of static interference.[3] In other words, this system was deliberately designed on the basis of knowledge as to the distortion which must be encountered, and is directed at making the effect of a given distortion small, rather than at the actual reduction of the distortion itself.

Because of this intimate relation between signal distortion and its effect, it is not possible to undertake a purely general discussion of the requirements which must be imposed on the transmission system. The conditions in many picture transmission systems, and in practically all television systems do, however, approximate those used as the basis for our study of the scanning operation. Consequently, this general method may be retained as the basis for our study of the transmission system.

The first element of the transmission channel is that in which the amplitude of an electric current is controlled by the intensity of the varying luminous signal. The most usual means now employed for this purpose is the photo-electric cell. This contains two electrodes between which, with a suitable maintained potential difference, a current flows with an intensity directly proportional to the amount of light reaching the cell. Since this current is ordinarily very small, it is necessary to provide considerable amplification in order to obtain a wave suitable for transmission to any distance, or for the control of the illumination at the receiving terminal. Inasmuch as the average value of the signal intensity is quite as important as its varia-

[3] Richard H. Ranger, "Transmission and Reception of Photo-Radiograms," Proc. I. R. E., **14**, 161–180; April, 1926.

tions, a direct solution of this part of the problem would require what is known as a direct-current amplifier; that is, an amplifier, the output of which is strictly proportional to the absolute value of the impressed potential. Such amplifiers are notoriously difficult to build and a number of expedients have been devised for avoiding them. In some cases a few stages of direct-current amplification have been employed, whereby the signal has been built up to an amplitude such that it may be used for modulating a carrier current. This procedure effectively relocates the signal on the frequency scale, placing it in a region where it may be more conveniently handled. This relocation is unfortunately accompanied by a doubling in the extent of the frequency range occupied by the signal. An alternative method introduces the modulation into the original light source. This can be accomplished by means of a vibrating or rotating shutter interrupting the light at a frequency corresponding to that of the carrier wave.

In the photo-electric cell circuit itself there is, ordinarily, very little distortion encountered, particularly in the case of still picture transmission. The cells are able to follow variations occurring up to very high frequencies. The entire circuit, however, due to the shunting effect of the capacity of various portions of the circuit to ground, may be unable to respond accurately to frequencies in excess of about 50,000 cycles per second. Over the normal operating range of light intensities and within the frequency limits outlined above, it has been found that the amplitude of the controlled current is almost exactly proportional to the intensity of the illumination. This statement applies strictly to monochromatic light or to light of a fixed spectral distribution. In the transmission of black and white pictures the photo-electric cell introduces no tone value distortion. In television, however, the variation of sensitivity with the color of the received light introduces a distortion similar to that resulting from the non-uniform color sensitivity of photographic plates. Most photo-electric cells are relatively insensitive at the red end of the spectrum and, consequently, treat any portion of the image having only this color as though it were black. The effect is most noticeable with yellow; people with light hair being reported by the television system as having very dark hair. At the other end of the spectrum the photo-electric cell is relatively more sensitive than the human eye and, consequently, makes little distinction between green and white surfaces. This characteristic distortion may be demonstrated effectively by means of a yellow-back bill. At a distance the eye sees the yellow side of the bill almost as a uniform light surface; when reproduced by a television system, however, this side of the bill appears to be made up of a distinct pattern on a light ground. The pattern on the green side of the bill, even at a distance, appears to the eye in sharp contrast to the background, whereas the image reproduced by the television system appears as a uniform white surface.

The importance of preserving the correct relation between the average amplitude of the signal wave and the amplitude of the variations has already been noted. In high quality systems such as are used for the transmission of still pictures, means are provided for accurately transmitting information regarding the average tone value. In view of the difficulty of amplifying a signal wave of this character this requirement adds much to the complexity of the terminal equipment.

In certain cases it is possible to avoid the actual transmission of this troublesome component as part of the signal wave. Obviously these cases are those in which there are other means of knowing what the average value should be. With two-tone pictures such as manuscript copy, typewritten material or line drawings, it is sufficient to transmit information as to the points at which the tone value changes. The choice of the two values as they appear in the reproduced copy can be a matter for local adjustment at the receiving terminal.

In television the situation is somewhat different. Here, due to the fact that the transmission of a given image is repeated at a fairly high rate, it will be apparent that the low-frequency component which follows the variation in average value occurring throughout a single scanning operation is repeated once during each such operation, and consequently has a frequency identical with that of the scanning operation. Neglecting the effect of motion in the object being scanned, it follows that there are no important components between zero and this frequency. Because of this, it is possible to eliminate the direct-current component from the remainder of the signal during the first stages of amplification, provided this is done without injury to the component of scanning frequency. At the distant terminal information will be received as to all the essential variations taking place during each scanning operation. If, therefore, information can be obtained from some other source as to the proper amplitude to be given the zero frequency component, this may be supplied locally. Actually, this can be done without appreciable injury to the result. For example, if anywhere in the image appear two portions, the tone values of which are known, the bias can be supplied by adjusting until these two portions appear in their proper relation.

In the case of an object with which the receiving operator is totally unfamiliar, this end may be accomplished by arbitrarily introducing into the area scanned two small indicator areas, such, for example, as a black card and a white card. Actually, in the operation of a television system used for reproducing images similar to portraits, the average value can be adjusted by trial to give an acceptable reproduction. As a matter of fact, the distortion due to supplying this component incorrectly is likely to be less than the distortion due to the improper color value rendering of the photo-electric cell. A person with a ruddy complexion, for example, would normally appear to have a skin which is almost black, whereas a person with a dark olive complexion would appear as being unusually pale. To some extent this can be compensated for by the proper choice of the re-introduced zero frequency component.

The manner in which the average value is controlled at the receiving terminal naturally depends upon the apparatus employed. It may be introduced as a bias on some vacuum tube, in which case succeeding stages, if used, must be capable of reproducing the zero

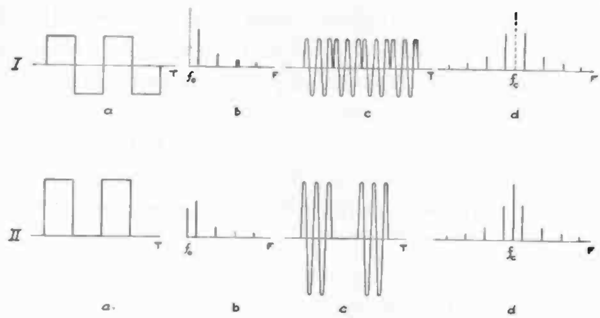

Fig. 4—Characteristic signal waves occurring in systems employing modulation.

The waves are shown as time variations. The companion charts show the frequencies and relative amplitudes of the constituent harmonic components. The original signal has no direct current component in Group I; in Group II it has no negative values.

frequency component. In practice, wherever neon lamps are used as the controlled light source the bias ordinarily required with such lamps may be made to include the bias for average value.

In picture transmission systems and in television the conditions in regard to modulation and demodulation differ materially from those found in sound transmission systems.[4] There are a number of points of particular importance which can be illustrated by the signal wave sketches in Fig. 4. The wave shown at *a* in Group I is a simple variation having alternate positive and negative values. It resembles a

[4] R. V. L. Hartley, "Carrier and Side Bands in Radio Transmission," Proc. I. R. E., **11**, 34–56; February, 1923.

sound wave in this respect and may be used to represent one in studying the phenomena occurring during modulation. At *b* are shown the frequencies and relative amplitudes of the more important sinusoidal components constituting this wave. The wave *c* illustrates the variation which would result if a high-frequency alternating current—or carrier wave—were modulated by this signal in such a way that the envelope of the final variation reproduced the original signal. Finally, at *d* are shown the components of this modulated wave.

Given only the modulated wave shown at *c* it is impossible to recover the original signal, *a*, by any known type of demodulator. The only difference between portions of the wave corresponding to positive and to negative signal values lies in their phase, and it is obvious that an ordinary rectifier would yield only a continuous current, in place of one having the desired positive and negative values. In other words, the original signal itself would be rectified during demodulation.

With the signal illustrated by Group II this is not the case. As in Group I, *a* represents the original signal, *b* its sinusoidal components, *c* the modulated carrier wave, and *d* its components. Here the original signal and, consequently, the envelope of the modulated carrier alternate between given positive amplitudes and zero. If this modulated wave is passed through a rectifier the signal will be recovered in its original form. Since the signal itself has no negative values it is apparent that it will not be altered by passing through a rectifying system.

An inspection of the two groups of components of the modulated waves shows that *d*-II differs from *d*-I only by the presence of a component, f_c, having a frequency equal to that of the carrier current first supplied to the modulator. It will be seen also that this component is related to the zero frequency component, f_0, appearing at *b*-II. Following the usual convention of looking upon every component of a modulated wave as either an upper or a lower sideband counterpart of a component in the original signal it appears that this component of carrier frequency is really the combination of the upper and lower sideband representatives of the zero frequency member. This is borne out by the fact that its amplitude is twice the value which would be necessary to maintain the correct relation with the other members of either sideband group alone.

These two signal waves demonstrate the procedure usually practiced in modulation and demodulation when sound is involved. The initial signal, with its positive and negative values, is caused to control the amplitude of the transmitted carrier wave so that the envelope will reproduce its shape but will have such absolute amplitudes as prevent negative values. This is done, in effect, by adding an arbitrary bias to produce a new signal similar in shape to the old, but having only positive values. Such a signal may be recovered from a modulated wave by the process of demodulation. The removal of the artificial bias restores the initial signal. The component which represents this bias in the modulated wave need not actually be transmitted over the system. It may be introduced at the receiving terminal as a carrier identical in frequency with that supplied at the transmitter. In other words, the central member of d-II, f_c, may be added directly, rather than as the result of having added a direct-current bias. This method is used in multiplex telephony in what are known as suppressed carrier systems. The use of the arbitrary bias in carrier and in radio telephony has caused the component of carrier frequency to be spoken of as "unmodulated" carrier. It does, however, correspond definitely to a component of the original signal exactly as do other sideband components.

In picture transmission and in television the initial signal has no negative values. Hence it is unnecessary to supply an artificial bias, or to alter its form in any way, in order to obtain a signal which may be recovered from a modulated wave by demodulation. In a modulated wave controlled by a picture signal it is clear that the component having a frequency identical with that of the carrier impressed on the modulator is a true signal component.

With certain types of demodulators it is not sufficient that the envelope of the transmitted wave remain always positive. These demodulators deliver a signal wave which approaches the shape of the envelope of the modulated wave only when the ratio between its maximum and minimum values becomes small. That is to say, these circuits function properly only with signals in which the amplitude of the variation is less than the average value of the wave. In the case of sound signals it is necessary, in order to use such a detector, merely to provide sufficient bias to satisfy the above condition. After demodulation the bias may be removed in any convenient way. In picture transmission, however, it is not permissible to alter arbitrarily the ratio between maximum and minimum signal values. If a bias—or something which may be called unmodulated carrier—is required in order to avoid distortion during demodulation, it must be removed from the signal before it can be used to control the light variations at the receiving terminal. Since the bias is equivalent to an added zero frequency component it cannot be distinguished from the signal component of zero frequency used for conveying information as to the average tone value of the picture. Consequently, its removal after demodulation can be effected only when information in addition to that contained in the signal wave itself is available to indicate how much of this component is bias and how much is a true signal component.

In any transmission channel, regardless of whether modulation processes are involved or not, the over-all performance may be described in terms of five operating characteristics. These describe

(1) The variation of transmission efficiency with the frequency of the impressed signal

(2) The variation of transmission efficiency with the amplitude of the impressed signal

(3) The variation of transmission efficiency with time

(4) The variation of phase shift with the frequency of the impressed signal

(5) The nature of any extraneous components which may be introduced into the signal wave, due to coupling between the channel transmitting the signal and other electrical sources.

Each of these results in introducing distortion into the reproduced picture, the nature and the magnitude of the effect being dependent upon the method used for reproduction.

We have already given some thought to the importance of various sinusoidal components to the final picture. In the transmission of still pictures similar to photographs, no deviation from uniform transmission efficiency at the low end of the frequency scale may be tolerated. At the upper end of the scale the injury which may be introduced by the transmission channel should not exceed that caused by the use of an aperture of finite dimensions. In general, the transmission efficiency should be constant from zero to a frequency equal to $v/2d$, which is the fundamental frequency resulting from passing over elementary areas of the size chosen for the picture structure. This does not permit the transmission of harmonics of this fundamental frequency. Consequently, even with an ideal aperture an abrupt change from one value to another will be distributed in the final picture over a finite length of path. In other words, the system will not permit the amplitude of the current to change with sufficient speed to form an abrupt transition from one value to the next. If the system is capable of transmitting uniformly up to the fundamental frequency occurring as the elementary areas are scanned, the change will take place in a length so short as to be negligible in comparison with other distortions. In pictures reproduced by the method on which our present discussion is based, the effect of reducing the upper limit of the transmitted range is very similar to the effect produced in photography when the picture is out of focus.

In television the difficulty of transmitting the zero frequency component makes it desirable, as we have already seen, to limit the lower end of the frequency range as well as the upper end. It is unavoidable that in permitting the amplifiers to reject the zero frequency component there shall be some discrimination against components of very low frequency. To obtain some idea of the distortion resulting from this let us imagine that each scanning line is constituted by a variation in tone value taking place about some average value, and that each scanning line has its own average. Information as to changes in these average values is transmitted by components having frequencies near that of the scanning operation. If these components are not transmitted at their proper value relative to other variations it follows that certain of the individual lines will be reproduced as variations about an incorrect average value.

Today it is an almost universal accomplishment to be able to listen to speech or to music reproduced by a loud speaker and to form an opinion as to the fidelity with which the low-frequency components are transmitted. There is appearing a rapidly increasing group who can, by looking at a television image, detect improper transmission of the low frequencies. One noticeable effect appears in the reproduction of images of faces. At the upper part of the picture there will probably be a clear area of background. Consequently, the first few scanning operations will result in negligible variations about an average intensity of fairly high value. As the lines pass across the upper part of the sitter's head, the light intensity alternates between that corresponding to the background and that corresponding to the hair, which is invariably reproduced as black. Consequently, the current alternates between widely different values and varies about a mean value generally less than half that of the entire picture. If the system is incapable of changing the average value quickly in passing from the upper background to the upper part of the sitter's head, it will reproduce the upper part of the background too dark, that is, with a value corresponding to the average of the picture as a whole. The upper portion of the hair will be reproduced as being of lighter color than the lower portions. Whenever an area known to be of uniform tone value, such as a background screen, is reproduced as having striations of varying darkness, it may be known at once that the system is discriminating against components having frequencies near that of the scanning cycle.

Should the system exhibit variations of transmission efficiency as the amplitude of the impressed signal is increased, the result will be to introduce incorrect tone values. It is probable that in picture transmission and television this non-linear distortion may exceed by a considerable amount the limits permissible in the reproduction of speech and music. In the latter case any non-linear relation between input and output amplitudes results in the production of components which were not present in the original signal. In many cases these are not harmonics of proper signal components and their presence, uneven in small amounts, is instantly detected by the ear. It is true that in picture transmission non-linear distortion results in components in addition to those belonging to the signal. Their effect, however, is rarely to alter the outline of the picture as might be at first expected. The chief result of their appearance is to reproduce a given tone value improperly. This distortion is encountered every day in photographic processes, and may exist in an appreciable amount without being objectionable. Actually, considerable non-linear amplitude distortion may be permitted even in the transmission of high-quality still pictures before the resultant injury to the picture approaches that which would be encountered in making a contact print by direct photographic processes.

The effect of any variation in transmission efficiency which occurs during the reproduction of a picture will appear as a proportional change in each tone value involved. If, during the transmission of a single still picture over wires, the attenuation of the line or the gain of some repeater were to be suddenly altered, the final picture would appear exactly like a contact print, a portion of which had been covered by a card during part of the printing process. The sensitivity of the eye to changes of this character is such that a change in transmission efficiency of the order of one or two-tenths of a decibel can be detected. If music were being reproduced a change in level of approximately one or two decibels would be needed to give a comparable disturbance. If the change occurs gradually the effect is identical with that which would be produced in photography by holding the printing light nearer one end of the printed frame than the other. A gradual drift in transmission efficiency can, therefore, be permitted provided it does not exceed something in the neighborhood of one decibel.

In television it is impossible to distinguish between variations in transmission efficiency and variations in the intensity of the light used for illuminating the scanned object. Here we have a distortion identical with a familiar phenomena, and consequently are reconciled to accepting very appreciable disturbances.

In the case of normal telephony it is known that the shape of the received wave differs materially from the shape of the transmitted wave. An analysis of the two, however, shows that they contain the same sinusoidal components and that the relative amplitudes of these have not been altered. The change in wave shape is due to the fact that the relative phases of the several components have been changed. It is fortunately true that the ear, to a certain extent, reacts to each of the sinusoidal components independently, and practically disregards their relative phases. In fact, in listening directly to ordinary sounds, the relative phases depend largely upon the acoustic properties of the space in which the sounds are created and heard. If the time variation in amplitude of a given sound could be photographed at a number of places in a single room it would undoubtedly be found to vary considerably from point to point. As we move about the room, however, we do not ordinarily notice marked variations in the quality of the sound, although these differences are unconsciously utilized by the ears in helping us to locate the position of the sound source. It is possible, therefore, to permit sound transmission systems to introduce a very considerable variation in the phase shift suffered by each of the components. In picture transmission, however, both the outline of the picture and the tone value of each area are dependent upon the actual shape of the received wave. Consequently, it is quite as important to retain the correct relative phases between the several components as it is to retain the correct relative amplitudes. In Fig. 5, *a* is

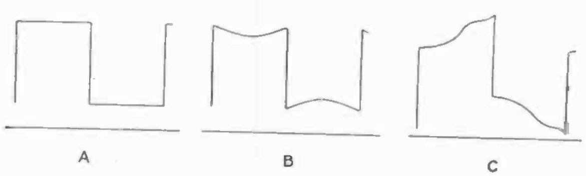

Fig. 5—Effect on a square topped wave, *A*, of distortion encountered during transmission.

At *B* the relative amplitude of the fundamental component has been reduced 20 per cent. At *C* the phase of the fundamental has been advanced 20 degrees.

a graph of the wave resulting as alternate black and white bars are scanned. The change in wave shape resulting by reducing by 20 per cent the amplitude of the fundamental relative to the remaining components is shown at *B*. The effect of shifting the phase of the fundamental by 20 degrees is indicated at *C*. In this last example the relative amplitudes of the several components are unaltered.

In the transmission of electric currents over wires the reactance encountered of necessity introduces appreciable phase shifts. If, however, the actual change in the phase of each component appearing at the receiving end, referred to the phase of the same component at the transmitting end, is proportional to the frequency the effect of the phase changes is equivalent to a delay in the time of arrival of the signal. In fact the ratio of the phase shift to the frequency indicates the time required for the transmission of the component. Obviously, if all components are transmitted at the same time the shape of the wave is unaltered. This requires that the characteristic relating phase shift to frequency be linear, and also that it pass through zero. In case modulation processes are involved in the transmission, the relative phases of the components in the recovered signal depend upon any alteration in phase suffered during transmission by the components making up the modulated high-frequency wave. Actually, the effective shift is equal to the difference between the phase shift of the side band component representing the original signal component and the phase shift of the component of carrier frequency.[4] Because of this, it is necessary that the relation between the phase shift and the frequency be linear throughout the region covered by the modulated wave. It is not necessary that it pass through any particular value. The frequency of the carrier stands in the position of the zero frequency components; consequently, if the characteristic is linear throughout the range, differences in phase shift between the carrier and any side band components are proportional to the difference in their frequency, and the resulting phase shift of the recovered component is proportional to its frequency.

The effect of components appearing in a signal wave used for reproducing sound as a result of coupling between the circuit carrying the wave and other electrical circuits is familiar to everybody, and is commonly spoken of as noise. It is hardly necessary to point out that the interference is actually not noise, except as it causes the acoustical reproducing system to produce noise. In picture transmission and in television, electrical interference produces flaws in the picture which may affect both the outline and the tone value. With still pictures any such flaw is permanent and a very small amount of interference is sufficient to impair seriously the quality of the reproduced picture. In television, however, the effect of electrical interference is to produce only a momentary alteration in the value of a particular point, and consequently a considerably greater amount may be tolerated. It is probable that the allowable ratio of interference to signal in television is about the same as for speech, and probably greater than for high-quality musical programs. This is certainly true for television images of the quality now possible. With improvement in other directions it is only natural to expect that an improvement in the matter of interference will also be desirable.

The preceding discussion may be said to have treated several of the more basic factors of picture transmission in a qualitative manner. This is true as far as the actual design of apparatus is concerned. It has been shown, however, that certain relations are inherent in the problem, and rigorously fix the operating requirements once the performance limits have been set. It is to be expected that future development of this art will result in a very considerable simplification in the means of satisfying these requirements, where the demands made on the system are more severe than those now encountered with other types of information we may have every confidence that ways will be found of meeting them.

The matter of fixing desirable performance limits is one which will have to be settled by extensive experimentation, and which will ultimately come within the scope of one form of the law of supply and demand. Picture transmission systems and television systems, like every other product of industry, will be built to those limits where the quality of the performance obtained has a value identical with the cost of securing it. Scientifically, the problems were all solved years ago; economically, it is just beginning to appear that a solution may be possible.

Acknowledgment

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MECHANICAL DEVELOPMENTS OF FACSIMILE EQUIPMENT*

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Continued operation of the photoradio equipment has emphasized the value of certain modifications and developments for increasing efficiency and ease of operation. Where there are so many links in the complete chain from transmitter to receiver with all the necessary radio appurtenances to make the radio transmission of pictures and printed matter a success, the utmost simplicity of operation must be given the operator at both terminals to insure continued success of actual traffic handled.

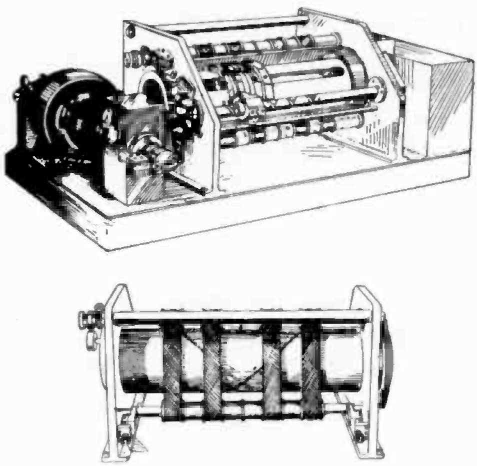

Fig. 1

In the April, 1926, issue of the Proceedings of the Institute of Radio Engineers is given a description of the first commercial equipment used for this purpose. This apparatus still continues to function well at the speeds for which it was designed. But its operation has shown where changes would be efficacious, and equipment has been evolved which not only does better what the old did, but is also able to do the transmission by a new method of transmitting across the paper in diagonal directions corresponding somewhat to the halftone line pattern of engraving.

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The first machine of this type is shown in Fig. 1. The paper is carried around a stationary half cylinder continuously from a roll. On the inside of this half cylinder is carried the head for the analyzing of the picture. At the transmitter it consists of a lens system. This head rotates and at the same time reciprocates from side to side of the sheet. The lens system is double ended with one lens 180 deg. opposite the other so that as the head rotates, one lens or the other is always actively analyzing inside the half cylinder. Around the lens is placed a doughnut light which illuminates the part of the picture being copied at each instant. Inside the head, the lens system carries back the light to the axis of the cylinder and thence axially to one end where the photocell is placed.

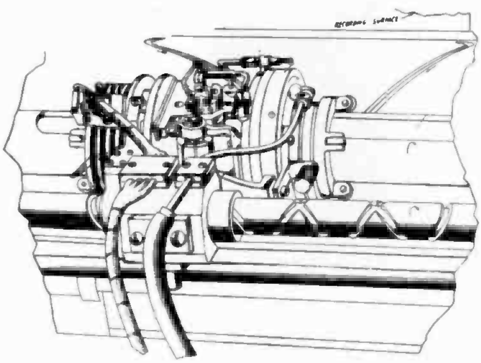

Fig. 2

The transmitter may be used as a receiver merely by substituting a neon light or similar variable light source actuated by the incoming picture signals. The doughnut light would of course not be used for reception.

In place of light recording, the hot-air recording may be used by employing a double ended hot-air gun as shown in Fig. 2.

It is seen that both transmitter and receiver work down their respective sheets of paper with a series of crossing diagonal lines in the manner shown in Fig. 3.

The value of cross diagonal transmission lies chiefly in smoothing out half-tone transmission, where the crossing of the picture in two different directions at two different times gives a smoother result and likewise covers over any omissions made on one transmission by those on the other. This is particularly useful in reducing the effect of fading when using short waves.

One of the limitations in facsimile picture transmission of printed matter is the rate at which fine lines are crossed. The speed of the entire system must be lowered to the point to which such crossing gives a definite marking where the picture is covered once only as by the usual method. But with the cross diagonal method, the speed may be measurably increased due to the fact that the chances are better that whereas on one crossing the parts of letters may present a very short cross-section, they may present a much broader stroke on the other diagonal stroke.

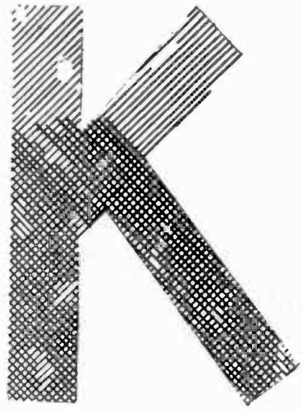

Fig. 3

A suggested result in analyzing the letter *o* is shown in Fig 4, corresponding to these conditions.

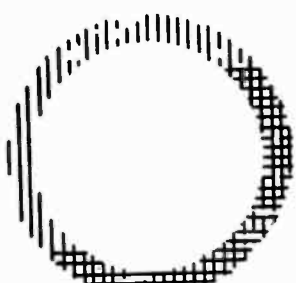

Fig. 4

A further extension of the diagonal principle is shown in Fig. 5. This equipment is capable of working either with horizontal strokes or with the diagonal strokes. The shift is accomplished by a clutch shown in Fig. 6.

As in some of our previous equipment the analyzing head is carried back and forth by means of a cross spiral thread. For straight horizontal analyzing, the head moves back and forth horizontally while the brass cylinder carrying the paper turns slowly upward. So that for each crossing of the analyzing head, the paper is fed forward the requisite small amount to give the next analyzing line of the picture. This of course gives a continuous paper feed.

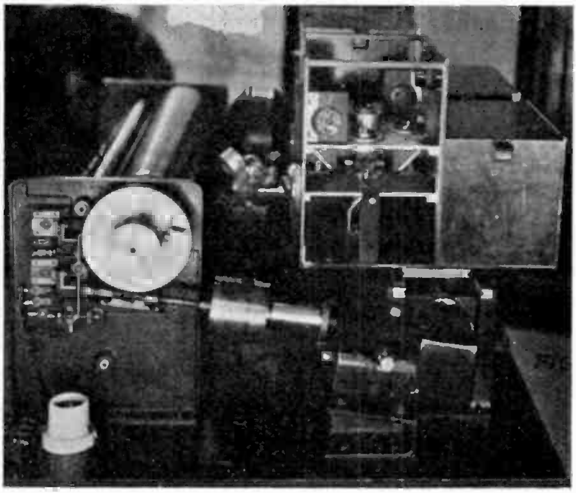

Fig. 5

To make diagonal pictures, the brass cylinder is rotated at a much faster speed; in fact it rotates just a little more than once for every complete excursion of the analyzing head back and forth. It rotates a

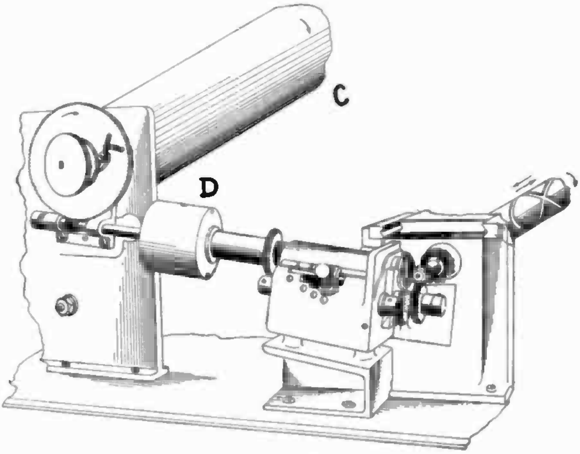

Fig. 6

little more than once in order that the diagonal line shall be just the width of a line further down on the next stroke of the analyzing head.

To accomplish this slight increase in revolution, a rather interesting arrangement is used. As seen in the illustration of Fig. 6, the motion from the double thread is carried through a bevel gear to a differential gear in the cylindrical case D. If the cylindrical case were held stationary, the motion transmitted in one end of the differential would be duplicated, except for a reversal in direction at the other end. This would rotate the brass cylinder exactly in step with the double thread screw movement. But in place of keeping the differential case rigid, it is slowly rotated by other gearing so that the brass cylinder C is moved forward slightly more than a complete revolution for each complete action of the double thread.

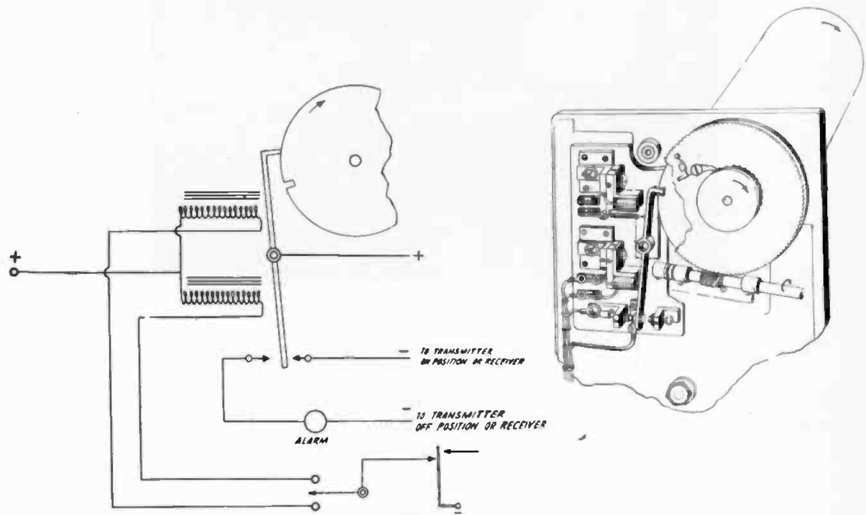

Fig. 7

Likewise a gear shift arrangement is provided on the side of this slow differential drive such that the amount of this advance may be changed at will to give different analyzing line advances, to take care of different types of matter.

There is a further modification embodied in this machine which is used on straight horizontal analyzing. This is the fact that the cylinder is made double, such that either duplicates of the same transmission may be made on the receiver, or two entirely different pictures may be made, presuming that two different pictures are placed on the transmitter. These pictures may be handled over a duplex circuit, or they may take turns about on a single circuit; the one on the left for example having the radio circuit when the analyzing heads at both transmitter and receiver are moving from right to left, and the one on the right having the circuit when the heads are moving from left to right.

The advantage of this latter method of working is that it is then not necessary to have such accurate framing of the analysis at the receiver as is the case when the single picture is worked on both ways. In which case there must be an absolute line-up such that the points fall directly under each other on the alternate left and right strokes.

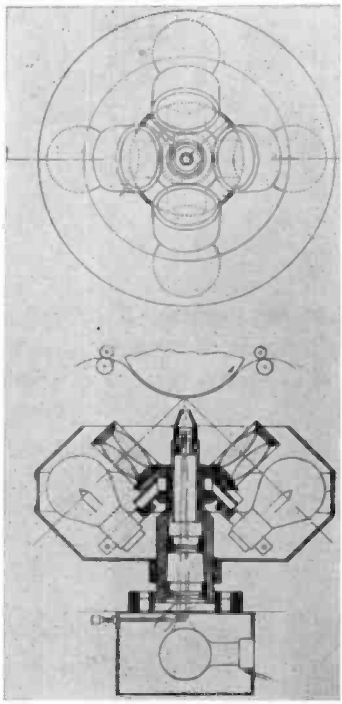

Fig. 8

A further detail is that of the automatic throwout which shuts off the transmission when the picture is completed. In Fig. 7 an arm at the left L is actuated by a contact which makes at one end of each complete movement of the analyzing head. There is one notch in the disk K in which this lever L may engage. It is started by hand from the position in which it engages. On the next stroke around, the notch will have moved forward slightly, due to the slightly faster movement of the cylinder, so that the lever arm will no longer engage. It cannot again engage until the brass cylinder has gained enough lines to carry it completely around. When it does engage the second time, it makes a contact which shuts off the transmission and gives an indication to the operator.

The light system as shown in Fig. 8 on the transmitter is likewise unique. It consists of four lights fastened directly about the pick-up

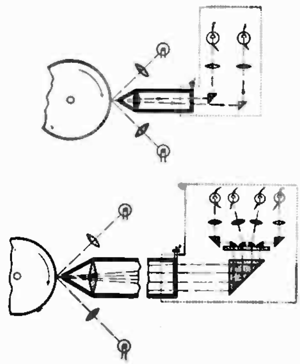

Fig. 9

lens which is to analyze the picture. Four automobile lights are used and they give a very intense illumination of the spot being traced. The pick-up lens then carries a picture of this spot back to the slit,

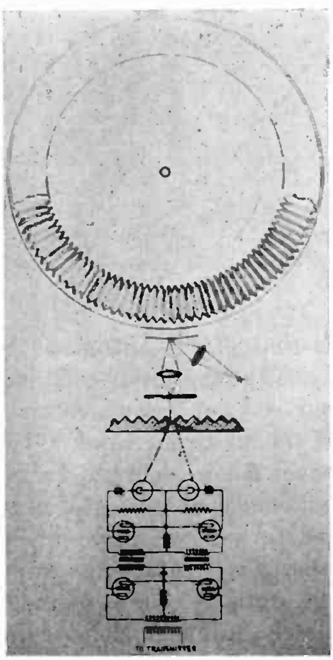

Fig. 10

giving a more accurate definition of the exact spot being considered, and then the light is carried back to the photocell.

In place of analyzing a single point at a time, arrangements have been made to analyze as much as five points simultaneously. It is accomplished by means of splitting the light by the use of very small prisms which carry off the light of each of five different photocells as shown for four cells in Fig. 9. The purpose of this multiple scanning is looking forward to the time when it will be feasible economically

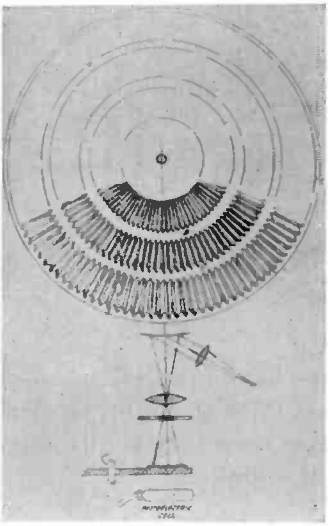

Fig. 11

to multiplex picture transmission. Then the analyzing may be speeded up by the number of channels that may be handled simultaneously.

Push-Pull Photocells

For a long time we have been aware that it was very difficult to get linear output in the complete set-up from photocell through the associated amplifiers. The natural thought is to make use of push-pull action. After many trials, I am glad to be able to report that this has now been accomplished in the rather simple form shown in Fig. 10.

It consists of the use of a glass disk on which are grouped many small prisms. The glass prisms deflect the light first in one direction and then in the other as the analyzing pencil of light comes on to first one and then the other side of these glass prisms. The deflected light is carried first to one photocell and then to the other.

In place of driving this glass disk by the usual electric motor, which would have to be shielded most carefully to prevent it acting on the sensitive photocells and amplifiers, we have broken away completely from the electric drive and use a small air turbine. A small mechanical

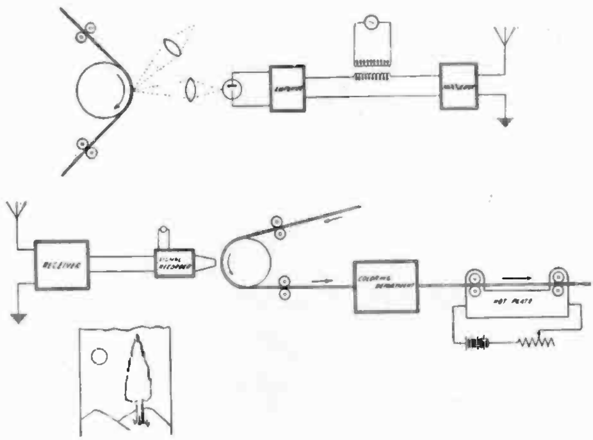

Fig. 12

governor keeps the speed within the desired scope. Two pounds of air will drive the turbine at three thousand revolutions per minute with no difficulty. This makes for a very light compact arrangement with a very small amount of vibration.

Fig. 13—Heat recording on wax. Left half shows roughened surface before inking, right half after inking. Any color may be used on roller.

Two push-pull amplifier stages are associated directly in the camera box to pick up the voltage variations from the push-pull photocells. The resultant audio tone is then of quite sufficient proportion to be carried away from the outfit to be further amplified and put on the line to the transmitting station. In place of a single row of such glass prisms, a multiplicity of rows of such prisms has been made as

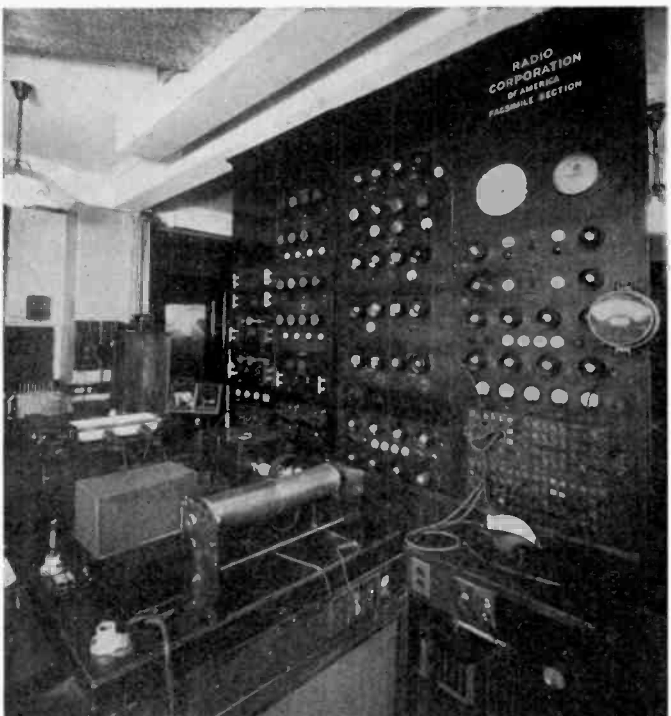

Fig. 14

shown in Fig. 11. A different number of prisms is ground in each row, and therefore different audio notes come from each row. The result is that two or more analyzing points may be picked up from the picture and separated out by appropriate tone filters later. For short distance work, the multiple tones may be carried directly out to modulate the amplitude of the radio transmitter, and be filtered apart in the final reception. It should be pointed out that without the push-pull photocell action, the wave form of each tone would be so bad that the filtering would be extremely difficult.

It should be mentioned that the above job fell distinctly in the class of "it cannot be done," and Mr. J. N. Whitaker undertook the removal of this hoodoo most successfully as shown above.

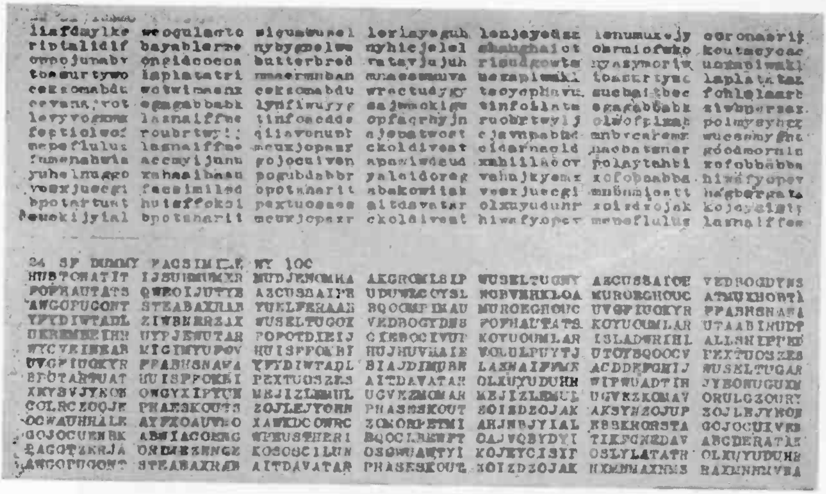

Fig. 15

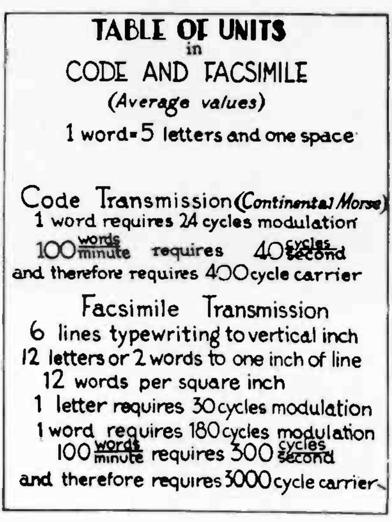

TABLE OF UNITS
in
CODE AND FACSIMILE
(Average values)
1 word = 5 letters and one space

Code Transmission (*Continental Morse*)
1 word requires 24 cycles modulation
100 $\frac{\text{words}}{\text{minute}}$ requires 40 $\frac{\text{cycles}}{\text{second}}$
and therefore requires 400 cycle carrier

Facsimile Transmission
6 lines typewriting to vertical inch
12 letters or 2 words to one inch of line
12 words per square inch
1 letter requires 30 cycles modulation
1 word requires 180 cycles modulation
100 $\frac{\text{words}}{\text{minute}}$ requires 300 $\frac{\text{cycles}}{\text{second}}$
and therefore requires 3000 cycle carrier

Fig. 16

Wax Paper

At the receiving end, we are continuing the use of hot-air recording, and have now a paper developed in the hands of our chemist, Mr.

F. G. Morehouse. It is much more sensitive to heat than the previous papers. A thin wax coating is placed on top of specially selected paper. This wax coating penetrates the paper as little as is possible. As such, the wax coating acts as a water repellent. However, when the hot-air, at a temperature in the vicinity of 80 deg. C strikes the paper from the fine nozzle, the wax diffuses into the paper and the repellent characteristic of the paper at that point is destroyed. After the transmission is finished, the wax paper is removed from the recorder, and it may then be quickly inked by a water ink from a roller.

This ink is much more permanent than our previous records, and gives a more pleasing finish to the work, as well as sharper definition.

Photo Color

Likewise in place of giving only a black record, any color may be used. And in fact the color may be applied selectively as directed by the transmitting operator. The result is a photoradio in color. This is shown schematically in Fig. 12. The first of such transmitted across the continent from San Francisco to New York is shown in Fig. 13. Unfortunately the colors cannot be reproduced here.

A general view of the amplifier equipment associated with the operations of both the transmitter and receiver is shown in Fig. 14. Some of results of recent transmission are given in Fig. 15. A synopsis of the frequencies involved in picture transmission is tabulated in Fig. 16.

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THE DRUM SCANNER IN RADIOMOVIES RECEIVERS*

By
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In the art of transmitting pictures electrically, the accepted plan is to synthesize, as well as analyze, the picture surface in a successive consideration of the several elementary areas of the surface.

For example, if the picture surface is divided into 48 horizontal lines, each of these lines is assumed to be divided into 48 elementary areas, making 2304 elementary areas for the whole picture surface.

If the complete reception of the picture takes five minutes, obviously a recording surface must be employed; for example, a photographic film or plate, an electrolytic paper, or a plain piece of paper on which ink or other coloring means is used.

However, if the speed of completing each picture is reduced to 1/15th of a second, and repeated every 15th of a second, no recording surface is needed, for, because of persistence of vision, the picture can be assembled directly on the eye, and "radiovision," "radiomovies," or television becomes an accomplished fact.

This is the method, fully described as long ago as 1884, which has been employed by all workers to the present time.

The picture scanning mechanism employed in this 1884 device and by others since, consists of a rotatable disk with 48 miniature apertures therein, the diameter of each aperture being about 1/48th the length of the scanned line, or 1/2304th part of the whole scanned area, and conveniently termed the "elementary area" of the picture surface.

As each aperture in the disk lies on its particular radius, of 48 such radii; and each aperture located approximately its diameter nearer than its neighbor to the axis of the disk, namely, in a spiral, it will readily be seen that when the disk is rotated the locus of each aperture in succession produces a linear scanning of the whole picture area.

Because this scanning disk limits the illumination to the light which can pass through a single one of these tiny holes, a powerful source of light is required for adequate lighting, just as is required in a pin-hole camera, with which it is comparable.

As such a powerful light was not available in my laboratory, I put a lens over each aperture in the disk, making the aperture as large as the working area of the lens, and a comparatively small light-source, e.g.,

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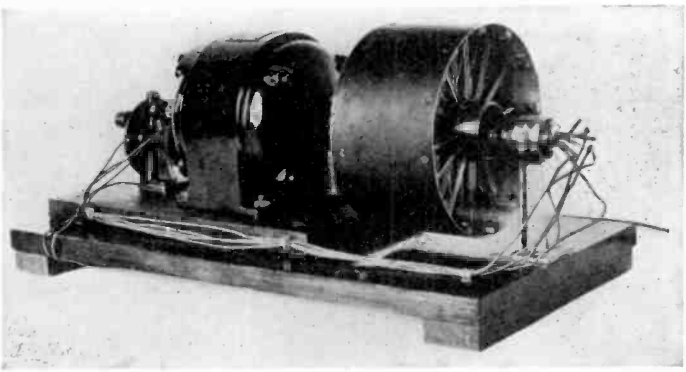
an automobile headlight lamp, was then quite adequate. The necessary elementary area was attained by focusing the light source into a pin-point on the subject or surface to be scanned.

This lens-disk was shown in some of the illustrations used with a descriptive article previously published.[1]

The same lens-disk was also used in a public demonstration of radiovision and radiomovies on June 13, 1925, broadcast from Navy Station, NOF, Anacostia, and received in my laboratory in Washington, in the presence of Navy Secretary Wilbur; Acting Secretary Judge Davis, Commerce Department; Director Dr. George M. Burgess, Bureau of Standards, and many other government officials.



The quartz rods end under the four helical turns of scanning apertures in the drum surface, and act as light channels from cathode targets.

But the disk scanner, whether apertured disk or lens disk, has physical limitations in practical application which seem, as at present employed, not to permit very much development.

In the scanning disk, the minimum separation of the apertures determines the width of the picture; and as the picture is approximately square, this aperture separation also determines the offset of the ends of the spiral.

A disk 36 in. in diameter is required, therefore, for a picture 2 in. square. A 4 in. picture would require a disk of 6 ft. in diameter—a rather impractical proposition in apparatus for home entertainment, even if it were possible to get power enough out of the house wiring to bring the disk quickly up to the proper speed.

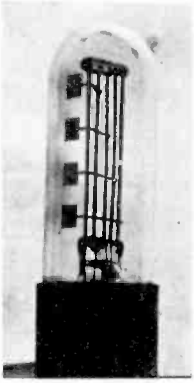
To lay the apertures out in a multiple turn spiral does not help, for the picture size is still determined by the separation of the last two

[1] C. Francis Jenkins, *Radio News*, December, 1923.

apertures nearest the axis of the disk. And such an arrangement requires a rotating mask or other complications which more than offset any theoretical advantage.

For a source of light to make up the picture in an apertured disk receiver, it is usual to provide a glowing plate cathode in a neon gas lamp.

This glowing cathode plate is looked at through the flying apertures of the rotating disk, the incoming radio signals modulating the cathode glow to build up the picture. The cathode plate for a 2 in. picture must, to provide a marginal latitude, be somewhat larger than the picture, say, 2 1/2 in. square.



The four-cathode lamp used in the hub of the drum scanner.
The cathodes glow in succession.

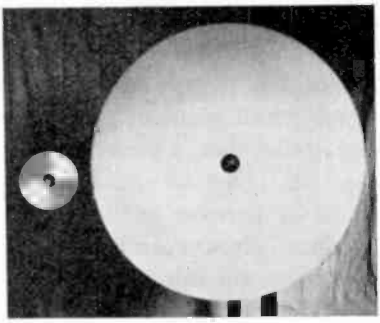
To light this 2 1/2 in. cathode plate requires from 90 to 110 milliamperes of current, necessitating special amplification of currents obtainable from the plate of the last amplifier tube of usual radio sets.

And so the proposition as a whole does not look very enticing, and it was for these reasons that I never employed the elementary-area apertured scanning disk. The lens-disk was the nearest I ever came to it.

The drum method, however, is much more promising, for a cylinder, or drum, is free from many of the limitations of the disk, and has some very meritorious features of its own.

To get a mental picture of the drum, structurally, let us image a hollow cylinder 7 in. in diameter, 3 in. in length, and 1/16 in. wall; with a hub, hollow for the length of the drum, and about 1 1/2 in. inside diameter. The hub has an extension outside the drum which slips onto the 1/2 in. shaft of a small motor.

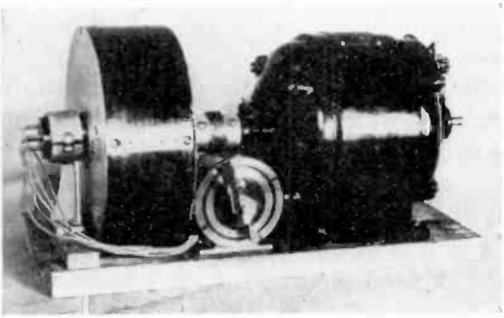
There are 48 scanning apertures punched or drilled in the peripheral wall of the drum, each aperture of elementary area, say, 1/24th in. diameter. The apertures are arranged in four helical turns and spaced 2 in. apart circumferentially, the turns being 1/2 in. apart.



The Jenkins drum (left) and the disk scanner (right) make the same size picture.

Inside the drum-hub a 4-target cathode-glow neon lamp, 1 1/8 in. in diameter, is held by a clamp mounted on the motor platform at the open end of the drum, preferably.

Between the lamp and the periphery of the drum are tiny quartz rods, each rod ending under its particular minute aperture in the drum surface.



Mechanism of drum radiovisor.

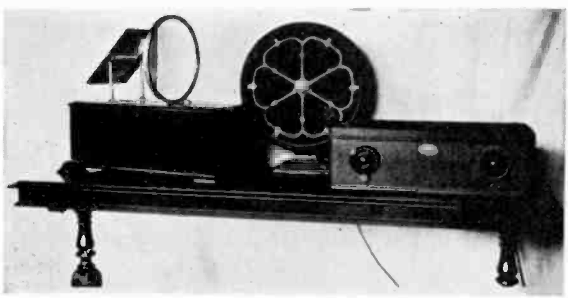
A quartz rod has a peculiar property, in that light flows through it as water flows through a pipe. That is, the use of quartz rods may be thought of as avoiding the light loss due to the inverse square law.

One of the cathode targets is located under each of the rows of quartz rods, and they are lighted in succession through a 4-segment commutator, by current from the plate of the last tube of the radio receiver-amplifier.

Because the movement of the inner ends of the rods is so short, these cathode targets need be only about 1/8 by 3/16 in. in size, or, for ample latitude in setting the lamp, say, 3/16 by 1/4 in.

Such small size targets obviously require only a very small amount of current compared with the current required for the 2 1/2 in. square cathode plate of a disk scanned picture; say, 3 to 5 milliamperes. The light-modulation of these small cathode targets seems to be just as easily done, if not more easily, than a large plate.

The quartz rods are employed to avoid the light-loss due to the inverse square law. And to discover how effective they are, one has but to remove the rods, for no picture can be seen without them, though every other condition remains the same.



Showing by comparison size of radiovisor.

The miniature cathode targets lie about 3/16 in. from the inner end of the quartz rods, which at this point have relatively small movement. The size of the picture, however, is limited only by the arcuate distance from the outer end of one rod to the outer end of the next. But as the light at the outer end, that is, the picture end, of the rods is just as intense as it is within 3/16th in. of the light source itself, we get an acceptably lighted picture, for there is no loss of light in its travel along the quartz rods.

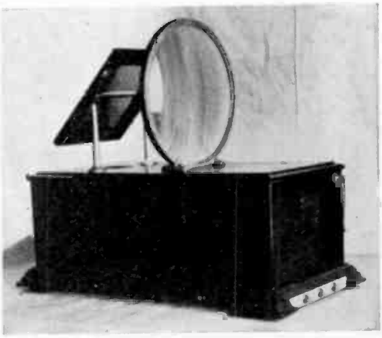
Neither does the drum scanner have another of the limitations of the disk. That is, the scanning apertures in the drum may be arranged in a plurality of helical turns without in any way changing the spacing between any of the apertures.

A drum 7 in. in diameter with scanning apertures in four helical turns gives a 2 in. picture. Magnified, the picture appears about 6 in. square; and in daily use it has been found that five or six people, the whole family, can very conveniently enjoy the story told in the moving picture.

The same size drum with six helical turns gives a 3 in. picture, unmagnified, which is more than twice the area of any picture possible with a 36 in. disk.

If the drum is increased to 10 1/2 in. diameter and turned six times per picture, the picture is 4 in. square; magnified it appears about 10 in. square; and 12 to 15 people can watch it.

The light intensity is the intensity of the tiny cathode source, which, because it is so small, requires but little current for a definite light intensity and a given size picture, the picture generated by the outer ends of the quartz rods being a virtual magnification of the light source.



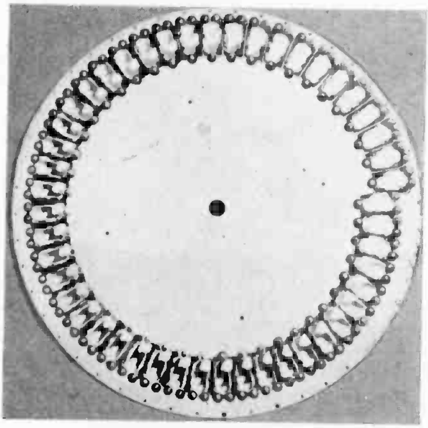
The Jenkins radiovisor by which motion pictures are received in the home by radio. The picture appears in the magnifying glass to be about 6″×6″.

The light source need be but little larger than the elementary area of the picture, for the arcuate movement of the outer end of each quartz rod through which the light is flowing is comparable to the movement over the picture area of this small light source itself.

An increase in the size of the picture does not, therefore, require an increase in the light source, namely, the size of the cathode, but only a lengthening of the quartz rods; for the width of the picture is determined by the length of the arc of the angle subtended by radially-adjacent quartz rods; and the height of the picture by the number of parallel lines, each the locus of the outer end of a quartz rod from which the light emerges undimmed by its distance from the source in the hub of the drum.

The motor we most use to turn the drum is just a 60-cycle synchronous motor, for there are more homes in the a-c district of cities than in the d-c district. Even the slight frequency differences in the

60-cycle current of separate cities often gives little trouble in the 1/15th of a second that it takes to complete each picture of the composite movie story. We have tried synchronous motor transmission and reception between Chicago and Washington successfully, and also between Washington and New York. Radiovisors for use in d.c. districts are fitted with a d.c. motor with an adjustable friction-control with quite acceptable success. Someone adjusts the drum speed as he watches the picture. If he sees a picture at all the receiver is in approximate synchronism with the transmitter; a little further adjustment makes the picture stand still. If he does not see a picture, the speed is



The Jenkins spiral lens-disk scanner.

not correct, and he turns the adjusting screw until he has a picture in frame. Synchronism in radiomovies is much more simply attained than in still pictures. We also have automatic synchronizers, but they are no part of this drum description.

Looking to the possibility of future development in this art, may I again cite for consideration the impeding fundamental in this method of picture production, namely, that each elementary area is lighted, if and when it is lighted, only 1/2304th part of the whole time.

Obviously, therefore, in the case of the single plate cathode neon lamp scanned by a disk, the current required is at least twenty-five hundred times more than it need be if it were possible to apply all the light to each elementary area in succession.

It will readily be seen that my drum method is a step in this direction. And while we have made a great gain in the multiple-target-lamp-quartz-rod combination, we are still a long way from my ideal.

And please let me remind you also that the apparent intensity of illumination of the whole picture is the intensity of the light coming to the eye from a single elementary area, divided by the elementary time fraction, which is also equal to the number of elementary areas, namely, 2304. That is why the picture seems so dully lighted when the machine is running, though the scanning spot is very bright when the machine stops.

Multiplying this light reduction by the fractional inefficiency of the current, it will be seen that the total current-light efficiency on the eye in the scanning-disk method is less than 1/50,000th of one per cent.

Doubtless, this discouraging handicap is one of the factors which has delayed the art so long in coming into useful service.

But I am confident the solution is possible. For example, I am attacking the problem in still another way, namely, by substituting persistence of light for persistence of vision.

This new principle is incorporated in a radiomovies receiver I am now building, in which the light of each elementary area persists for an appreciable time, say, 1/10th of a second after the exciting current has passed on.

Actual tests of the fundamental mechanisms involved have convinced us that we shall have more light available than is now employed for illuminating present picture-theatre screens. And the light is white light, not neon pink; and fortunately the light source is readily available in the open market.

This same principle applied to picture transmission, namely, the substitution of persistent for transient elementary area illumination, will be an important contribution toward bringing into the home the long-promised radiovision reception of inaugural ceremonies, baseball games, flower festivals, mardi-gras, and baby parades.

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THE SELECTION OF STANDARDS FOR COMMERCIAL RADIO TELEVISION*

By

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Summary—*The basis of a system of television standards suitable for commercial television service, with specific standards, is discussed. The elements considered in this paper are the following: picture proportions, number of scanning elements, number of picture repetitions per second, scanning method and direction, phase of transmitted current.*

Synchronizing is considered, with possible methods, and also various arrangements for utilizing the television channel.

It is now generally recognized that radio television and audible broadcasting differ in one extremely important respect, in that there are certain fixed elements in a television receiver which must possess constants identical with those of similar elements at the transmitting station, while in audible broadcasting receivers such a requirement does not exist. These elements are the following:

1. In the image to be reproduced, the total number of picture elements and their distribution (vertically and horizontally), together with the method of scanning.
2. The number of picture repetitions per second.
3. Phase of the transmitter modulation with respect to original object.
4. The synchronizing frequency or method to be employed for maintaining the transmitting and receiving scanning devices in synchronism.
5. The relation between the carriers of the television, synchronizing and audio signals, if both or either of the last two are radiated from the television transmitting station and all are intended to be received by a single receiver.

It is self-evident that before television can become a national service, there must be some degree of standardization of these elements among those who desire to operate television transmitting stations and those who propose to manufacture television receiving equipments. The purpose of this paper is to discuss the various factors on which the selection of standards for these elements may be based,

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and to discuss certain possible standards for consideration by engineers engaged in the television art.

The starting point for any discussion of this nature must be a definition of the grade of service which is to be considered. The rapid commercial development of the audible broadcasting art was made possible through the rendering of high grade entertainment and educational service to the public, by many broadcasting stations. If the television field is to develop similarly, we must choose for our standards those which will provide for a service of similarly high quality, or, as we will refer to it hereafter, a "commercial" television service.

A definition of what constitutes "commercial television" was given recently by a special committee of the National Electrical Manufacturers' Association, appointed to deal with the subject, and this is quoted below:

"Commercial television is the radio transmission and reception of visual images of moving subjects comprising a sufficient proportion of the field of view of the human eye to include large and small objects, persons and groups of persons, the reproduction of which at the receiving point is of such size and fidelity as to possess genuine educational and entertainment value and accomplished so as to give the impression of smooth motion, by an instrument requiring no special skill in operation, having simple means of locating the received image, and automatic means of maintaining its framing."

The phrase "genuine entertainment and educational value" really determines the degree of picture detail or the number of picture elements. In an effort to clarify this phrase one of the writers consulted with various persons engaged in the motion picture and theatrical fields and reached the conclusion that "genuine entertainment value" would be achieved if a clear reproduction of a "semi close-up" of two persons was obtainable. (A "semi close-up" in motion picture parlance is a view of a person showing half or two thirds of the figure). It appears that the majority of dramatically interesting situations reduce to two, or at most three persons; and in motion picture practice it is customary to photograph 80 or 90 per cent of a picture in close-ups or semi close-ups. It was therefore felt that if one chose a degree of picture detail that would acceptably render two persons in a semi close-up view, one would be able to meet the entertainment requirement, at least, in the early stages of the art. At the same time, it was felt that other types of subjects, such as general views, would be rendered sufficiently well in a picture of this degree of detail, to convey a satisfactory impression.

This point of view is necessarily a tentative one at best, and is considerably influenced by apparatus and ether channel limitations. In other words, engineers are striving for a type of service which will satisfy moderate entertainment requirements and not require channels thousands of kilocycles in width or apparatus which is as yet unknown. Fortunately, as will be shown later on, the requirements given above may be met by the use of the television channels which have been made available in the United States, each 100 kc wide, and it is believed that the present state of apparatus development is also such as to make the effective utilization of these channels a possibility.

We will now proceed to a detailed discussion of the various system elements and possible standards which may be considered for each.

The authors wish to make clear at this point that the specific standards which are discussed in the following do not in any way involve the present practice or the possible future procedure of the Radio Corporation of America. These standards are considered by the authors as a suitable basis for study by radio engineers engaged in the television art, and as available for the purpose of stimulating discussion, so that at a later date a group of operating standards may be evolved which will be acceptable to the majority of those engaged in this field.

Number of Picture Elements and Picture Proportions

It has been assumed that to possess entertainment value, a received television image must reproduce a "semi close-up" of two persons with satisfactory detail. The determination of the number of elements into which the picture is to be broken is then to be made.

The greater the fineness of detail in a television picture, the wider must be the radio channel and the more complicated or expensive the receiving amplifiers, scanning and illuminating devices. Therefore some practical compromise has to be chosen which will give sufficient detail and not result in unduly complicated or expensive equipment.

In order to determine a suitable compromise, Mr. R. A. Braden of our staff conducted a series of experiments, using conventional halftones of various degrees of fineness of detail. He first arrived at a correlation between the number of "halftone lines per inch" and the corresponding television "scanning lines." Halftones of letters and photographs were made up, and their appearance compared with the television image on a 48-line system of the same original until apparent equality of detail was obtained; from this data, other halftones were made which simulate the appearance of images on television systems having various numbers of scanning lines. Some of these are reproduced and referred to later in this paper. The conclusion reached was that acceptable detail would just be obtained with an approximately 60-line scanning system, and, while greater detail would naturally be obtainable with a greater number of lines, such a system would meet the "entertainment requirement." This conclusion was also in agreement with the results of early work of Dr. Frank Conrad of the Westinghouse Electric and Manufacturing Company. It will be taken for granted that for any unit square area of the picture, the horizontal and vertical detail should be equal. The vertical detail is determined by the number of scanning lines and the horizontal detail by relation between the width of the scanning spot and the width of the picture. If a round or square scanning spot is employed, without overlap of rows of lines, the horizontal and vertical detail will be about equal.

Fig. 1—Equivalent detail of 60×72 picture; semi close-up.

Fig. 2—Equivalent detail of 60×72 picture; view of single person.

Fig. 3—Equivalent detail of 48×48 picture.

In determining the *proportions* of the picture, it seems logical to consider the standards of sound motion picture film, since it is believed that transmission of sound motion picture may form a considerable part of television programs. These proportions are in the ratio of 5 to 6 (height to width).

Experiments made by Mr. Braden showed that two scanning lines per inch on a human figure will give sufficiently clear reproduction for commercial television. Thirty inches is the height which, we assume, will be scanned for a semi close-up view, hence, about 60 scanning lines are sufficient. In Figs. 1 and 2 are shown the detail with which an image 60 lines high and 72 lines wide would be reproduced. Such a picture contains 4320 picture elements. Fig. 3 shows a 48×48 picture for comparison.

We have found that the improvement in detail gained by increasing the number of scanning elements over approximately 4000 is not of material advantage, when the picture contains moving objects. This is due to the fact that in following action the eye does not appreciate detail to the fullest extent. A limit is also fixed by the channel width assigned by the Federal Radio Commission as the radio sidebands are determined by the number of elements and the picture repetition rate.

Picture Repetition Rate

The number of pictures to be transmitted per second is a compromise which is determined by the amount of flicker perceived at the image,[1] and the frequency band available for transmission. Although flicker will be apparent on bright television images up to 24 pictures per second, it appears more practical to use a rate not greater than 20 pictures per second. While there is some flicker observable with 20 pictures per second and, as illumination of the screen is improved it may become worse, higher rates of scanning result in what are in our opinion unduly wide radio sidebands, since the frequency band is directly proportional to the picture repetition rate. If substantially less than 20 pictures per second are scanned the flicker becomes excessively annoying, particularly so for an image projected on a screen.

The frequency band required for transmission with the values now determined will be about 90 kc if both sidebands are transmitted, which can be conveniently placed in the 100-kc bands assigned for television stations by the Federal Radio Commission.

Phase of Transmitted Picture

When light variations impressed on the transmitting photo cells are finally converted into modulating currents for the radio transmitter, the number of amplifier stages (whether even or odd) following the photocell will determine whether the picture as transmitted is a positive or a negative. Each stage of the photocell amplifier causes a reversal of phase, so that if light portions of the picture correspond to maximum current in one stage, they will correspond to minimum current in the following stage. Similarly, the amplifier feeding the light source in the receiver reverses the picture (in effect) in each stage.

It seems desirable to propose that the standard method of transmission should be for a television station to transmit a positive picture; that is, maximum amplitude of radio-frequency currents should correspond to light places on the object being transmitted and minimum amplitude to dark places. Receiving equipment should be designed to reproduce a positive image from an input of this type.

[1] Throughout this paper, the word image has been used to indicate the view which will be seen on the screen of the television receiving apparatus by the observer.

Synchronization

In order to reconstruct correctly an image from the transmitted impulses, every element must bear the same relation to the receiving screen on which the image is projected as did the corresponding element of the original picture at the transmitter. Thus, picture repetition rate must be constant and exactly equal to the transmitter scanning repetition rate.

There are in general two methods of producing identical rates of synthesizing and analyzing. The first is to have at the receiver some local periodic source which is adjusted to synchronism with the transmitting scanner. Such a local source might be an oscillator, electrical or mechanical; or a governor controlling some non-constant device.

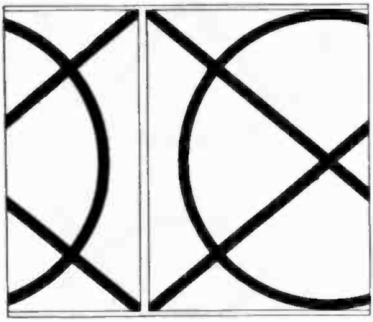

Fig. 4—Image out of frame horizontally.

In order to judge the requirements of a local synchronizer, it is well to note what accuracy is demanded of it. If, for example, 20 pictures are to be transmitted per second and about 4,000 elements per picture, then about five million impulses will be transmitted each minute. In one hour about three hundred million impulses will be sent.

Any slight change in frequency will be seen as a drifting of the picture sideways, and if the picture continues to drift it will become "out of frame" vertically. In Fig. 4 is shown an image out of frame horizontally, and in Fig. 5 one which has drifted until it is out of frame vertically.

It may be safely assumed that a drift of one-tenth of the picture width will not be troublesome, but beyond this, details of the picture may be lost. Fig. 6 shows an image one-tenth out of frame horizontally.

It is assumed that no one would wish to adjust a receiver for framing oftener than once every few minutes. A somewhat similar parallel would be to listen to a broadcasting receiver which continually required retuning.

If these two assumptions are adopted, then an accuracy in frequency slightly greater than one part in seven millions is required. Mr. E. S. Purington of the Hammond Research Laboratories has suggested as a parallel the corresponding accuracy of a clock, which in three months would gain or lose no more than one second. The greatest accuracy of crystal oscillators so far attained is about one part in five millions. Thus it will be seen whatever advantages local sources may possess, they are nullified by the extreme accuracy and stability which is required unless occasional framing adjustment is deemed permissible.

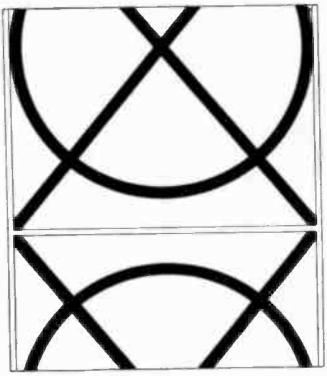

Fig. 5—Image out of frame vertically.

The other method of synchronization is by transmission of a synchronizing frequency which controls the rate of image repetition. The synthesizing rate cannot then be different from the analyzing rate; at the worst a small variation in phase may occur.

The standard of frequency which comes to mind at once is that of the electrical power supply, usually 60 cycles per second. This is undoubtedly the simplest and most widely available frequency. However, in order that the frequency at the receiver be identical with that at the transmitter, it is necessary that the power systems supplying the two be interconnected. The power system at the transmitter must therefore be interconnected with the power supply of every television receiving set to which service is rendered.

In a survey of the power distribution systems of the United States made by the General Electric Company, it was shown that while there are at least four extensive systems which tie in the power companies serving a number of large cities, there are many more which are not tied in. For example, such cities as Baltimore, Denver, Duluth, Kansas City, Minneapolis—St. Paul, New Orleans, Portland (Maine) and New York have no connections with other power systems at present. Hence they would be unable to synchronize with a station using another 60-cycle frequency. In addition many smaller cities have municipal power supplies.

In the case of New York City, while the power systems in the city are interconnected, a large part of Manhattan is supplied by direct current. There is no tie-in with either New Jersey or Long Island, and any station using Manhattan's power supply for synchronizing cannot render service to the neighboring populous districts of New Jersey, Long Island, and Connecticut.

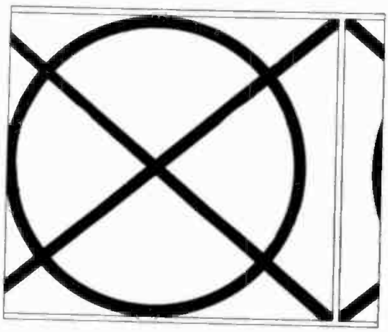

Fig. 6—Image 1/10 out of frame horizontally.

It will be obvious that until all power systems are interconnected and a uniform 60-cycle supply is universally available, no successful national synchronization can be maintained by this means. It therefore appears desirable, for the present at least, that either a synchronizing frequency be supplied by the transmitting station or occasional manual adjustment be provided.

Direction of Scanning

It appears logical to propose that scanning be arranged to proceed from left to right and from top to bottom, as observed by viewing the receiving screen, viz. Fig. 7. This is the normal method of reading a printed page and may well be adopted in television.

As regards the type of scanning, we may consider that scanning systems fall into two general classes:

1. Simple linear consecutive scanning, that is, scanning in which

each horizontal line of the picture is traversed consecutively, as by the Nipkow spiral scanning disk.

2. More complicated or irregular scanning; for example, by means of a reciprocating device, or by the scanning of non-consecutive lines in the effort to reduce flicker.

It is likely that the simplicity of the linear scanning system will justify its adoption.

Economic Use of the Radio Channel

After the frequency and channel width shall have been decided upon for a commercial television system, the proper sub-division of the

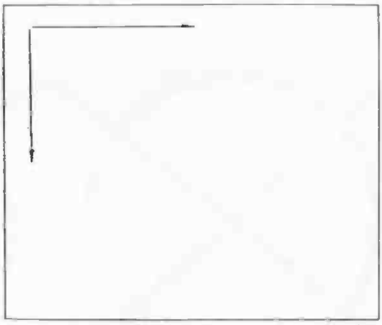

Fig. 7—Scanning direction.

available band must be made to allow for the best economic use of the frequencies in the band. At the present stage of the art, the existing regulation of 100 kc seems to be a reasonable compromise for the band width. Besides the television signal, there may be located in the band a synchronizing signal and conceivably, later on, the speech or music signal, accompanying the picture. The problem is to arrange these signals in relation to one another so as to use the whole range of frequencies provided in the most advantageous manner. This problem can only be discussed generally at the present time.

The simplest system would provide a single carrier located centrally with respect to the band. All three signals, television, speech, and synchronizing, modulate this carrier. Numerous difficulties immediately present themselves with such an arrangement. If the synchronizing signal is within the audible range, the speech would be interfered with. In addition, television frequencies would be heard and the speech frequencies would produce interfering spots and lines in the reproduced picture.

To eliminate this cross-interference, three separate carriers may be considered, one for each of the three transmitted signals. These carriers with their respective side bands would be spaced throughout the band. Some definite separation would be necessary to allow for distinguishing the signals in the receiving set. When the characteristic selectivity of radio receiving systems is considered, it will appear that the frequency channels available for the three signals, especially the television signal, are very limited in width.

A third possible solution is to attempt to make one of the carriers serve for two signals. Again, a number of arrangements are possible. One system which has been proposed employs two carriers, the first for the speech and the second for both television and synchronizing.

A system which seems to offer some possibilities as far as eliminating cross-interference and using the available band in an advantageous manner is one which employs two carriers, the speech and synchronizing signals modulating a common carrier. It appears logical to make the carriers of equal intensity, since each carries a necessary portion of the entire signal. The speech and synchronizing signals would be incor-

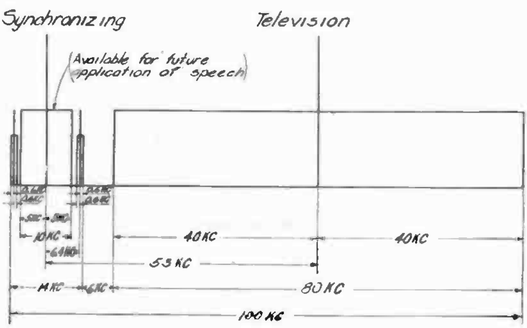

Fig. 8—Spectrum of 100-kc television band.

porated with their associated carrier so as not to interfere with one another. This might be accomplished in a number of different ways. For instance, a low-frequency synchronizing signal may be superimposed on the speech frequencies. A necessary condition is then that the intensity of the synchronizing signal be made very low compared to the speech. This arrangement has disadvantages. There is the danger of using such a strength for the synchronizing signal that it will interfere with the speech when the latter is weak. The synchronizing signal would have to be amplified to a very high degree, and, while this is no particular hardship so far as the circuits are concerned, noise and strays may easily overpower the signal. These disdadvantages do not apply to a system which puts the synchronizing frequency beyond the highest frequencies desired for the speech signal.

Fig. 8 shows the proposed arrangement of synchronizing and television frequencies. It will be observed that a space is left for the later addition of the speech or music signals, should this become desirable.

It will be gathered from the discussions contained in this paper that a close study of all the problems of television is essential before definite working standards can be proposed or adopted. It is hoped that radio engineers engaged in television development will study these problems and publish their views.

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NAVAL COMMUNICATIONS—RADIO WASHINGTON*

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Summary—*This article describes the radio facilities at Radio Washington. There is included a brief description of receiving equipment and of methods of control of transmitters in use at the Navy Department, Radio Central, and of the transmitting equipment installed at Arlington, Va., and Annapolis, Md.*

THE purpose of this article is to give a brief description of the radio installations in the Washington Communication System, and of the methods of handling radio traffic from the Navy Department Radio Central.

The office of Naval Communications, Navy Department, is a division of the office of Naval Operations. The office of Naval Communications, under the command of the Director of Naval Communications, is divided into subdivisions for the administration of the entire Naval Communication Service.

One of the subdivisions of the office of Naval Communications is the Navy Department Communication Office. This office is further divided into three sections known as the Communication Office, Radio Central, and Telegraph Office.

The first of these sections, the Navy Department Communication Office, is maintained for the proper handling and filing of messages. In this office a commissioned officer of the Navy, known as the communication watch officer, is on duty at all times to supervise the handling of message traffic.

Adjoining the Communication Office are the second and third sections, the Radio Central and the Telegraph Office, respectively, both of which are connected with the Watch Officer's desk by an endless belt automatic pick-up-and-drop system. These offices like the Communication Office are in operation continuously on a watch standing basis.

About twelve hundred messages are handled by the Navy Department Communication Office each week day, such traffic averaging over one million words per month. Of this amount approximately 75 per cent is Navy business while the remaining 25 per cent is traffic for other government departments, such as War, Treasury, Agriculture, Commerce, Interior, etc.

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However, not all of the Government traffic originating in, or destined Washington, is handled by the Navy. The Army maintains a Message Center at the War Department similar to the Navy Department Communication Office, and, in cooperation with the Navy, handles traffic to points which can be reached by the Army or Navy radio and telegraph net, or to the nearest point reached by the net for transfer to a commercial landline, cable, or radio system for ultimate delivery to the addressee. The Commerce Department, Airways Division, and the Department of Agriculture also maintain a central station for handling certain additional governmental message traffic.

With the above brief description of the Navy Department Communication Office as a whole, I will pass on to a detailed description of Radio Central—the main receiving and the control station, the monitor receiving station at Bellevue, and the two major transmitting stations—Annapolis and Arlington.

Radio Central

It will be seen in Fig. 1 that the heart of the Navy's Radio Communication System in the Washington District is at the Navy Department Radio Central. It is here that the transmitters of the Arlington, Annapolis, Washington Navy Yard, and Bellevue stations are operated by remote control, and where the actual reception and manual transmission of messages takes place.

Continuous watches are maintained for San Francisco, Balboa, Charleston, Norfolk, San Juan, Great Lakes, New Orleans, and Key West, Commander-in-Chief U. S. Fleet, Commander Scouting Fleet, and with ships of the Navy. Schedules are carried out daily with certain other flag ships and with shore stations at Rome, Rio de Janeiro, and Nicaragua. Daily broadcasts are made of messages to Shipping Board vessels and army transports, and of press, storm warnings, time signals and weather reports.

Automatic transmission by perforated tape is used in the transmission of broadcasts of weather and press, and to a limited extent for routine traffic. All weather reports and time signals are keyed from the U. S. Weather Bureau and the Naval Observatory, respectively, the transmitters being "patched" through at Radio Central.

While at present nearly all traffic is received aurally, the facilities of the office will soon be expanded to permit working high speed with San Francisco, and teletype with Norfolk.

The supervisor on duty in Radio Central may connect any transmitter by patch cord and jack arrangement to any one of the twenty-four individual operating positions. Certain additional features in the wiring of the control board permit him to listen in on any receiver or transmitter, or to talk to any one of the operators through their head telephones, thereby allowing him to control the entire sequence of events connected with the handling of any dispatch without leaving

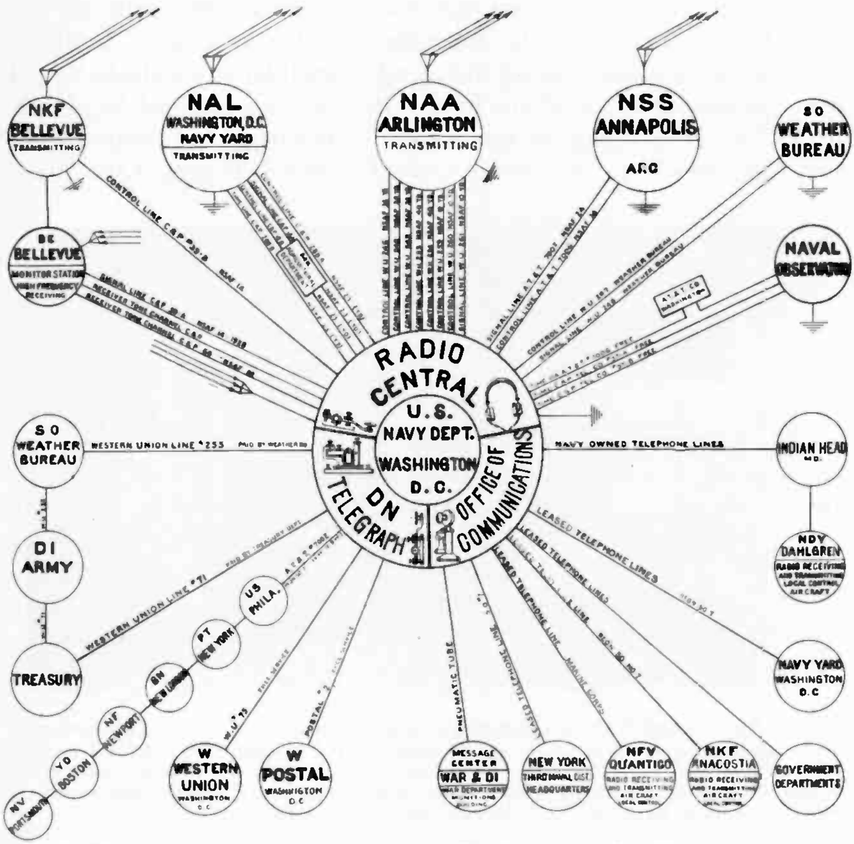
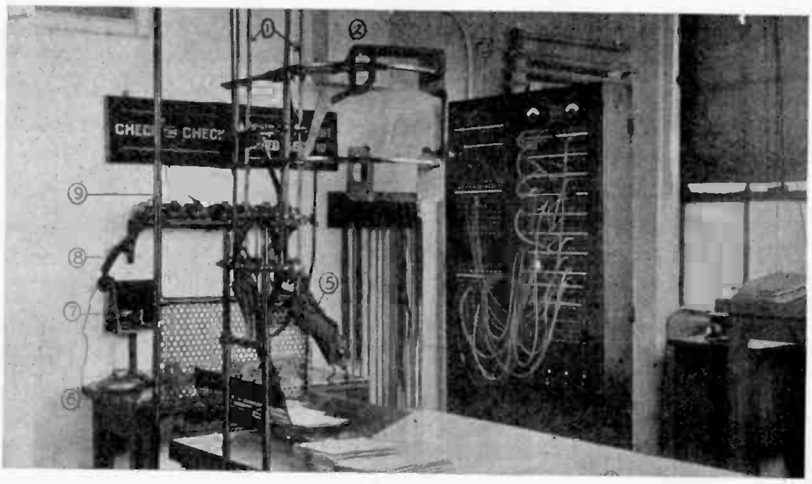


Fig. 1—Naval communication system. Washington, D. C. Chart Note: Bellevue (NKF) transmitters use call NAA when controlled from Navy Dept. Navy Yard broadcast transmitter uses call NAA. All *R/T* weather broadcasts are keyed from the Weather Bureau, and time signals from the Naval Observatory.

his position. Such an arrangement further enables the supervisor to keep himself informed of the progress of work at all times without disturbing the operators to make inquiries.

The control board, which is 75 in. high and 40 in. wide is completely shielded throughout. Mounted on its front are two meters for measuring the control and signal line current and voltage. About four hundred standard telephone switchboard jacks are installed to permit the use of patch cords for maximum flexibility. The total length of lead cable within the board exceeds 1500 ft., and there are about 4,000 soldered connections on the rear of the panel.

An open, shorted, or grounded circuit on any control or signal line between Radio Central and the various transmitters will be immediately evidenced to the supervisor by the ringing of a buzzer alarm which is common to all lines, and a signal lamp which shows red over the terminal jack of the line. The board is equipped to permit paralleling or grouping of the several transmitters for simultaneous transmissions on any one circuit. Added features will permit the super-

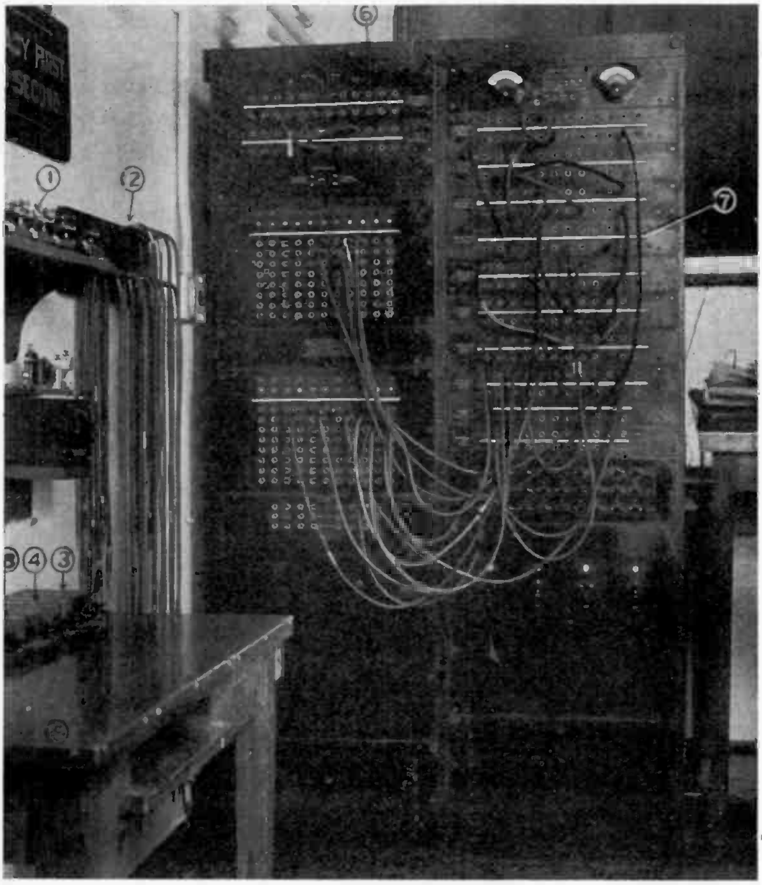


Radio Central, Navy Department, Washington, D. C. View of supervisor's desk, message carrier, sounder shelf, and control board. (1) Vertical carrier drop. (2) Clock circuit switch and relay box. (3) Control board. (4) Supervisors' desks. (5) Message holder. (6) Carrier guard. (7) Signal line sounder. (8) Inter-phone hand set. (9) Relays used as sounders.

visor to connect any one or more operating positions to any control or signal line, and also to any listening or operating receiver. Non-inductive resistors and condensers connected in series are shunted across the various control and signal lines to eliminate key click interference to receivers.

Because of the high noise level in summer which obtains at the Navy Department on high frequencies during office hours, due to stray currents from fans, automobiles, x-ray machines, etc., it was necessary to establish a receiving station at Bellevue so that uninterrupted service could be maintained. High-frequency signals, between 8:00 A.M., and 12:00 P.M., are thus "tuned in" at Bellevue and there amplified and monitored over a leased telephone line to the operator's ear phones at Radio Central.

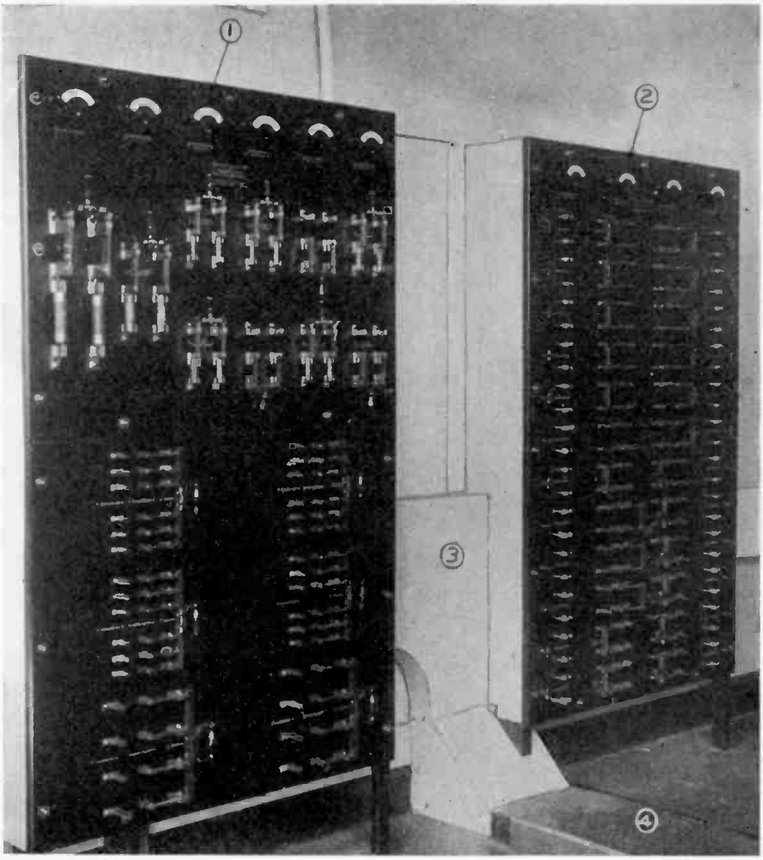
The receivers in use at Radio Central are of a standard type used throughout the Naval Service.



Radio Central, Navy Department, Washington, D. C. Front view of control board. (1) Bunnell relays used for sounders. (2) Patch-cord rack. (3) Test control key. (4) Signal line key. (5) Supervisors' telegraph table. (6) Control board. (7) Patching cord. (8) Building intercommunication key.

The frequency band 10 to 1,000 kc is covered by the two types of receivers of the same mechanical design,—the intermediate-frequency type of receiver having a tuning range of 75 to 1000 kc, and the low-frequency type a range of 10 to 100 kc.

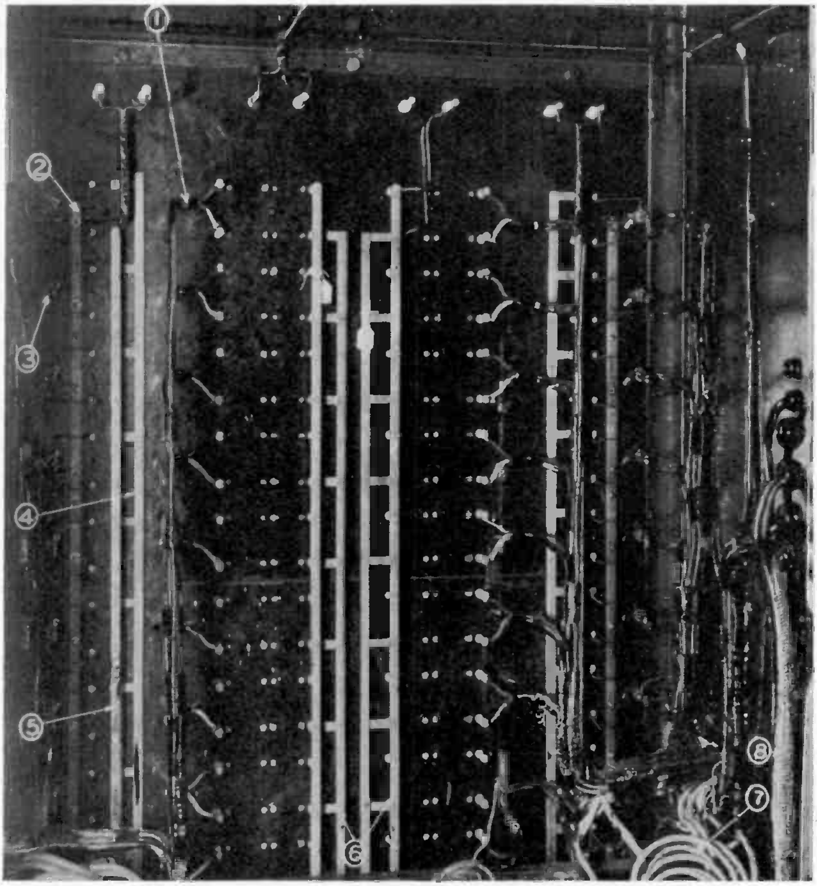
Intermediate- and low-frequency receivers consist of four major units completely shielded; namely,—antenna coupling unit, four-stage untuned radio-frequency amplifier, regenerative receiver, and two-stage audio-frequency amplifier,—set up from left to right in the order named. Seven Western Electric tubes are used in each complete receiving equipment. The high-frequency type of receiver which is



Radio Central, Navy Department, Washington, D. C. Front view of battery charging panel and battery distribution panel. (1) Charging panel. (2) Distribution panel. (3) Steel cable trench. (4) Steel cable trench.

completely shielded and similar in mechanical design to the low— and intermediate-frequency receiver, consists essentially of a single neutralized stage of tuned radio-frequency amplification capacitively coupled to a tuned autodyne detector circuit, and two stages of audio-frequency amplification. Five sets of plug-in coils covering the range 1,000 to 20,000 kc are supplied with each receiver.

Both the Creed and Kleinschmidt type of perforators and trans-



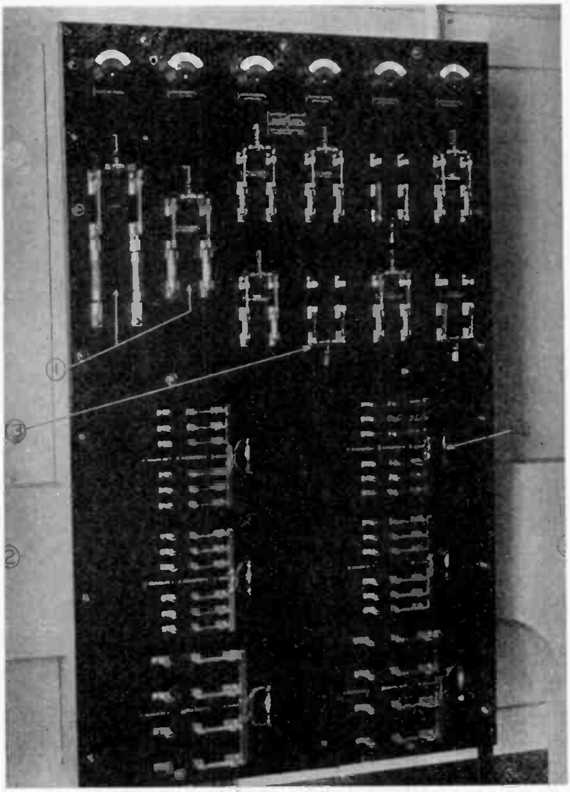
Radio Central, Navy Department, Washington, D. C. Rear view of battery distribution panel with door open. (1) Filament supply cables to positions. (2) Minus plate battery and ground bus. (3) Plate battery switch. (4) 90-v bus. (5) 45-v bus. (6) 2-v busses. (7) Spare cables. (8) Belden braid shielding over rubber-covered wire.

mitters are used. Automatic tape reception is accomplished by means of the RCA power amplifier and ink recorder equipment.

Photoradio equipment for transmitting and receiving photographs 5 in. by 7 in. has recently been installed and is being used for experimental work.

Bellevue

A monitor receiving station located on the Ordnance grounds of the Naval Research Laboratory, Bellevue, D.C., is maintained by personnel from the Navy Department Radio Central for the purpose of monitoring high-frequency signal to the Navy Department during times of the day when noise level at the Department will not permit uninterrupted service.

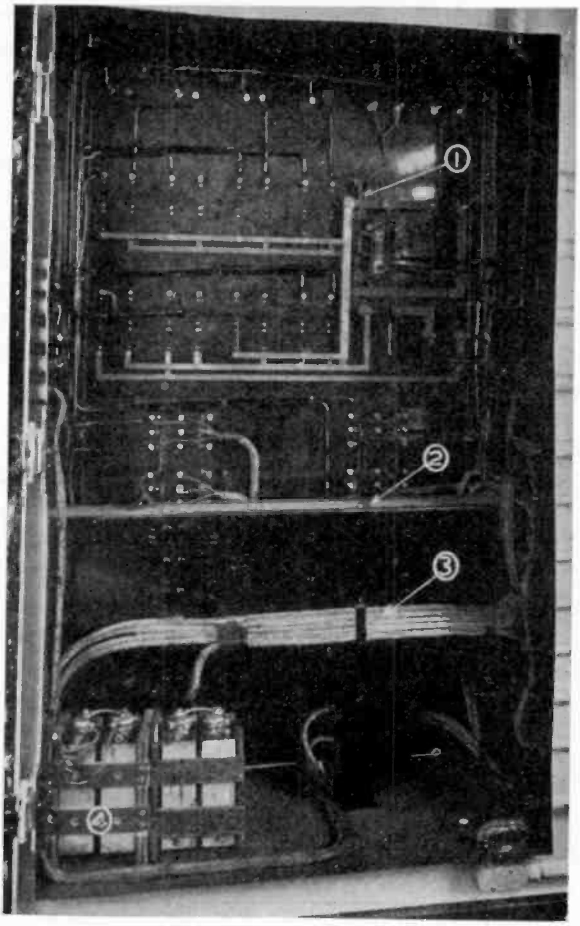


Radio Central, Navy Department, Washington, D. C. Front view of battery charging panel. (1) Main line switches 110 v. (2) Steel cable trench. (3) Spare switch. (4) Battery transfer switch. (5) Steel cable trench.

This station is equipped with two special receivers employing push-pull shielded grid radio-frequency amplification with push-pull type 201A tube detectors, and straight two-stage audio-frequency amplifiers.

The monitor man on duty is charged with the responsibility of keeping the desired signals tuned in and connected to the leased telephone wires which lead to Radio Central where operators copy the message direct on the typewriter.

A signal line employing a Morse sounder is used for signaling purposes between the stations.



Radio Central, Navy Department, Washington, D. C. Rear view of battery charging panel, door open. (1) Ammeter shunt resistor. (2) Steel cable trench. (3) Belden-braid shielding on rubber-covered wire. (4) Batteries for clock.

The leased telephone lines, or tone channels, are run underground in a lead cable from the Telephone Company's pole outside the Bellevue reservation for a distance of approximately 500 ft. to the monitor station.

Two transmitters of crystal control design are installed in the machine shop of the Research Laboratory. These transmitters are used primarily for experimental work, except at night when traffic conditions demand they are controlled from the Navy Department Radio Central.

The control line leading to the Bellevue Laboratory is also used to give new transmitters a service test in handling traffic from Radio Central, prior to releasing the transmitters to the ships or stations for which they were developed.

Annapolis

Across the Severn River from the U. S. Naval Academy, there is situated the U. S. Naval High Power Radio Station, Annapolis, Md., which was first commissioned on August 6, 1919. The station is located about three miles by paved highway from the city of Annapolis on a tract of land comprising thirty-eight acres. This location was chosen because of its close proximity to the Navy Department for economical remote control, and yet distant enough not to interfere with reception at Radio Central in the Department.

Towers

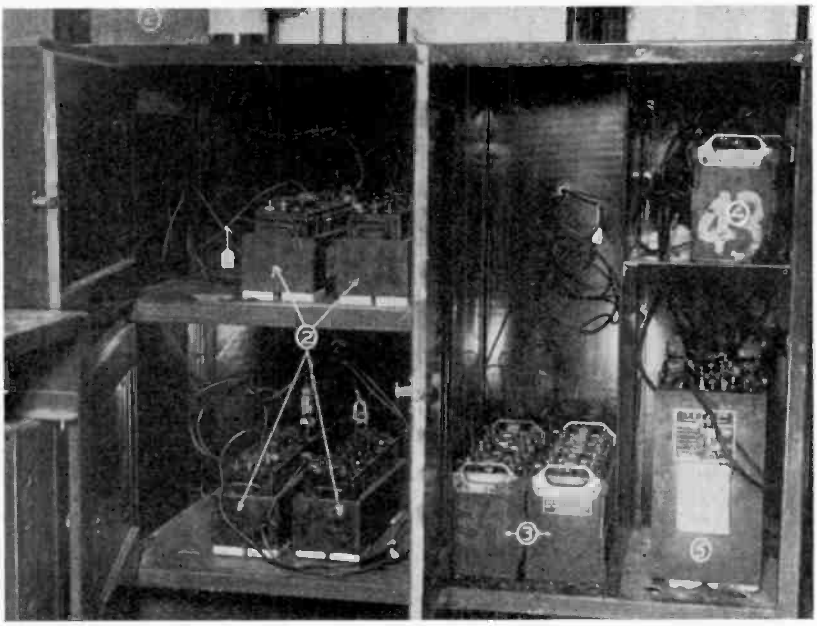
The six Annapolis steel towers are triangular in plan, 600 ft. high, and rest on concrete foundations. They are designed to withstand a maximum safe horizontal pull (at top) of 20,000 lbs. Four of the towers are spaced on a rectangle, 860 ft. square, the remaining two being spaced laterally 975 ft. and 1,250 ft. measured on the longitudinal center line. The six towers thus appear to the casual observer as being arranged in two rows of three each.

Antenna System

The antenna is supported by 5/8-in. plough steel triatic cables suspended between the towers. Each of the three triatics is insulated from the towers by double porcelain strain insulators. The antenna connections are such that the triatic cable is normally at antenna potential. Antenna wires are secured to the outer end (south) triatic and are run through special antenna wire sheaves on the middle and north triatics from which they lead to an anchorage tower and to the entering arrangement on the roof of the helix room. The sixteen antenna wires, where secured to and crossing the triatics, are insulated therefrom with 10-in. disk suspension insulators, except antenna wires number three, five, and eleven which are bonded to triatics number one, two, and three, respectively, to maintain the triatics at antenna potential.

The antenna is insulated for a maximum of 50,000 volts and has a fundamental frequency of 191.6 kc.

Because of the extremely high mechanical loads which the triatics are required to carry, together with the high voltage current applied to the antenna, it was necessary to develop a special porcelain tubular insulator ten ft. in length. These insulators are designed to withstand an ultimate strain of over ten tons, and an electrical flash-over voltage, when dry, of about 190,000 volts at a frequency of 50,000 cycles.

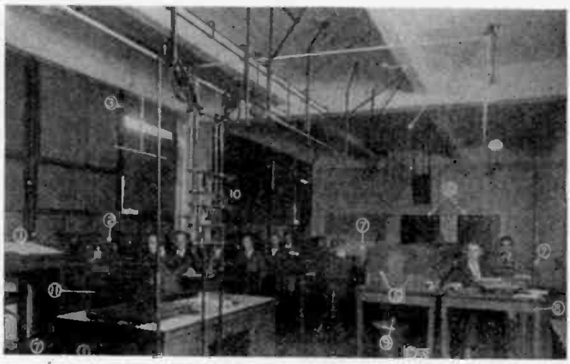


Radio Central, Navy Department, Washington, D. C. View showing right half of battery locker with doors open. (1) Steel cabin. (2) 45-v plate batteries. (3) Signal batteries. (4) Battery for Marshall receiver 6-v filament. (5) 2-v filament batteries.

These insulators act as safety links to prevent overstressing the towers should excessive weight be added to the antenna by the formation of ice on the wires and supporting triatics, or by excessive strain from high winds. The insulators will fail before the tower breaking point is reached, thus causing the antenna to fall to the ground and thereby prevent overloading and possible collapse of the towers.

The maximum sag of the antenna wires with their supporting triatics is 115 ft. while the electrical effective antenna height as measured was found to be 360 ft.

The 20-kw tube antenna system consists of two fans of four wires each, stretched at an angle of 45 deg., and supported by a silicon bronze 3/8-in. cable running between the two north towers. At a distance of 75 ft. from each tower the cable is broken by porcelain strain insulators. The lower ends of each fan converge at insulators about 150 ft. above the tube transmitter house from which point a single 3/8-in. cable is led to two steel anchor posts north of the transmitter house where the lead-in wires are taken off at right angles and connected to the transmitter.



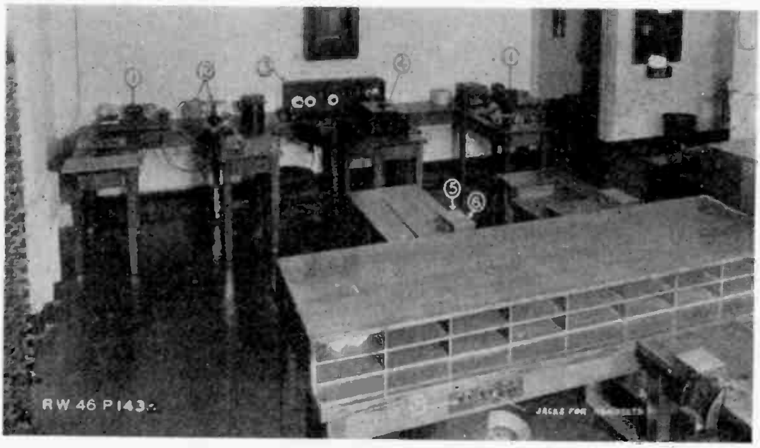
Sectional view showing operating positions. Radio Central, Navy Department, Washington, D. C. (1) Supervisors' desks. (2) RG receivers. (3) Lead-in insulators and lightning arrestor. (4) Antenna lead-in wires. (5) RE and RF receivers. (6) Battery panels. (7) Steel cable trench. (8) Operator's typewriter and key table. (9) Cable conduit. (10) Vertical drop of message carrier. (11) Message carrier guard.

The Ground System

Two ground systems totalling 36 miles of wires are installed, one system being for the 500-kw arc transmitting equipment, and the other for the 20-kw tube transmitter.

The main ground system for the arc transmitter consists of 240 No. 12 copper wires radiating in all directions from the power house. The wires are buried approximately six in. in the ground and are led from the power house to their outer ends where they are soldered to one seven-strand copper wire which encircles the area encompassed by the two center and two north towers. This encircling wire is about 700 ft. from the power house.

The 20-kw tube ground system consists of 8 No. 12 copper wires, buried approximately 3 in. underground, in a fan shaped formation, the apex being at the tube house and the wires running under the tube antenna. Under the concrete foundations of the tube house, 5 strands of No. 0 copper wire are connected to the apex of the fan shaped ground system. The far ends of the fan system are interconnected by a single strand of No. 0 copper wire. Running in a straight line from the apex of the fan ground system at the tube house to the northwest tower are 3 No. 0 wires buried in a trench 2 ft. deep; three similar wires running to the transformer house in a trench 1 ft. deep, and two wires buried in a trench running in the direction of the northwest tower.



Radio Central, Navy Department, Washington, D. C. View of operating room, showing high speed transmitters, recorders, tone amplifier, Klienschmidt perforator and tape puller. (1) High speed transmitter. (2) Tape rolls. (3) Tone amplifier. (4) Tape perforator. (5) Position 20-signal key. (6) Position 20-control key. (7) Jacks for keys.

The arc and tube ground systems are connected at all intersections.

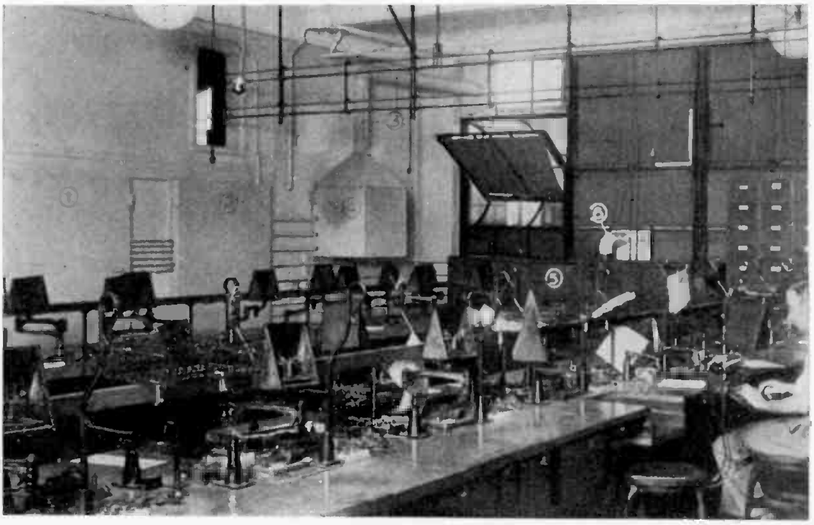
Ice Melting System

A special ice melting system is installed to prevent accumulation of ice on the antenna.

Close observation of weather conditions, temperature, and occurring changes in frequency are required to determine when ice is forming on the antenna. Even an experienced observer has difficulty at times in forecasting probable ice accumulation. The only certain method of guarding against serious casualties to the antenna as a result of ice is to apply the ice melting current during sleet or rain every hour for twenty consecutive minutes whenever the temperature is between 27 deg. and 32 deg.

Melting ice on the main antenna is accomplished by switching the antenna into two series sections, paralleling these two sections and applying 325 amperes direct current at 1,000 volts to the series parallel circuit, the power being obtained from any one of the three arc motor generator sets.

To provide ice melting for the 20-kw tube antenna, a 400-kw arc motor generator supplies 250 amperes direct current at 125 volts through a special switching arrangement to the antenna.



Radio Central, Navy Department, Washington, D. C. View taken in wire room showing the rear view of battery distribution and charging panels closed, charging resistor unit and battery locker. (1) Battery distribution panel. (2) Battery charging panel. (3) Hot-air vent pipe. (4) Battery charging resistance box. (5) Battery cabinet. (6) Battery vapor exhaust pipe.

Electric Power Supply

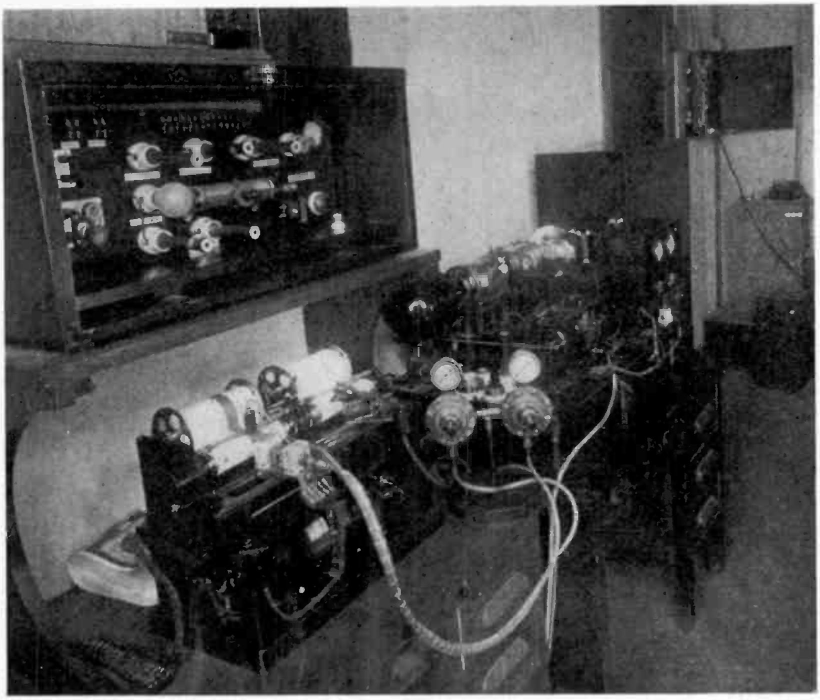
The electric power supply is obtained from the Annapolis and Chesapeake Bay Power Company's substation in Annapolis, at 33,000 volts, 3 phase, 25 cycles. The power is actually generated, however, at the Bennings, Washington, D. C., power house. Three 333-kva 20-cycle transformers owned by the Navy are installed in the Annapolis substation.

Transmitters

The transmitting equipment installed in the Annapolis station consists of one 20-kw tube transmitter, and two 500-kw arc radio transmitters complete in duplicate throughout to guard against possible interruption to service due to possible failure of one.

The arc radio transmitters are of the Federal-Poulsen design of arc converter, originally produced in Denmark, but later developed and perfected in the U. S., and are based on a method of obtaining radio-frequency current oscillations by means of an electric arc burning in an airtight chamber containing hydrogen.

The essential items of the Federal-Poulsen arc converter comprise an airtight chamber of bronze, a "positive" electrode of copper, a "negative" electrode of carbon, two electromagnetic iron pole tips,



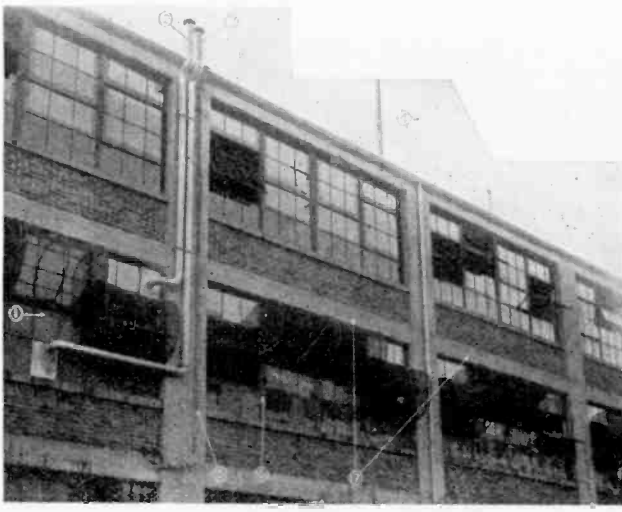
Radio Central. Photoradio.

and a hydro-carbon feed supply. The electric current supply of 1,450 volts direct current is converted from 2,200 volts 25 cycles alternating current from either the 750-kw motor generator, or from the two 400-kw motor generators operated in parallel.

The main loading inductance used in the arc transmitter consists of two coils of thirty-two turns each mounted on one helix supported by thirteen insulator columns. The average space between turns is $3\frac{1}{4}$ in., and the diameter of the outside coil of the helix is 13 ft. 9 in.

The conductor used in constructing the loading coil is a special radio-frequency cable consisting of 10,656 strands of No. 36 enameled wire. This wire is stranded 18 by 16 by 37.

A special high tension condenser of 78 plates (40 high tension, 38 low tension) is used in the arc current transformer circuit. The size of each plate is 18 ft. by 11 ft. 9 in., and is constructed of brass pipe frames covered on one side with inch mesh wire netting and soldered and seized at all intersections.



Radio Central, Navy Department, Washington, D. C. Outside view showing entering insulators, battery vent, and charging resistor heat exhaust. (1) Wire room. (2) Hot air pipe from resistor box (3) Battery vapor vent. (4) Antenna lead-in wire. (5) Cables from roof. (6) Lead-in insulator. (7) Radio central.

Tube Transmitter

The 20-kw transmitter is distantly controlled by the Army from the War Department, Munitions Building, Washington, D.C.

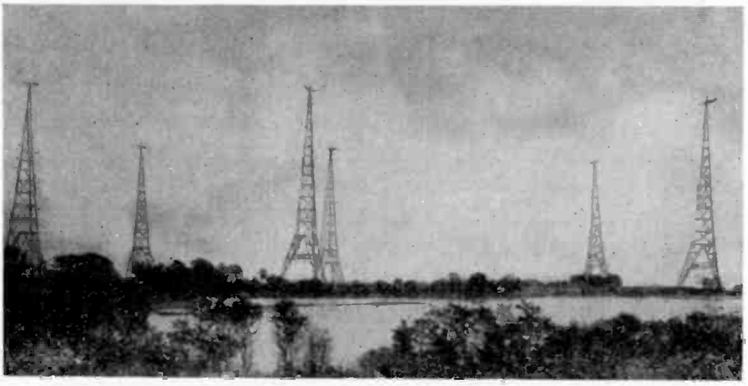
Power supply for this transmitter is taken from 6,600 volts three-phase 25-cycle line and stepped down to 220 volts. The 220 volts alternating current is rectified into direct current by means of twelve Kenetron rectifier tubes, which supply the d-c plate current for the oscillator tube.

The rectifier output voltage is variable from 7,000 to 15,000 volts direct current and is regulated by a switching device which changes the number of primary turns of the rectifier transformer.

One 20-kw tube is used as an oscillator, and is keyed in the grid circuit. Through the keying system a negative bias is applied to the grid of the 250-watt tube, which in turn, according to key position, governs the oscillation of the tube.

The oscillator is connected to a modified Hartley circuit, the primary of which is coupled to the antenna by means of condensers.

Filament current for the rectifier and oscillator is obtained from an a-c supply through step-down transformers. The grid d-c supply is obtained from the 220-volt transformers and two 50-watt rectifier tubes.



Annapolis, showing 600-ft. towers viewed from west.

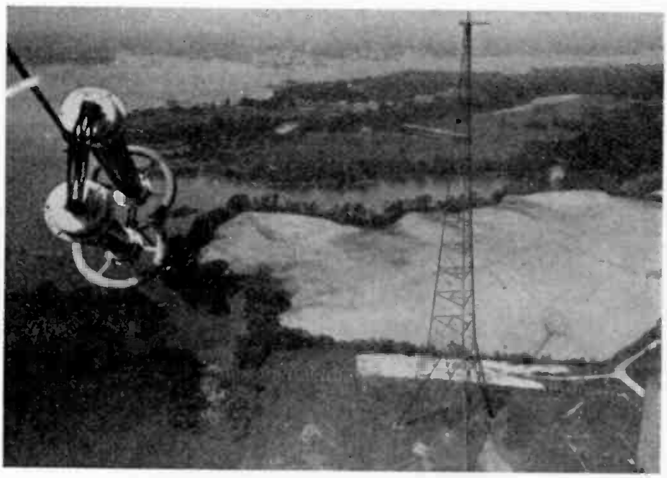
Signaling System

The Annapolis station NSS main arc signaling system is operated by means of a leased control line from Radio Central of the Navy Department. An additional leased wire known as the signal line is used for communicating between Radio Central and the Annapolis station, and as an emergency control line if desired.

The control line is looped through the station from the Annapolis telephone office and is connected at the radio station with two standard telegraph relays and a local hand key. One of these relays is connected with the key on the operator's desk in the arc room for local control, and the other forms part of the high speed key system panel, its secondary being connected to the coils of a polarized master relay. The secondary of the master relay controls ten polarized relays of a similar type. Three of these control three groups of six main keys, each located in the circuit across the nodal point resistance in the radio-frequency circuit; five polarized relays control five groups of four keys each, which are connected in series with the power balance loop and resistance of the radio-frequency circuit. The action of these eight groups of main relay keys produces a uniwave system without sparking. The two additional main relay circuits are used as spares, and for key testing from the electric shop.

Power Outfits

Twenty-nine miscellaneous power outfits are installed at the station for auxiliary purposes. There is also installed an auxiliary power



Annapolis, showing triatic insulator in position and suspension insulators on triatic number one viewed from top of tower.

plant consisting of steam boiler, reciprocating engine, generators, etc., to supply emergency power for lighting and ice melting, and for supplying heat and hot water to the station.

Arlington

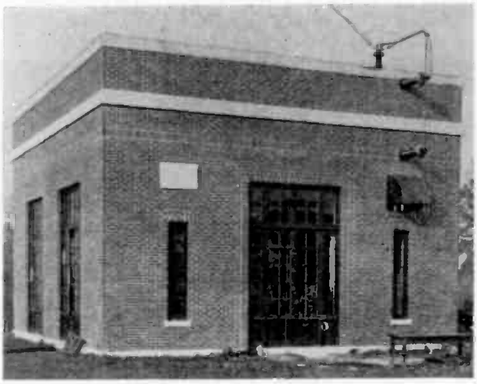
The U. S. Naval Radio Station, Radio Virginia, generally referred to as "Arlington" or "NAA" was first placed in active commission on 13 February, 1913 and was the first high power radio station owned by the Navy Department.

The original installation at Arlington consisted of a 100-kw Fessenden spark transmitter using a synchronous rotary spark gap.

The original receiving equipment of the station was of the crystal and electrolytic type, and all receiving took place at the station rather than from a distantly controlled Radio Central as is now being done.

Arlington ceased to be a receiving station on November 5, 1915 when the Navy's first remote control Radio Central was established in the Navy Department at the State, War and Navy Building in Washington, and since that date Arlington has been used only as a distantly controlled transmitting station.

The Arlington Station is located about four and one half miles from the Capitol in Washington. The ground, 13.4 acres, was transferred from the War Department to the Navy Department by act of Congress. Three additional acres of ground adjoining the station were purchased in 1917 making a total of 16.4 acres. The average elevation in the vicinity of the towers is 190 feet above sea level.



Tube transmitter house. NSS. Showing lead-in for transmitting and ice melting.

Towers

The three main towers, one 600 ft. high from the ground, and two 450 ft. high, are of ornamental steel construction. The centers of the towers form an isosceles triangle, the base of the triangle being 350 ft. long and the altitude 350 ft.

Each tower is constructed on four legs, the base of which is mounted on a concrete foundation about six ft. square at the top, gradually increasing in size until at the bottom, 14 ft. from the top, it is 12 ft. square.

Each tower leg is insulated from the ground by means of a large marble slab and marble washers. These slabs have been tested up to 150,000 volts. The legs are securely grounded, however, by means of a copper cable which may be disconnected at will.

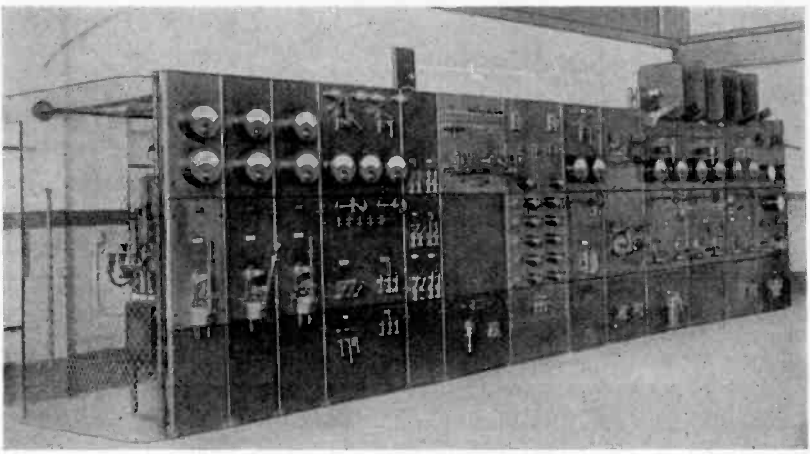
The 600-ft. tower is estimated to weigh 444.5 tons and the 450 ft. towers 275 tons each. The towers are designed to withstand a maximum safe horizontal pull (at top) of 10 tons.

In September, 1922, two new towers were erected, one about 200 ft. east of the south tower, and the other about 800 ft. east of the north tower. They are of steel construction, 190 and 200 ft. high, respectively.

The Antenna System

There are eight entennas in use at the Arlington Station, four of which are used for high-frequency transmitters and four for the intermediate- and low-frequency transmitters.

The largest or main antenna is supported by the three main towers and is used with the 20-kw tube transmitter.



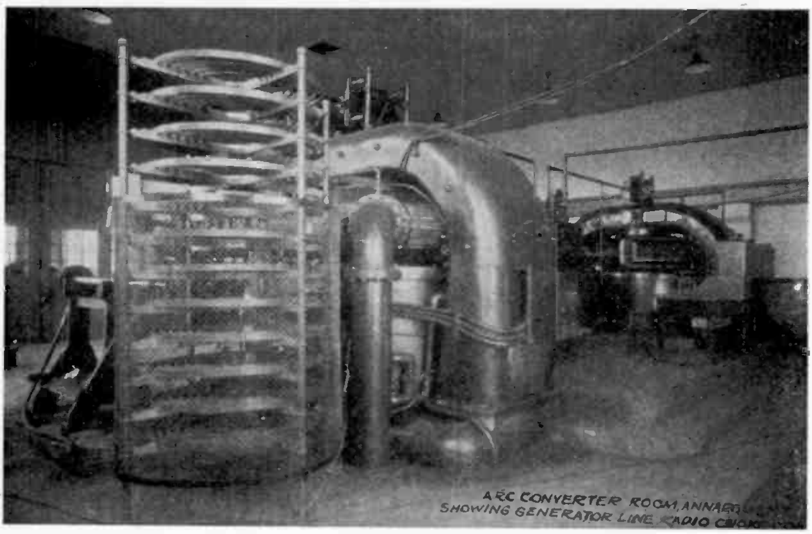
The converter room, Annapolis, Md., showing main switchboards.

The 10-kw tube transmitter antenna is supported by the north 450-ft. and the northeast 200-ft. towers. The antenna for the 1.5-kw tube transmitter is supported by the south 450-ft. and southeast 190-ft. tower, and the antenna for the 1-kw tube from the north 450-ft. and the southeast 190-ft. tower.

High-frequency antennas are supported from the north 450-ft. tower and 2-in. galvanized iron pipe masts on the roof of the transmitter building.

The main antenna, constructed in December, 1926, by station personnel, consists of 15,000 ft. of No. 12 silicon bronze and antenna wire, supported from the 600-ft. tower by two spreaders and two double porcelain strain insulators. A wire cable, three quarters of an inch in diameter, is stretched between the two 450-ft. towers to support the lower part of the fan-shaped antenna. This cable is insulated from each tower by one double porcelain strain insulator.

The flat top consists of sixteen wires which are secured to the two spreaders at the top of the 600-ft. tower and then rove over a brass block attached to the triatic cable where they are divided into two sections of eight wires each, and lead down in four fans to the lead-in arrangement.



Arc converter room, Annapolis, Md. Showing generator line radio choke coils.

The Ground System

The Arlington ground system consists of several miles of No. 12 copper wire buried at various depths in the ground under the main antenna. These wires form a checkerboard pattern and are soldered at each intersection. Strips of copper, 6 in. wide and $\frac{1}{4}$ in. thick, were laid under the foundation of the building when they were first erected. These strips are connected to the network ground system which extends in all directions from the transmitter building.

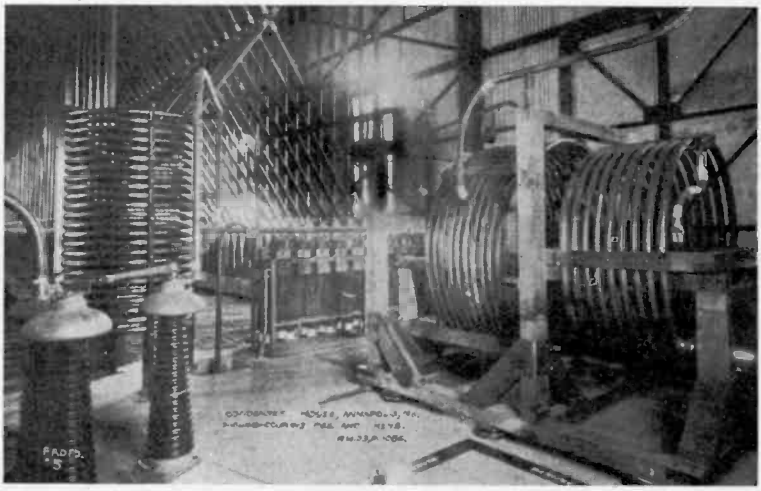
Electric Power Supply

The Virginia Public Service Company of Alexandria, Va., supplies the Arlington station with 3-phase, 13,200 volts, 60 cycles power which is stepped down to 220–440 volts through three 333-kva transformers.

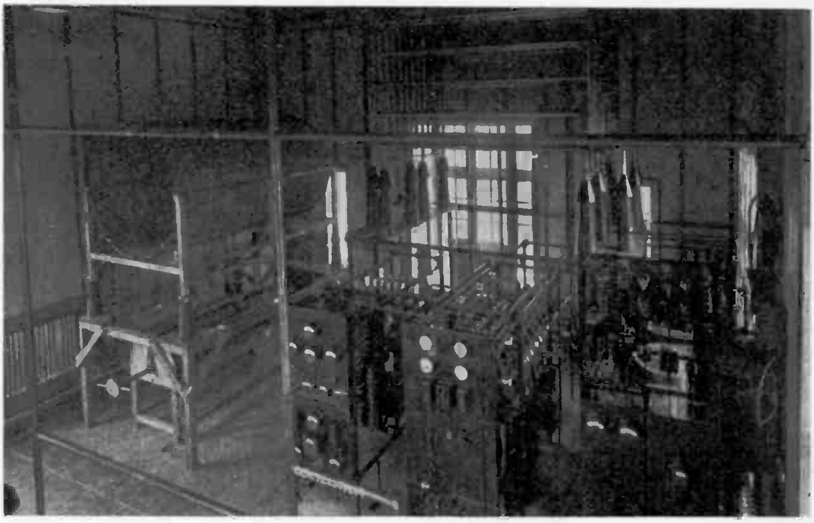
Additional power at 25 cycles, single phase, 6,600 volts is supplied by the Potomac Electric Power Company of Washington, D.C., and is stepped down to 250–440 volts through three 50-kva transformers.

TRANSMITTERS

The 20-kw tube transmitter, which was first placed in active commission on July 1, 1925, consists essentially of a single-phase 60-kw



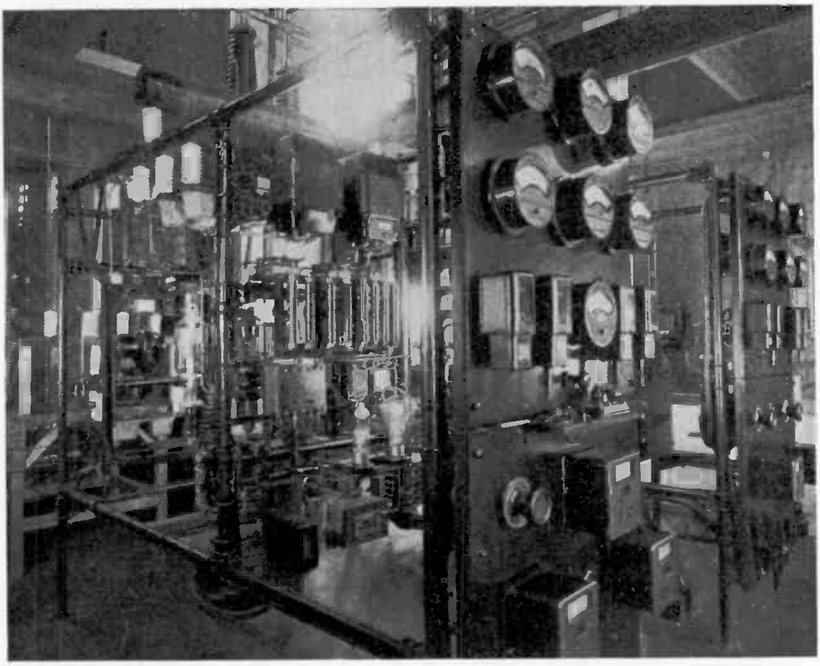
Condenser house, Annapolis, Md. Showing coupling coil and keys.



20-kw tube transmitter NSS. Closed circuit assembly.

rectifier, supplied by either the 100 or 60-kw 500-cycle alternators formerly used on the NAA spark transmitters. The 500-cycle supply is stepped up from 220 to 36,000 volts rectified by two water-cooled tubes, type UV214, and delivered at 15,000 volts direct current to a master oscillator power amplifier circuit consisting of one 5-kw tube as a master oscillator, and two 20-kw water-cooled tubes as power amplifiers. These tubes supply a tank or closed circuit, which feeds the antenna system by capacity coupling.

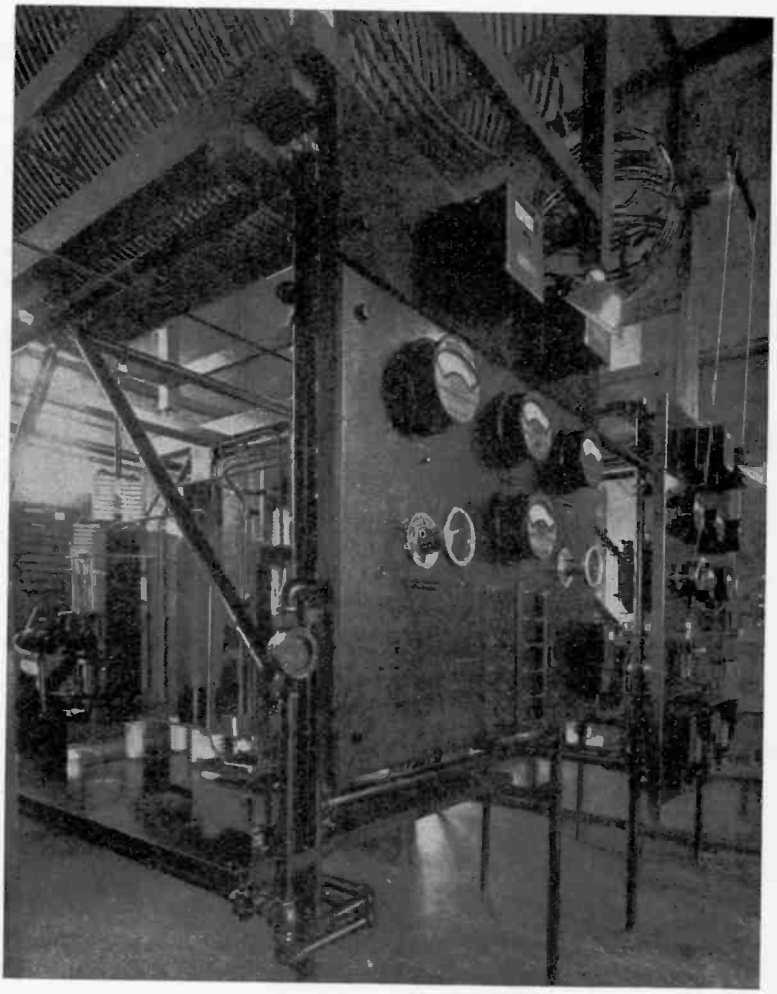
This transmitter is used almost exclusively at the present time for communication with San Juan, Porto Rico.



NAA 20-kw tube transmitter. December, 1925.

The 10-kw tube transmitter is not of the master oscillator type. The 500-cycle supply for this transmitter is rectified by two type UV219 tubes and is then supplied to the plate of a 20-kw oscillator tube. An inverse time limit relay system breaks the d-c source for the radio telegraph relay. Inasmuch as this relay makes and breaks the primary of the 500-cycle transformer, no 500-cycle supply can be applied to the transmitter until the radio telegraph relay is energized.

Except for the type of tubes, the rectifier unit of this set is similar to that of the 20-kw transmitter. In the 20-kw unit, water-cooled rectifying tubes are used, while in the 10-kw transmitter air-cooled tubes have given good results.

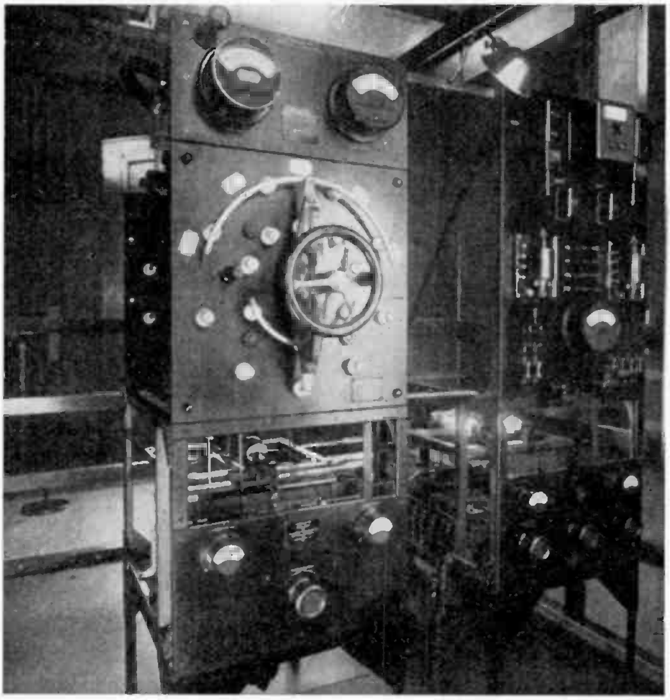


NAA 10-kw tube transmitter. December, 1925.

The oscillator unit is constructed in duplicate. Should one oscillator tube fail in service, it is only necessary to throw a switch and connect the other tube in circuit, and the operation of the transmitter may immediately continue.

The 10-kw tube transmitter is calibrated to operate on three frequencies. The first two of these frequencies are used on the New York, Philadelphia, Norfolk, Charleston, Washington circuit, and the latter frequency for daily broadcasts of weather, press, etc.

The 1.5-kw tube transmitter is operated by remote control from Bolling Field and is used exclusively by the Army.



NAA 1-kw tube transmitter. December, 1925.

This transmitter rectifies the 500-cycle supply by means of two UV218 rectifying tubes which supply is applied to the plate of one 5-kw UV208 oscillator tube. The transformer has a five-point frequency change switch for rapid change of frequency.

The 1-kw tube transmitter rectifies the 500-cycle supply by means of two UV218 rectifying tubes and applies it to the plate of one 1-kw UV851 oscillator tube.

Keying of the 1.5-kw, |and 1-kw transmitters is identical to that of the 10-kw transmitter. Inverse time limit relay system is also similar.

The 1-kw tube transmitter is operated by the Department of

Commerce, Airways Division, by remote control from Washington.

The NAA Broadcast Transmitter operated on 690 kc and is located at the Washington Navy Yard.

This set is rated at 1 kw, using a 50-watt tube for the master oscillator, and one 1-kw tube as a power amplifier. Modulation is obtained by modulating the output of the 1-kw power amplifier by means of a second tube of similar stype.

Four high-frequency transmitters were installed in 1927 and these were developed by the U. S. Naval Research Laboratory, Bellevue, D.C.

The transmitters now installed are of crystal control and each transmitter has its individual 10-kw motor generator set to supply 10,000 volts direct current to the plate.

ACKNOWLEDGMENT

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MICROPHONIC IMPROVEMENT IN VACUUM TUBES*

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Summary—*The paper contains a discussion of the causes and effects of microphonic disturbances in small receiving tubes and the nature of these disturbances, and gives methods of testing for microphonic disturbance whereby the sources of the disturbance may be located and corrected, as well as methods of testing tubes as a means of comparison of individual tubes of different types. A new type of tube with low microphonic output but with low filament power for uses where microphonic troubles may be serious is also described and its characteristics are given.*

MICROPHONIC effects are usually considered to include all of that class of noises in a vacuum-tube output circuit which are due to external disturbances acting upon the tube in some fashion other than through the electrical circuits. Microphonic output is caused by relative motion between the various elements of the tube with resultant variations in plate current due principally to change of plate resistance of the tube.

In the past the only important occurrence of microphonic difficulties has been in radio receivers where acoustic feedback has occurred between the loud speaker and the small receiving vacuum tubes. The more recent application of vacuum-tube equipment in positions where the tubes are subjected to considerable vibration has resulted in the appearance of new and more serious problems of microphonic response that require investigation.

Vibration of vacuum tubes in receiving sets may be excited by sound waves in the air reaching the bulb or by waves transmitted from speaker to tube through the cabinet, socket, and tube base. The variation in microphonic response between different receiver arrangements has resulted in considerable attention being paid to mounting and shielding to prevent microphonic difficulties. Spring suspension of the socket and covering of the bulbs with caps lined with sound absorbing material have been among the most useful examples of such work. However, such shielding is of limited possibility in sets subjected to severe vibration, as for example, aircraft receivers. In such receivers flexibility of tube mounting is limited by the effect of displacement of the tube itself on radio-frequency circuits before acoustic isolation is attained. Packing with sound absorbing material is likewise limited because of space restrictions. For satisfactory operation under such

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severe service lower microphonic response of the tube itself is required. The possibilities of such improvement are considered in this paper.

Methods of Microphonic Testing

The simplest test for microphonics consists of an audio-frequency amplifier of fairly high gain, the tube under test being used in the first stage. If the tube is struck with the finger the output from the amplifier may be heard in a loud speaker. The relative loudness and the time of damping of the sound wave serve as a means of comparison of the tubes. This test depends upon the judgment of the operator and the severity of the blow. Such a test may be used in comparing different lots of vacuum tubes of the same general type, although obviously, different operators will not agree exactly upon the merits of tubes and the test is therefore of no quantitative value.

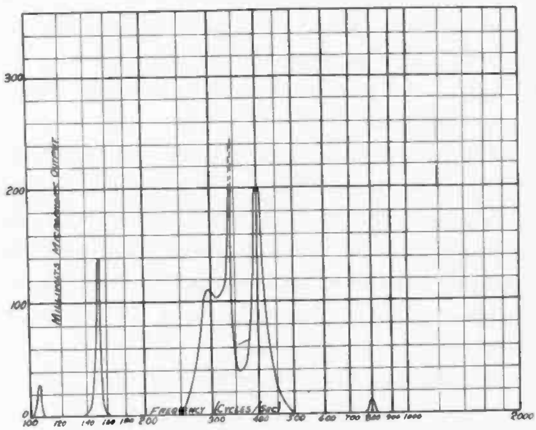

Fig. 1

The above test may be modified by directing the loud speaker towards the tube. A howl from acoustic feedback may be built up if the tube is close enough to the loud speaker or the socket is sufficiently rigid to transmit vibrations from the speaker. If the initial sound dies out in two or three seconds under this test the feedback will not generally be serious. Although this test may be used in checking uniformity of a vacuum-tube production it still does not give a quantitative measure of microphonic response. The absence of a howl in one circuit is not necessarily an indication that one will not be built up in another circuit. For test purposes the tube mounting and speaker distance must be adjusted to give the best possible percentage correlation with actual receiver performance. This discrepancy between a test circuit and receiver performance is even more pronounced in modern broadcast receivers with built-in speakers. In such combinations the acoustic characteristics of the cabinet and location of the

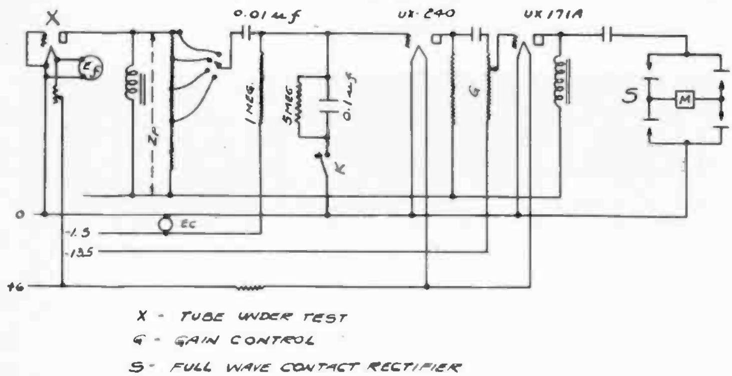

Fig. 2

components will determine the possibilities of tube response in the particular equipment. Individual receivers of the same type may vary so considerably that the tubes quiet in one receiver may build up sus-

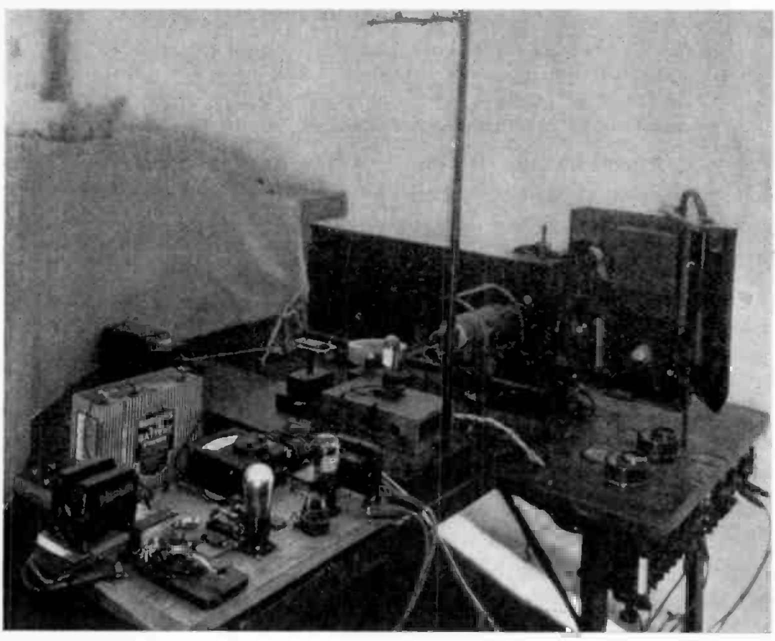

Fig. 3

tained howls in the other. As a consequence, tests of tubes in such a receiver do not show whether the tubes or the receiver itself are abnormal.

For the determination of the effect of forced vibrations a test has been devised in which the tube is strapped to the moving element of a moving coil loud speaker which is excited from a variable frequency

Fig. 4

oscillator. Microphonic output voltage across the plate circuit load is measured by a tube voltmeter and plotted against frequency. The resultant graph forms a vibration spectrum consisting of peaks at the resonant frequency of the various parts of the tube. Although a few peaks are quite broad the greater number are very sharply defined

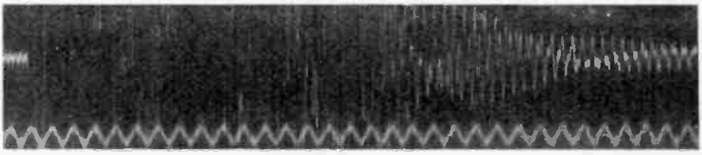

Fig. 5

and easily missed in measurement unless the operator detects them by the sound in head-phones in the voltmeter circuit. Other tests have shown that a number of large peaks indicate a tube which will be poor under operating conditions. This method enables the location

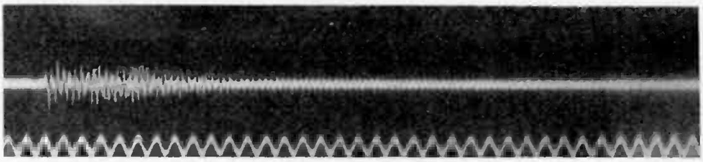

Fig. 6

of the principal source of disturbance since whenever a large peak occurs one or more of the elements of the tube can be seen to be vibrating quite strongly. A typical vibration frequency record is shown in Fig. 1.

This vibration test is useful but does not give an adequate criterion of the disturbances in the output circuit when the tube is subjected to shock excitation. The number and magnitude of resonance points may be used as a rough measure of possible microphonics, but the difficulty in determining the peaks of the resonance points prevents the use of the readings for quantitative comparisons. For this reason a ballistic impact test has been developed as the best means of obtaining a definite reading to indicate the merit of the tube. The impact is

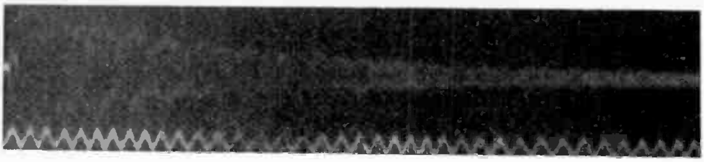

Fig. 7

given to the base of the tube and the variation of voltage across the plate circuit load is amplified and recorded on an oscillograph. The oscillographic records show the exact performance of the tube and form an excellent means of studying the problem of microphonic disturbance in tubes. The final form of the apparatus used for this test is indicated by the diagram of Fig. 2 and photograph of Fig. 3. The excitation is supplied by dropping a ball pendulum against the base of the tube which is mounted on a semi-rigid wood chamber. The tube is operated with a plate circuit load of 20,000 ohms impedance and

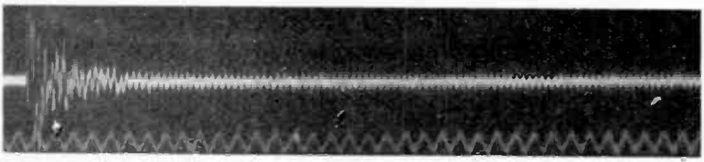

Fig. 8

the output disturbance amplified and placed on the oscillograph vibrator. Oscillograms are taken on standard motion picture film carried in a 200-ft. magazine in the film housing. In taking records the oscillograph driving motor is started by the same switch which releases the ball and one foot of film run off. A sixty-cycle timing wave is also placed on the film. Multiple impacts are prevented by attraction of the pendulum to a permanent magnet at one side of the socket.

Oscillograph impact records show the magnitude of initial microphonic response and the duration of the disturbances until the tube is again quiet. Both are important. Either or both may be the cause of disturbance in radio equipment, the actual voltage in the output circuit being a complex effect depending upon the character of the external disturbance. In addition the records indicate the principal frequency which is set up by such forced excitation of the tube elements. Typical oscillographic impact records are shown in Figs. 4 to

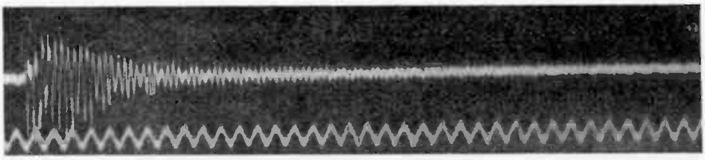

Fig. 9

14. Experience has shown that the records are entirely free from any major discrepancies between repeated tests or with impacts in different planes with respect to the tube elements.

Observation of the elements of the tube during the taking of the vibration frequency spectrum permits the determination of the

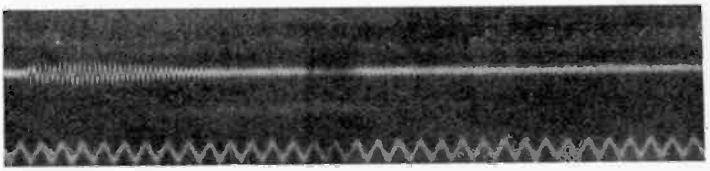

Fig. 10

principal sources of microphonic disturbances. Reference to Fig. 1 shows the multiplicity of resonance points within the tube itself. These points are usually sharply tuned. Any one of them may be sufficient to cause variation in plate current with a consequent ripple in the

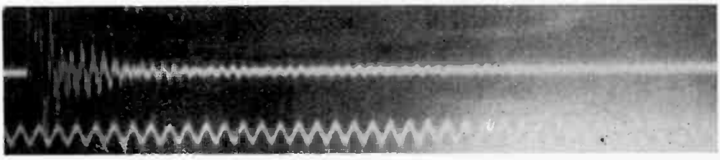

Fig. 11

output circuit when the tube is excited at the proper frequency. Likewise any freedom of motion may permit forced vibration when the whole tube is subject to a sudden impact of large magnitude. In this latter case the amount of microphonic ripple will be limited by the damping of the vibrating part.

In radio broadcast receivers where loud speaker feedback is the most serious microphonic defect the damping factor of the elements of the tube forms the limitation on microphonic output. If the amount of energy fed back is sufficient to overcome the loss by damping the effect will be to produce a sustained howl. In aircraft receivers on the other hand, where the vibrations of the various parts of the plane are

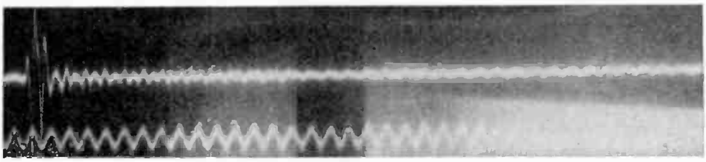

Fig. 12

transmitted to the tube, the effect is to force vibrations in the tube which are not of a transient nature and do not depend upon the damping factor in the same way. Stiffness of the electrode structure is important here.

The most common sources of trouble are filament vibration, mount[1] vibration, and grid vibration. The filament gives the most trouble because it is necessarily the freest part in the tube and can build up the largest amplitude. Filament vibration may be serious not only at its own natural period but also at that determined by the fila-

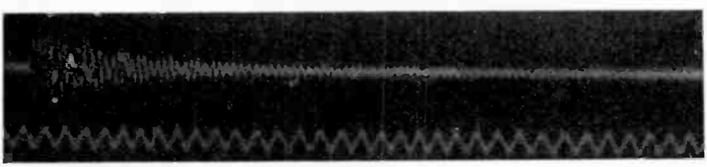

Fig. 13

ment and its supports taken together. Mount vibration gives trouble because of the vibration of the assembly of the tube elements at the natural period of the whole, permitting relative vibration of the various parts. Such vibration may also serve to force the filament into vibration at a frequency determined either by the period of the mount or by that of the filament. The grid vibration is important because of its large effect on the plate current. Its movement also may be sufficient

[1] The "mount" is the complete assembly of tube elements in place on the stem.

to force vibration of the bead and consequently of the filament and other parts.

The great effect of the filament on tube noises is well shown by a series of oscillograms which have been taken on a group of tubes with amplification factors of approximately thirty. The tubes tested are indicated in Table I. The oscillograms as given were taken with the same impedance load (20,000 ohms at 60 cycles including a shunt resistor of 35,000 ohms to limit the impedance at higher frequencies)

TABLE I

STRUCTURE OF SPECIAL 30-μ TUBES

Oscillograms in Fig.	Filament Voltage	Filament Current (ampere)	Filament Shape	Filament Type	Plate	Remarks
4	3.3	0.06	Straight	Thoriated	Cylin.	Typical tube
5	3.3	0.06	Straight	Thoriated	Cylin.	Extra filament tension
6	5.0	0.25	V	Thoriated	Flat	Selected tube for special measurement work
7	5.0	0.25	V	Thoriated	Flat	Tube unsatisfactory as detector
8–9	1.5	1.0	V	Coated	Flat	Typical tubes
10	2.0	1.0	V	Coated	Flat	Specially reinforced elements
11–12	4.5	1.1	V	Thoriated	Flat	350-volt heavy duty tube
13–14	2.5	1.8	—	Cathode	Cylin.	

NOTE: Cylindrical plates were similar to UX199 with single side rod support. Flat plates were similar to UX201A or UX210 with double side rod.

and the same plate voltage. The difference in degree of disturbance is so great that it is readily shown up without attempting to adjust the amplifier gain to exactly the same for each tube. The oscillograms shown are made with a scale of 240 mv per cm.

These oscillograms show the improvement in initial disturbance and in time of decay as stiffness is obtained by the use of shorter and

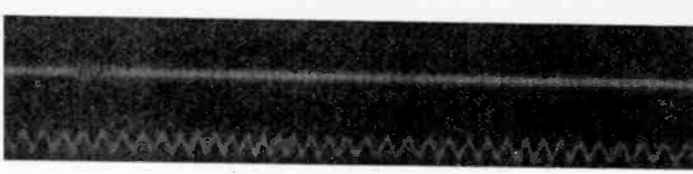

Fig. 14

heavier filaments. The 60-ma filament tubes (Figs. 4 and 5) show the filament disturbance resulting with the use of this light and low current filament. The five-volt V filament tubes show the extremes possible in this type of tube. High amplitudes such as in Fig. 7 may result from mounting of the filament so it is loose on the center hook. The best of these tubes are those of Figs. 8 and 9, which have large filaments such as are used for a-c filament operation. This is evident upon comparison with the tubes of Figs. 6 and 7, which are the same structure other than filaments. Small power tubes such as those in Figs. 11 and 12 are inherently freer from microphonic difficulties than the smaller tubes because of their heavier filaments and construction.

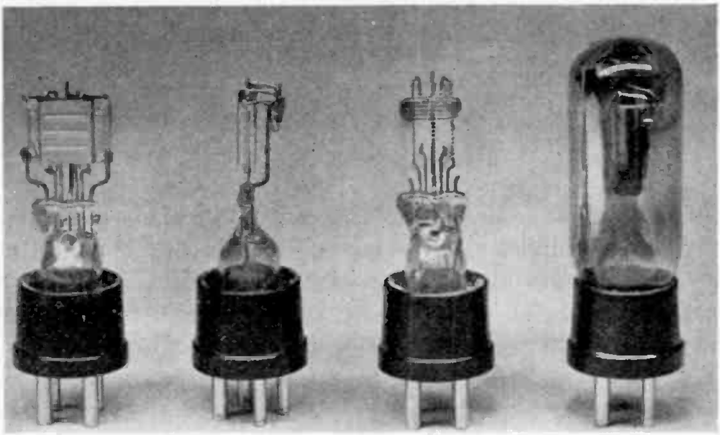

Fig. 15

One of the best solutions of the microphonic problem would be the use of such heavy filament tubes in receiving circuits, but such an arrangement is impractical because of the power requirements in most radio installations.

Experience has shown that an equipotential cathode tube such as the UY 227 is the least subject to microphonic disturbances of any of the

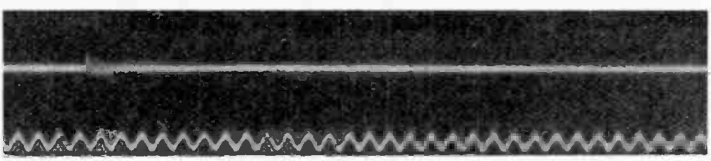

Fig. 16

small receiving tubes customarily used for detectors. The low amplitude of disturbance of such tubes is evident from the oscillograms of Figs. 13 and 14. The low microphonic response of the equipotential cathode tubes makes them particularly suitable for laboratory work where high gain amplification is required for measurement purposes.

The change in type of filament used will not change the microphonics of a given style of tube providing the same dimensions and weight of filament is used. In general, a coated wire will be heavier than a tungsten wire of the same filament rating, but the improvement to be obtained by change in the wire material is negligible as compared with that to be obtained by improvement of structure.

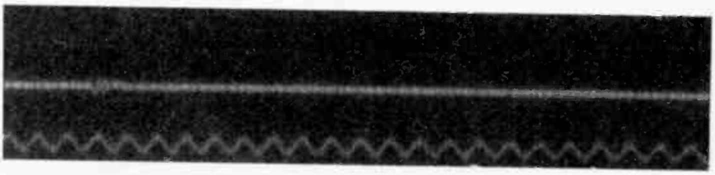

Fig. 17

As in many other design problems accentuation of one design factor can only be accomplished by some sacrifice of one or more other factors. Thus in a low microphonic tube low cost, gain per stage, and filament power may all be adversely affected in getting the desired freedom from tube noises traceable to mechanical vibration. For the

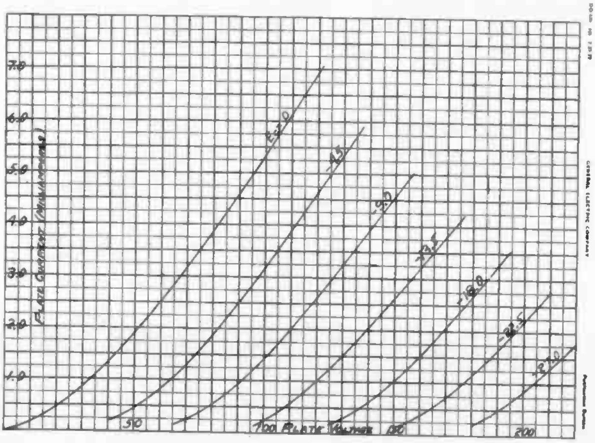

Fig. 18

great majority of applications freedom from the effects of vibration to the greatest extent is not justified because of this impairment in the other qualities of the tube.

A Low Microphonic Tube for Special Applications

A new vacuum tube which will not respond to external vibration has been developed for use where filament power is limited. This tube is Radiotron UX864,[2] the construction of which is indicated by the photograph of Fig. 15. Comparison of the oscillograms of Figs. 16 and 17 with the others previously given indicates the improvement obtained. Electrical characteristics and physical dimensions are given in Table II and a plate-voltage plate-current family in Fig. 18.

TABLE II

RADIOTRON UX864

Filament Voltage	1.1 volts
Filament Current	0.25 amperes
Plate Voltage	90 volts maximum
Average Characteristic Values at $E_b = 90$ volts, $E_c = -4.5$ volts, $E_f = 1.1$ volts	
Plate Current	2.5 milliamperes
Plate Resistance	15500 ohms
Mutual Conductance	425 micromhos
Amplification Factor	6.6
Plate-Grid Capacitance	5.2$\mu\mu$f
Maximum Over-all Dimensions	
Length	4 in.
Diameter	1 3/16 in.

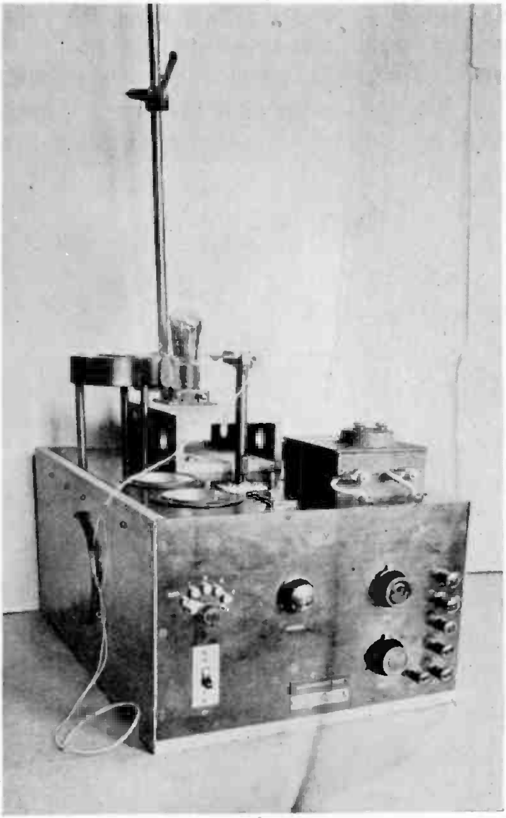

Fig. 19

[2] Jointly designed and produced by the General Electric and Westinghouse Companies for the Radio Corporation of America.

Uniformity tests on microphonic response on a regular production of such tubes require a special apparatus because of the expense of taking individual oscillograms on each tube. An equipment for quantity testing is shown in Fig. 19. The same pendulum and mounting are used as before with the microphonic transient rectified and measured on a microammeter. The maximum deflection is proportional to the quantity of electricity represented in the transient wave. Since both high amplitude and poor damping are generally caused by looseness or weakness of parts a large deflection serves to indicate either or both defects. The amplifier is calibrated by discharging a condenser and subsequent charging through a high resistance grid leak.

The considerable activity in the field of aircraft receiver applications has caused a demand for an especially quiet tube which is being supplied by the UX864. Other applications include receivers and multi-stage tuned audio-frequency amplifiers on small motor driven boats where hull vibration is severe and studio condenser microphone amplifiers where the stand is frequently jarred during a performance. In addition it is being used in various commercial receiver equipments which are subject to either continuous vibration or momentary shocks.

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EQUIVALENT CIRCUITS OF AN ELECTRON TRIODE AND THE EQUIVALENT INPUT AND OUTPUT ADMITTANCES*

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Summary—*This paper is presented in two parts. In Part I two fundamental equivalence theorems concerning a triode and its circuits are rigorously derived. These theorems give the simple circuits which are equivalent to the plate and grid circuits of the triode. These equivalent circuits contain only constant circuit elements and fictitious electromotive forces, the use of which greatly simplifies the calculation of currents in the triode circuits when the electrical variations are small. In Part II the equivalence theorems are used to obtain the equivalent input and internal output admittances of a triode with its associated circuits.*

Part I

DEFINITIONS.[1] The instantaneous plate current i_p and the instantaneous grid current i_g through a triode are both uniquely determined by the instantaneous plate and grid potentials e_p and e_g, provided first, that the filament temperature remains constant, secondly, that the internal capacities of the tube are considered external to the tube so that the charging currents of these capacities are not included in i_p and i_g, and finally, provided that the time of flight of the electrons through the tube is negligible. The above stated in analytic form is

$$i_p = \psi(e_p, e_g)$$

$$i_g = \phi(e_p, e_g)$$

The total differentials of i_p and i_g are

$$di_p = \frac{\partial i_p}{\partial e_p} de_p + \frac{\partial i_p}{\partial e_g} de_g \tag{3}$$

$$di_g = \frac{\partial i_g}{\partial e_p} de_p + \frac{\partial i_g}{\partial e_g} de_g . \tag{4}$$

The four partial differential coefficients in (3) and (4) have the dimensions of conductances, and are given certain distinguishing names and

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[1] The system of nomenclature used in this paper is that described by the author in a paper called "Vacuum-Tube Nomenclature," Proc. I.R.E., 15, 181; March, 1927.

letters as follows:

The first partial coefficient in (3) is called the incremental or variational plate conductance, and is denoted by the letter k_p. Hence

$$k_p = \left(\frac{\partial i_p}{\partial e_p}\right)_{e_g = \text{constant}}. \tag{5}$$

The second partial coefficient of (3) concerns two circuits and, for want of a better term, is known as the incremental or variational mutual conductance and is denoted by the Greek letter σ_p. Hence

$$\sigma_p = \left(\frac{\partial i_p}{\partial e_p}\right)_{e_g = \text{constant}}. \tag{6}$$

It should be noted here that while the quantity defined in (6) expresses the change in plate current due to a change in grid voltage, there is no equal reverse effect implied by the term mutual.

The first partial coefficient of (4) is intrinsically a negative quantity under most normal conditions, and hence the coefficient with a negative sign is defined as the incremental or variational inverse mutual conductance and is denoted by the letter σ_g.

$$\sigma_g = -\left(\frac{\partial i_g}{\partial e_p}\right)_{e_g = \text{constant}}. \tag{7}$$

The comment in the previous paragraph regarding the use of the word mutual is also applicable here.

Finally, the second partial coefficient in (4) is called the incremental or variational grid conductance and is denoted by the letter k_g. Hence

$$k_g = \left(\frac{\partial i_g}{\partial e_g}\right)_{e_p = \text{constant}}. \tag{8}$$

Equations (3) and (4) can now be written

$$di_p = k_p de_p + \sigma_p de_g \tag{9}$$

$$di_g = -\sigma_g de_p + k_g de_g. \tag{10}$$

If we suppose that e_p and e_g vary so that i_p remains constant, then (9) becomes

$$k_p de_p + \sigma_p de_g = 0. \tag{11}$$

The ratio de_p/de_g, which under the assumed conditions is a partial differential coefficient with i_p constant, has from (11) the value

$$\frac{\sigma_p}{k_p} = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_p = \text{constant}}. \tag{12}$$

The quantity on the right hand side of (12) is called the incremental or variational amplification factor and is denoted by the Greek letter μ_p. Then

$$\mu_p = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_p = \text{constant}} \tag{13}$$

and from (12) the three partial coefficients are related as shown below:

$$\sigma_p = \mu_p k_p . \tag{14}$$

Similarly we may assume that e_g and e_p vary so that i_g remains constant. By placing di_g equal to zero in (10) we obtain

$$\frac{\sigma_g}{k_g} = \left(\frac{\partial e_g}{\partial e_p}\right)_{i_g = \text{constant}} . \tag{15}$$

The partial coefficient on the right side of (15) is defined as the incremental or variational inverse factor and is denoted by the Greek letter μ_g.* Hence

$$\mu_g = \left(\frac{\partial e_g}{\partial e_p}\right)_{i_g = \text{constant}} . \tag{16}$$

and from (15) we have

$$\sigma_g = \mu_g k_g . \tag{17}$$

One additional coefficient is of value and will now be defined. The total space charge current from the filament is equal to the sum of the grid and plate currents, or

$$i_s = i_g + i_p . \tag{18}$$

Now i_s is also a function of e_p and e_g expressed in the form

$$i_s = f(e_p, e_g) . \tag{19}$$

The total differential of i_s is obtained by adding (9) and (10) and is

$$di_s = (k_p - \sigma_g)de_p + (\sigma_p + k_g)de_g . \tag{20}$$

Now, if we define μ_s as the negative of the ratio of the increment in plate voltage to the increment in grid voltage to maintan i_s constant, i.e.

$$\mu_s = -\left(\frac{\partial e_p}{\partial e_g}\right)_{i_s = \text{constant}} . \tag{21}$$

* μ_g as defined here is the negative of ν defined by Llewellyn and called by him the reflex factor. F. B. Llewellyn, "Operation of Thermionic Vacuum Tube Circuits," *Bell Tel. Lab.*, August, 1926. Reprint B-20.

we have from (20), putting di_s equal to zero,

$$\mu_s = \frac{\sigma_p + k_g}{k_p - \sigma_g} \cdot \tag{22}$$

Relation (22) is of value because, although all of the coefficients defined in (5), (6), (7), (8), (13), and (16) vary considerably over the working ranges of plate and grid voltages, μ_s is practically constant and is equal to the ratio of plate voltage to the grid voltage, which two voltages, if acting singly, produce the same electrostatic field at the filament. The quantity μ_s depends then mostly upon the geometry of the tube and only slightly upon the space charge so long as the space charge is near the filament. The constancy of μ_s is shown by Fig. 1,

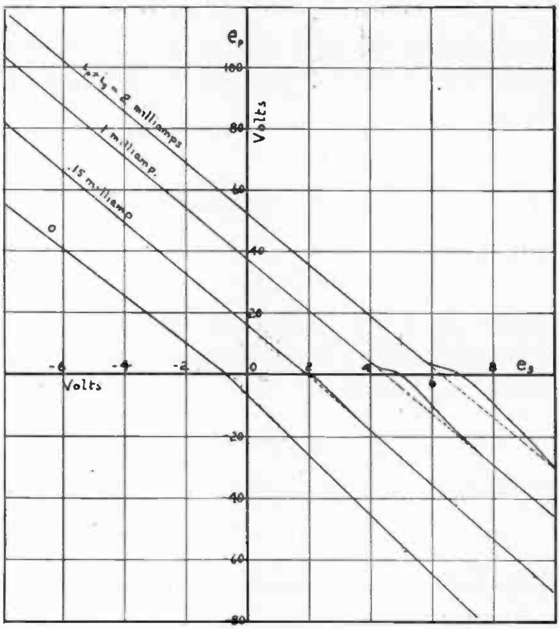

Fig. 1

which is a plot of constant i_s for a standard type low-power triode commonly used as an amplifier. It will be noted that μ_s, which is the slope of the curves of Fig. 1, deviates from its normal constant value only when e_p is near zero. Under this condition the electrons are attracted by the grid, but some pass through the meshes and because of the retarding field between the grid and plate are turned back toward the grid. These electrons may travel many times around the grid wires before finally entering the grid, thus producing a considerable space charge around the grid. This space charge alters the relative effects of the plate and grid voltages in producing a field at the filament and hence changes the value of μ_s.

It is obvious that over the range where μ_s is constant i_s can be expressed by a more specific relation than (19), i.e.

$$i_s = f(e_p + \mu_s e_g). \tag{23}$$

The definitions of the seven coefficients given above are made so that the coefficients are positive quantities under ordinary operating conditions for a high-vacuum triode.

Equivalent Plate-Circuit Theorem.[2] Fig. 2 shows a triode with impedances Z_c and Z_b in the grid and plate circuits, respectively. The instantaneous values of the currents and electromotive forces are defined by the figure. The steady polarizing potentials in the grid

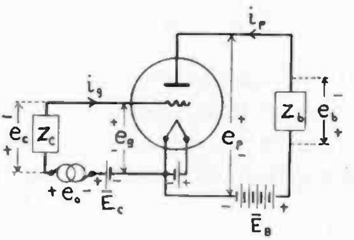

Fig. 2

and plate circuits are $\bar{E}_C$ and $\bar{E}_B$, respectively. There will be certain steady components of the grid and plate potentials designated by $\bar{E}_g$ and $\bar{E}_p$, respectively, and certain steady components of the grid and plate currents designated by $\bar{I}_g$ and $\bar{I}_p$, respectively.

Fig. 3 is the $i_p - e_p$ diagram for the triode, and if there is no varying potential impressed in the grid circuit, the operating point Q is determined by the steady components of the grid and plate potentials. Point Q is called the *quiescent* or *Q-point*.

If now the grid voltage changes by a small amount de_g, the operating point will move to some new position A, and (9) gives the relation

[2] This theorem has long been known and commonly used, but the author has been unable to find a simple but rigorous derivation. The first reference to this theorem which the author has found is in an article by J. M. Miller, Proc. I.R.E., **6**, 143; June, 1918. There, in a footnote, Miller states that the theorem was suggested to him by H. H. Beltz of the Bureau of Standards.

The theorem may appear to follow axiomatically from the definition of μ_p but the author believes that some may be helped if the elementary steps in the reasoning are supplied.

See "Theory and Operating Characteristics of the Thermionic Amplifier," by van der Bijl, Proc. I.R.E., **7**, 97; April, 1919, and "A Theoretical Study of the Three-Element Vacuum Tube," John R. Carson Proc. I.R.E., **7**, 187; April, 1919.

between the change of plate current and the changes of grid and plate potentials.

Since $\overline{E}_B$ is constant, then $de_p = -de_b$ and (9) can be rewritten combining at the same time with (14)

$$di_p = k_p(\mu_p de_g - de_b). \tag{24}$$

We may now define r_p, the variational plate resistance, as the reciprocal of k_p, and then (24) becomes

$$r_p di_p + de_b = \mu_p de_g. \tag{25}$$

Usually e_g varies with time in a predetermined manner so that by dividing by dt we have the following fundamental differential equation for the triode:

$$r_p \frac{di_p}{at} + \frac{de_b}{dt} = \mu_p \frac{de_g}{dt}. \tag{26}$$

In deriving the above equations the origin of coordinates was at O of Fig. 3. Since we may be interested only in changes of current and potentials, we may transfer the origin of coordinates to Q and consider small but finite changes from the point Q, the changes being always

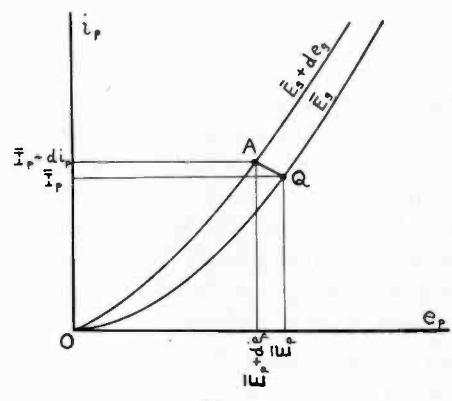

Fig. 3

so small that r_p and μ_p are essentially constant over the path travelled by the operating point. Then we may rewrite (25) in the form

$$r_p \Delta i_p + \Delta e_b = \mu_p \Delta e_g. \tag{27}$$

Equation (27) is one form of the equivalent plate-circuit theorem. According to (27) *the small plate current measured from the Q-point can be calculated assuming an equivalent circuit containing a resistance*

r_p, an impedance or combination of circuit elements Z_b, and a fictitious voltage $\mu_p \Delta e_g$.

If the nature of Z_b is known, then Δe_b can be expressed in terms of the current Δi_p. For example, suppose that Z_b consists of an inductance L_b and resistance R_b in series. Then $\Delta e_b = L_b \, d(\Delta i_p)/dt + R_b \Delta i_p$ and (27) can be written

$$L_b \frac{d(\Delta i_p)}{dt} + (r_p + R_b)\Delta i_p = \mu_p \Delta e_g . \tag{28}$$

If Δe_g is a discontinuous change with respect to time, then (28) gives the transient change in Δi_p. If Δe_g is a sinusoidal emf having an r.m.s. value of ΔE_g, then the r.m.s. value of the plate current measured from Q is

$$\Delta I_p = \frac{\mu_p \Delta \boldsymbol{E}_g}{r_p + \boldsymbol{Z}_b} \tag{29}$$

where bold-faced type denotes complex quantities. Equation (29) is the statement of the theorem for sinusoidal currents and potentials.

Equivalent Grid-Circuit Theorem.[3]—The derivation of the equivalent grid circuit theorem is exactly similar to the above derivation and will therefore be but briefly outlined. Equations (10) and (17) combine giving

$$di_g = k_g(de_g - \mu_g de_p) . \tag{30}$$

Now adding emf's in the grid circuit of Fig. 2 we have

$$e_0 - e_c - e_g + \overline{E}_c = 0 \tag{31}$$

or

$$de_g = de_0 - de_c \tag{32}$$

where e_0 is an impressed emf from an outside source. Combining (32) and (30), at the same time using r_g as the reciprocal of k_g, we have

$$r_g di_g + de_c = de_0 - \mu_g de_p . \tag{33}$$

The companion differential equation of (26) is obtained by dividing (33) by dt.

As before we may change the origin of coordinates to the grid quiescent point and write (33)

$$r_g \Delta i_g + \Delta e_c = \Delta e_0 - \mu_g \Delta e_p . \tag{34}$$

[3] The author has been unable to find any derivation or statement of the equivalent grid-circuit theorem. van der Bijl, in his book, "Thermionic Vacuum Tubes," 1920, on page 187 gives the equivalent of equation (10). Latour in *Electrician*, December, 1916, also derives equation (10).

Llewellyn (loc. cit.) takes fully into account the reaction of the plate voltage upon the grid circuit, but does not derive or state this theorem.

According to (34), one form of the equivalent grid-circuit theorem, *the small grid current measured from the quiescent point can be calculated assuming an equivalent grid circuit containing a resistance r_g, an impedance or combination of circuit elements Z_c, and an impressed emf of Δe_0 minus a fictitious voltage of $\mu_g \Delta e_p$.*

As in the former theorem transient changes measured from the quiescent point can be calculated, or if the impressed emf Δe_0 is sinusoidal, then the small alternating component of grid current can be obtained from the complex expression

$$\Delta I_g = \frac{\Delta E_0 - \mu_g \Delta E_p}{r_g + Z_c}. \tag{35}$$

Equation (35) is a statement of the equivalent grid-circuit theorem for alternating currents and potentials.

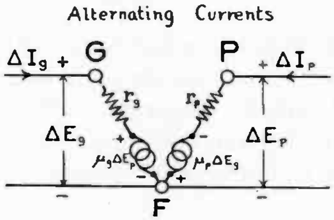

Fig. 4

Fig. 4 gives the equivalent internal circuits of a triode when the tube capacities are neglected. The points G, P, and F correspond, respectively, to the grid, plate, and filament terminals. The terminology on Fig. 4 is given for alternating variations, but the same figure can be used as a model for the calculation of transient changes.

Part II[4]

Equivalent Input Admittance of a Triode. In this part the effects of tube capacities are taken fully into account in the calculation of the input and output admittances of a triode. The complete equivalent network of a triode and its circuits is shown in Fig. 5. The three capacities of the tube and its socket are represented by C_g, C_m, and C_p. For simplicity in the analysis the plate-to-filament capacity C_p will be considered a part of the plate load. The admittance of the combination

[4] The equivalent input impedance of the triode, neglecting the effect of $\mu_g \Delta E_p$ was derived by J. M. Miller in 1919 (see Bureau of Standards, Bulletin No. 351), by Stuart Ballantine in 1920 (see *Phys. Rev.*, 15, No. 5, p. 409), and by H. W. Nichols in 1919 (see *Phys. Rev.*, 13, p. 405).

The equivalent internal output admittance or impedance has not been derived so far as the author knows.

is denoted by Y_b' where $Y_b' = Y_b + jC_p\omega$. Similarly C_g is considered a part of the grid circuit admittance $Y_c' = Y_c + jC_g\omega$. The final result is, however, expressed not in terms of Y_b' and Y_c' but in terms of their component parts.

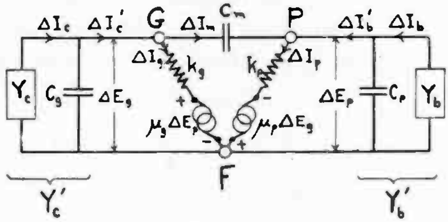

Fig. 5

The actual input admittance of the triode is

$$y_g = \frac{\Delta I_c}{\Delta E_g} = \frac{\Delta I_c'}{\Delta E_g} + jC_g\omega.\ ^5$$

The admittance $\Delta I_c'/\Delta E_g$ is obtained by solving the following equations for the network of Fig. 5.

$$\left.\begin{aligned} -\Delta I_m + \Delta I_c' - \Delta I_g &= 0 \\ +\Delta I_m + \Delta I_b' - \Delta I_p &= 0 \\ \sigma_g \Delta E_p + \Delta I_g &= k_g \Delta E_g \\ -k_p \Delta E_p + \Delta I_p &= \sigma_p \Delta E_g \\ +\Delta I_m + jC_m\omega \Delta E_p &= jC_m\omega \Delta E_g \\ +\Delta I_b' + Y_b' \Delta E_p &= 0 \end{aligned}\right\} \qquad (40)$$

Attention is called to the fact that the admittance between grid and plate is here assumed to consist only of a capacity. If conductance also exists between these terminals or in general if the admittance is Y_m, then Y_m should be substituted for $jC_m w$ in the fifth equation in group (40). The simple case has been carried through in this paper because of the algebraic complexity of the general solution.

The input admittance derived from the above relation is

$$y_g = \left\{ k_g + \frac{(\sigma_p\sigma_g + C_m^2\omega^2)(k_p + G_b) + C_m\omega(\sigma_p - \sigma_g)[(C_m + C_p)\omega - B_b]}{[k_p + G_b]^2 + [(C_m + C_p)\omega - B_b]^2} \right\}$$

$$+ j\left\{ (C_g + C_m)\omega \right.$$

[5] A small letter is used for y_g because the input admittance is a function of the plate and grid polarizing potentials. See reference 1.

$$+\frac{C_m\omega(\sigma_p-\sigma_g)(k_p+G_b)-(\sigma_p\sigma_g+C_m{}^2\omega^2)\left[(C_m+C)\omega-B_b\right]}{[k_p+G_b]^2+\left[(C_m+C_p)\omega-B_b\right]^2}\Bigg\} \quad (42)$$

Equivalent Internal Output Admittance. Because of the symmetry of the network of Fig. 5, the equivalent internal output admittance, or $y_p=\Delta I_b/\Delta E_p$ can be obtained from (41) by changing all p subscripts to g, and vice versa, and subscript b to c, and also reversing the signs of σ_p and σ_g.

$$y_p=\left\{k_p+\frac{(\sigma_p\sigma_g+C_m{}^2\omega^2)(k_g+G_c)+C_m\omega(\sigma_p-\sigma_g)\left[(C_m+C_g)\omega-B_c\right]}{[k_g+G_c]^2+\left[(C_m+C_g)\omega-B_c\right]^2}\right\}$$

$$+j\Bigg\{(C_p+C_m)\omega$$

$$+\frac{C_m\omega(\sigma_p-\sigma_g)(k_g+G_c)-(\sigma_p\sigma_g+C_m{}^2\omega^2)\left[(C_m+C_g)\omega-B_c\right]}{[k_g+G_c]^2+\left[(C_m+C_g)\omega-B_c\right]^2}\Bigg\} \quad (42)$$

The magnitudes of y_g and y_p depend upon the four tube coefficients k_p, k_g, σ_p and σ_g, all of which are functions of the plate and grid potentials. Since μ_s (23) is practically a constant for any given tube except for very low values of E_p, equation (23) can be used to eliminate σ_g from (41) and (42), making y_g and y_p functions of the variable factors k_p, k_g, and σ_p or μ_p.

Special Cases of y_g and y_p

Case 1. Input Admittance for $k_g=0$, $B_b=0$

This case applied to an amplifier whose grid is polarized negatively and whose plate load is a pure resistance. Equation (41), giving the equivalent input admittance, reduces to the following form on putting $k_g=0$ and $B_b=0$.

$$\begin{array}{l} \sigma_g=0 \\ B_b=0 \end{array}\left\{\begin{array}{ll} \dfrac{g_g}{k_p}=A^2\dfrac{\left(1+\dfrac{1}{x_b}\right)+\mu_p\left(1+\dfrac{C_p}{C_m}\right)}{\left(1+\dfrac{1}{x_b}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}\right)^2} & (43) \\[4ex] \dfrac{b_g}{k_p}=-A\left[1+\dfrac{C_g}{C_m}+\dfrac{\mu_p\left(1+\dfrac{1}{x_b}\right)-A^2\left(1+\dfrac{C_p}{C_m}\right)}{\left(1+\dfrac{1}{x_b}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}\right)^2}\right] & (44) \end{array}\right.$$

where $y_g = g_g - jb_g$; $x_b = R_b/r_p$; and $A = C_m\omega/k_p$. The expressions for the input and output admittances are much simpler of interpretation when expressed in ratio form. By dividing through by k_p, the equivalent conductance and susceptance divided by k_p are then functions of the simple ratios R_b/r_p, $C_m\omega/k_p$, μ_p, C_p/C_m and C_g/C_m. The last two ratios are constants and μ_p is nearly constant for any given tube.

In Fig. 6 are plotted g_g/k_p and b_g/k_p against $R_b/r_p = x_b$ as abscissas for various values of the parameter A. The values of μ_p, C_p/C_m, and C_g/C_m used in the calculations correspond approximately to a standard 201A tube, for which μ_p is 8 and the values of C_m, C_p, and C_g, including the capacities of the socket are taken as 10, 5, and 5$\mu\mu$f, respectively. The parameter A has the value unity if r_p is 16,000 ohms and the frequency is 10^6 cycles per second.

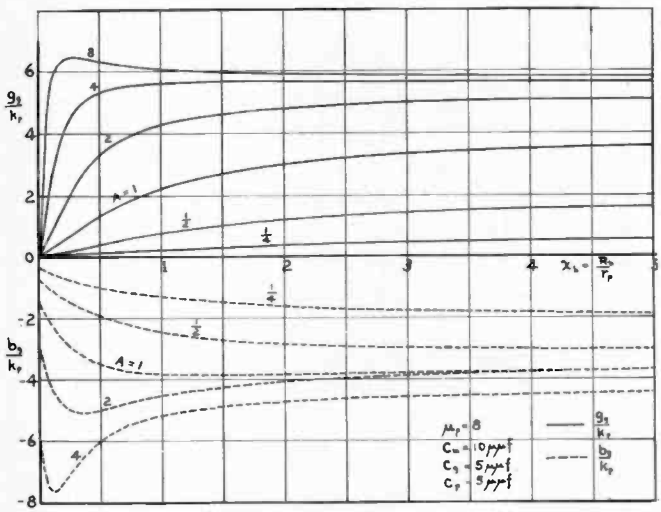

Fig. 6

Examination of Fig. 6 shows that when the plate load of an amplifier is a pure resistance or the equivalent the triode acts upon the input circuit as though there were connected from the grid to filament a resistance and capacity in parallel, both the resistance and the capacity reactance may be much less than r_p, especially if the frequency is high.

Case 2. Internal Output Admittance for $k_g = 0$ and $B_c = 0$

This case applies to an amplifier whose grid is polarized negatively and whose grid circuit contains a pure resistance. Equation (42) reduces to the following expression when $k_g = 0$ and $B_c = 0$.

$$
\begin{matrix} k_g=0 \\ B_c=0 \end{matrix}
\left\{
\begin{aligned}
\frac{g_p}{k_p} &= 1+A^2\frac{\dfrac{1}{x_c}+\mu_p\left(1+\dfrac{C_g}{C_m}\right)}{\left(\dfrac{1}{x_c}\right)^2+A^2\left(1+\dfrac{C_g}{C_m}\right)^2} && (45)\\
\frac{b_p}{k_p} &= -A\left[1+\frac{C_p}{C_m}+\frac{\dfrac{\mu_p}{x_c}-A^2\left(1+\dfrac{C_g}{C_m}\right)}{\left(\dfrac{1}{x_c}\right)^2+A^2\left(1+\dfrac{C_g}{C_m}\right)^2}\right] && (46)
\end{aligned}
\right.
$$

where $y_p=g_p-jb_p$, $x_c=R_c/r_p$ and $A=C_m\omega/k_p$.

Fig. 7 illustrates the shape of the curves obtained by plotting (45) and (46) against R_c/r_p as abscissas for a 201A tube having the same constants as in Case 1.

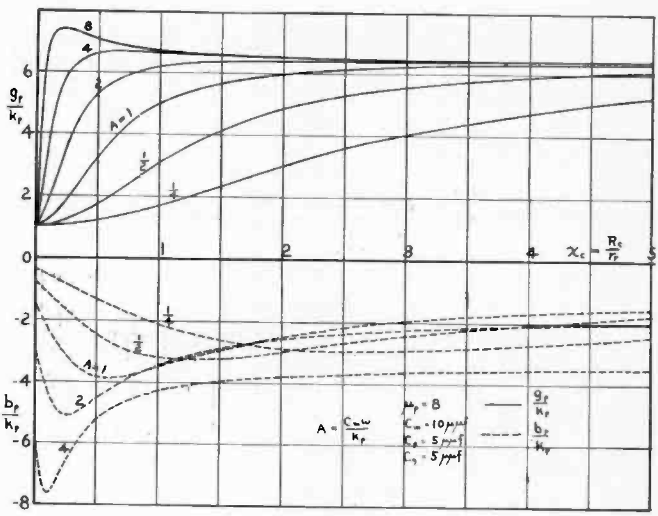

Fig. 7

Looking back into the triode from the plate load, the triode with its associate grid load of a pure resistance is equivalent to a resistance and capacity in parallel. Both resistance and reactance may be much less than r_p as shown by the curves of Fig. 7.

Case 3. Input Admittance for Reactive Plate Load, $k_g=0$.

This third case applies to an amplifier whose grid is polarized negatively and whose plate load has both resistance and reactance. Another parameter η_b is now introduced, its absolute value giving the ratio of the conductance to the susceptance of the load, or $\eta_b=G_b/|B_b|$. Equation

(41) is then reduced for this case by substituting for G_b the quantity $\eta_b|B_b|$ and putting $k_g=0$. The result is as follows:

$$
k_g=0\left\{\begin{aligned}
\frac{g_g}{k_p} &= A^2\frac{1+\dfrac{\eta_b}{|x_b'|}+\mu_p\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)}{\left(1+\dfrac{\eta_b}{|x_b'|}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)^2} && (47)\\[2ex]
\frac{b_g}{k_p} &= -A\left[1+\frac{C_g}{C_m}+\frac{\mu_p\left(1+\dfrac{\eta_b}{|x_b'|}\right)-A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)}{\left(1+\dfrac{\eta_b}{|x_b'|}\right)^2+A^2\left(1+\dfrac{C_p}{C_m}-\dfrac{1}{Ax_b'}\right)^2}\right] && (48)
\end{aligned}\right.
$$

where $y_g=g_g-jb_g$; $x_b'=k_p/B_b$ and $A=C_m\omega/k_p$. The coordinate x_b' is positive if the load is inductive and negative if the load is capacitive.

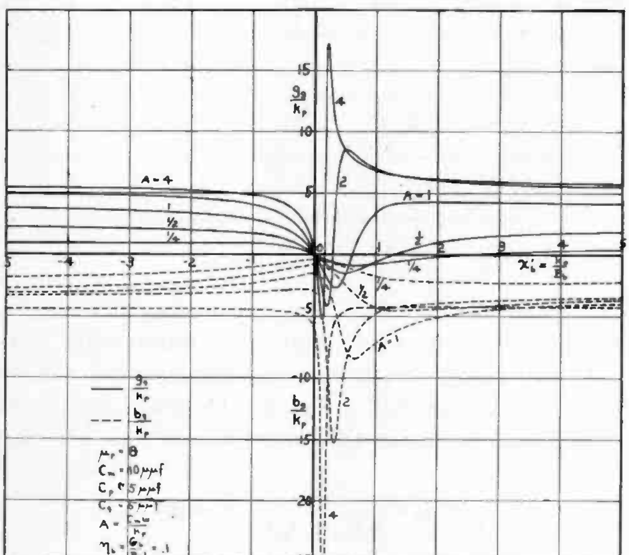

Fig. 8

In Fig. 8 expressions (47) and (48) are plotted for η_b equal to 0.1 and for several values of A. The values of μ_p, C_p, C_m, and C_g are the same as in Case 1 and correspond to those of a 201A tube.

In Fig. 9 expressions (47) and (48) are plotted for $A=1$ and for several values of η_b. The constants of the tube are as in Fig. 8.

Referring now to Figs. 8 and 9 it is seen that the susceptance of the input admittance is always capacitive no matter what may be the type of plate load. The input conductance is positive for all plate loads which have a capacitive susceptance, but the input conductance is negative for plate loads having certain ranges of inductive susceptance.

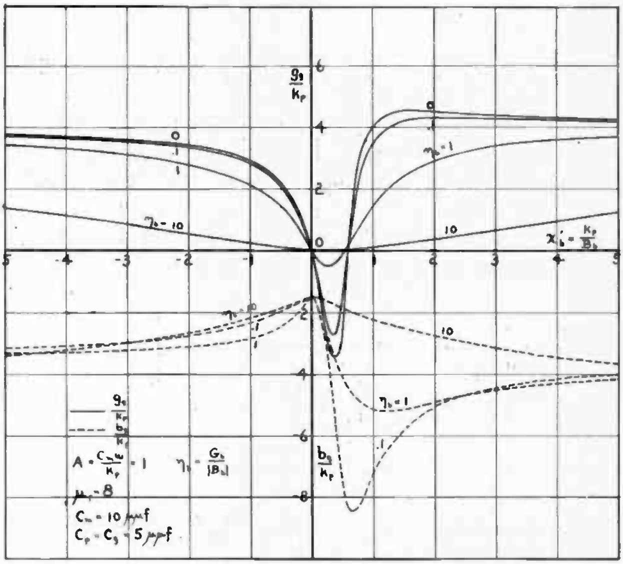

Fig. 9

The triode and its plate load may, so far as effects in Y_c are concerned, be replaced by its equivalent input admittance y_g in parallel with Y_c. It can easily be shown that the system will oscillate if $Y_c+y_g=0$ or oscillation will occur if the grid circuit contains an inductance and capacity in parallel where $R_c/(R_c^2+L_c^2\omega^2)+g_g \leqq 0$ and if

$$C_c\omega-\frac{L_c\omega}{R_c^2+L_c^2\omega^2}-b_g=0.$$

Case 4. Internal Output Admittance for Reactive Grid Circuit. $k_g=0$

This case applies to the internal output admittance of an amplifier tube whose grid is polarized negatively and whose grid circuit contains both resistance and reactance, the latter being either inductive or capacitive. As in Case 3 a new parameter $\eta_c=G_c/|B_c|$ is introduced. Formula (42) reduces to the following form:

$$
k_g = 0 \quad \left\{ \begin{aligned}
\frac{g_p}{k_p} &= 1 + A^2 \frac{\dfrac{\eta_c}{|x_c'|} + \mu_p\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)}{\left(\dfrac{\eta_c}{x_c'}\right)^2 + A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)^2} &\quad (49)\\
\frac{b_p}{k_p} &= -A\left[1 + \frac{C_p}{C_m} + \frac{\dfrac{\mu_p \eta_c}{|x_c'|} - A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)}{\left(\dfrac{\eta_c}{x_c'}\right)^2 + A^2\left(1 + \dfrac{C_g}{C_m} - \dfrac{1}{Ax_c'}\right)^2}\right] &\quad (50)
\end{aligned} \right.
$$

where $y_p = g_p - jb_p$, $x_c' = k_p/B_c$ and $A = C_m\omega/k_p$.

In Fig. 10 expressions (49) and (50) are plotted for η_c equal to 0.1 and for several values of A. The values of μ_p, C_p, C_m, and C_g are the same as in Case 1 and correspond to those of a 201A tube.

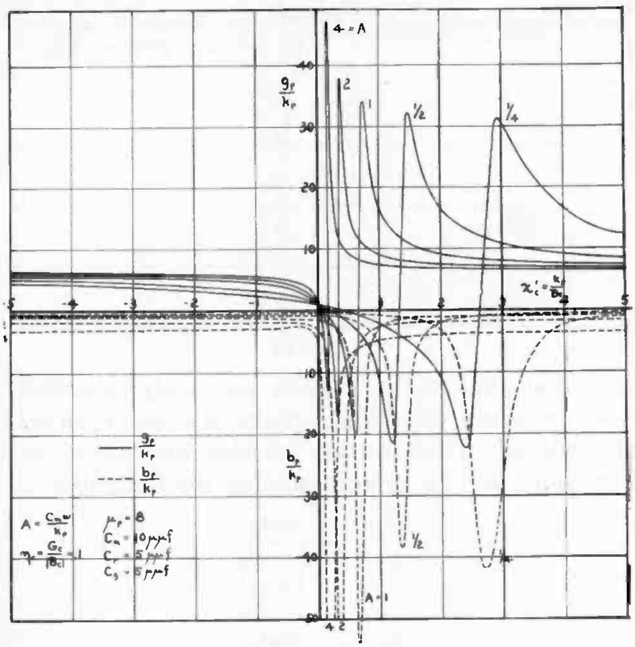

Fig. 10

In Fig. 11 expressions (49) and (50) are plotted for A equal to 1 and for several values of η_c.

The results in this case are analogous to those of Case 3 in that the equivalent output susceptance like the input susceptance is always capacitive. Further, the output conductance is positive if the grid circuit has a capacitive susceptance, but may be negative if the grid circuit is inductive. The conditions of oscillation are expressed by the relation $Y_b+y_p=0$ or $R_b/(R_b^2+L_b^2\omega^2)+g_p\leqq 0$ and

$$C_b\omega-\frac{L_b\omega}{R_b^2+L_b^2\omega^2}-b_p=0.$$

Case 5. Input and Output Admittance for $\sigma_g\neq 0$ and $\omega=0$.

In all of the first four cases the grid was assumed to be polarized negatively so that k_g was equal to zero. A detector is, however, often

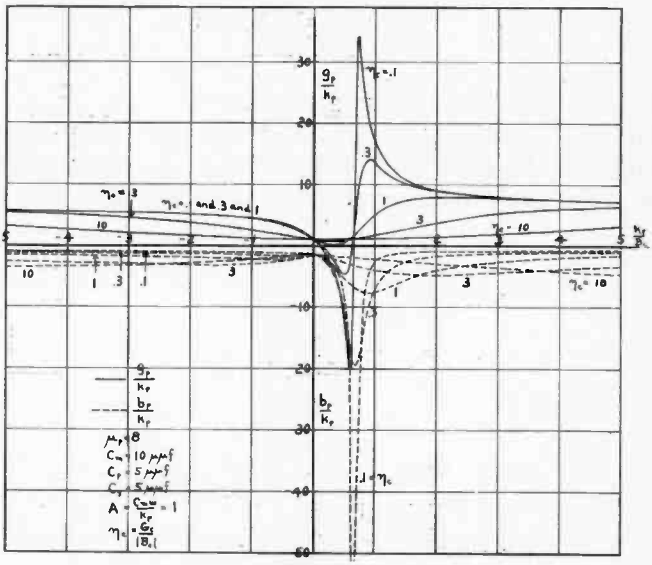

Fig. 11

operated so that the grid is slightly positively polarized. In this case k_g is not zero, and the terms containing σ_g and k_g in (41) and (42) must be considered. The formulas are then much more complicated. These expressions will be given assuming the frequency is very low.

$$\frac{g_g}{k_g}=1+\frac{\mu_p\mu_g}{1+\dfrac{G_b}{k_p}} \tag{51}$$

$$\frac{g_p}{k_p}=1+\frac{\mu_p\mu_g}{1+\dfrac{G_c}{k_g}}. \tag{52}$$

Expressions (51) and (52) show that if μ_g is positive as it usually is for a high-vacuum tube, the input and output conductances are increased as the grid is made more positive. On the other hand, μ_g may be negative if gas is present in a triode, so that the input and output conductances may be decreased and even become negative.

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AN INVESTIGATION OF THE PHENOMENA OF FREQUENCY MULTIPLICATION AS USED IN TUBE TRANSMITTERS*

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Summary—*A commonly used method is described for obtaining crystal control of high-frequency transmitters from crystals of lower frequency by means of a frequency multiplying vacuum-tube amplifier. An experimental study of the operation of the system is made when doubling and tripling the frequency of a 4000-kc crystal-controlled oscillator, and comparisons are made with the operation of the same system when balanced and amplifying the fundamental frequency.*

Relations between d-c negative grid voltage and r-f input voltage for maximum efficiency are shown to be critical and nearly constant for any one order of multiplication. Satisfactory operation of the system is shown to depend upon inductive reactance in the grid circuit, which produces regeneration through the grid-plate feed back in the tube.

The study is based on circuit efficiencies as measured by the contact pyrometer method.

It is known that a self oscillating vacuum-tube circuit does not maintain a constant frequency over a period of time. The use of oscillating quartz crystals for stabilizing the frequency of transmitters is common practice. Crystal control is useful in the intermediate frequency band from 300 to 10,000 kc for preventing interference between stations operating on adjacent frequencies. It is imperative in the high frequencies from 10,000 to 30,000 kc for keeping the beat note in receivers from changing beyond the limits of audibility due to small variations in transmitter frequency. The following example illustrates this point:

In receiving continuous wave signals with an oscillating detector, a change in beat note of 100 cycles occurs with a variation of 0.2 per cent in the frequency of a transmitter operating on 500 kc. If the transmitter were operating on 25,000 kc a variation of only 0.004 per cent in the transmitted frequency would produce the same change in the received beat note. It is therefore evident that the practical value of high-frequency transmitters rests in the possibility of maintaining their frequencies at extremely constant values.

The use of piezo-electric crystals for frequency stabilization has certain limitations. Inasmuch as the frequency of a crystal of a given nature is roughly determined by the physical dimensions of that crystal, there is obviously a limit to the frequencies which can be pro-

* Dewey decimal classification: R344.3. Original manuscript received by the Institute, April 15, 1929.

duced by this means. As a large crystal gives a lower frequency than a small crystal of the same nature, the lower frequency limit is fixed by the maximum size obtainable in such crystals. On the other hand, when a crystal is ground small for high frequencies it becomes fragile and, in the limit, breaks under the strain of oscillation. The maximum practical range for power crystals is about 25 to 6,000 kc. This range is far below the high frequencies where crystal control is almost indispensable.

For obtaining crystal control of high-frequency transmitters an ingenious frequency multiplying system was developed several years ago at the Naval Research Laboratory.[1] The system consists of a crystal-controlled vacuum-tube circuit oscillating on the crystal frequency, and a non-oscillating power amplifier tuned to a small integral multiple of the crystal frequency. The oscillatory current in the output circuit is on the higher frequency, to which it is tuned. This frequency multiplying amplifier is operated with a very high d-c blocking voltage on the grid and a correspondingly high radio-frequency voltage excitation from the oscillator. The output is nearly 100 per cent on the multiple frequency which is positively controlled by the crystal oscillator.

Shortly after this system was adopted a theoretical analysis of its operation was undertaken.[2] In this analysis the order of multiplication was expressed as a function of the period of time of plate current flow in terms of the period of the input voltage. The assumption was made that plate current would flow only during the positive half of one cycle of output current for each cycle of input voltage. If the period of input voltage be taken as unity, the period of flow of plate current would be one-fourth for doubling, one-sixth for tripling, etc. During the remaining three-fourths or five-sixths of the time the oscillatory current in the output circuit must maintain itself solely by its own inertia. The condition is illustrated in Fig. 1.

It has also been believed that the feed-back through the grid-plate capacity of the tube from the output to the input circuits must always have a damping effect on the input voltage and so limit the output and efficiency of the amplifier to low values. With this in mind a screened grid tube, which has a very low effective grid-plate capacity, was used in place of the three-electrode tube previously used. A reduction in both output and efficiency was the surprising result.

[1] Developed and patented by A. Hoyt Taylor and L. C. Young.

[2] Report filed at Naval Research Laboratory by Edwin L. White, now with the Army at Fort Shaster, Hawaii.

An investigation has recently been made to study the operation of this circuit and offer some explanation of the noted phenomena. A quarter kw transmitter was built for the purpose, with a 100-watt push-pull master oscillator crystal controlled in the 4000-kc band, and a frequency multiplying amplifier utilizing a single 250-watt tube.

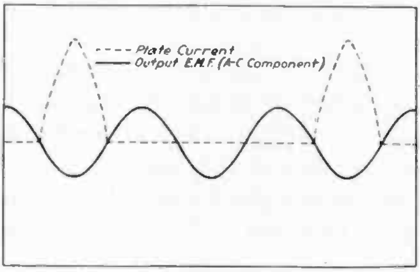

Fig. 1

Both circuits were tuned plate parallel feed, with capacitive coupling between oscillator output and amplifier input. The circuit diagram is shown in Fig. 2.

The efficiency and output of the amplifier was measured by the surface pyrometer method, in which the power dissipated in the tube is ascertained by the temperature of the glass wall of the tube.[3]

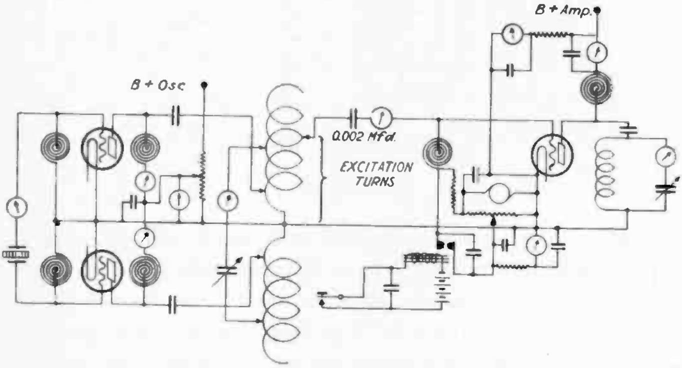

Fig. 2

The radio-frequency input voltage to the amplifier, hereafter referred to as the excitation voltage, was measured by using the amplifier temporarily as a blocked-grid vacuum-tube voltmeter. This method gives positive peak values when no load is being taken from the oscillator. When power is taken from the oscillator to operate the ampli-

[3] A. Crossley and R. M. Page, "A New Method for Determining the Efficiency of Vacuum-Tube Circuits," Proc. I. R. E., 16, 1375; October, 1928.

fier, the output voltage of the oscillator is reduced. Some means was therefore necessary for maintaining a constant excitation voltage while other factors in the amplifier were varied. An attempt was made to accomplish this by adjusting the d-c plate voltage on the oscillator tubes to keep a constant r-f current in the oscillator tank circuit. Under this condition, constant effective voltage excitation was assumed.

The d-c plate voltage on the amplifier was kept constant at all times. Output was varied by adjusting negative bias on the grid or by changing excitation voltage. The following paragraphs give a resumé of the findings made in this study.

It was found that for any given excitation voltage there is a fairly critical adjustment of negative "C" voltage for maximum efficiency

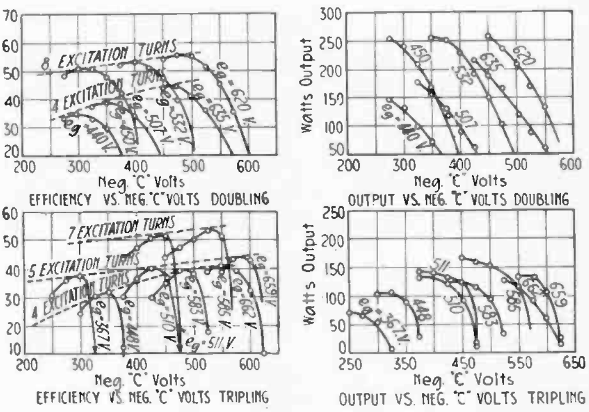

Fig. 3

and another critical adjustment for maximum output. As the order of multiplication is increased, these adjustments become more critical and the points of maximum efficiency and maximum output more nearly coincide. The curves of Fig. 3 illustrate these points. It will be noted also that higher efficiency as well as greater output is obtained for higher values of excitation voltage.

Fig. 4 shows graphically the relation between negative "C" voltage and excitation voltage at maximum efficiency. One horizontal line is obtained from each curve of Fig. 3. The line AB is an arbitrary reference line. The point C indicates the grid biasing voltage at the point of maximum efficiency for the excitation voltage represented by the length of the line CD. The d-c plate-current grid-voltage characteristic of the quarter kw tube used is dotted in to give an idea of proportions. Even ignoring the fact that the dynamic blocking voltage is considerably greater than that shown in the static characteristic, it is at once evident that Fig. 1 is not a true representation of the conditions shown in Fig. 4, for plate current obviously is flowing for longer periods of time than one-half of one cycle of output voltage. The condition may be more nearly approximated in the curves of Fig. 5, and suggests the possibility of regenerative feed-back in the amplifier.

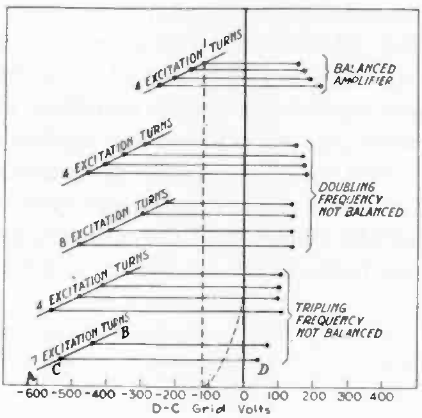

Fig. 4

A study of the connections of the circuit (Fig. 2) will show that with a very small number of excitation turns the reactance of the grid circuit of the amplifier to the output frequency will be inductive, inasmuch as the inductance of these turns is in parallel with the small grid-ground capacity with respect to the feed-back e.m.f.

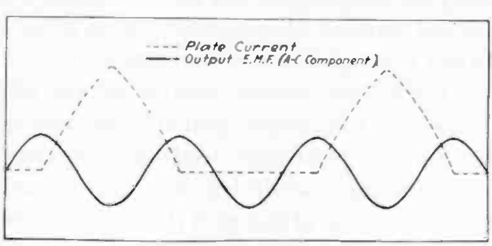

Fig. 5

This is the condition for regeneration in the amplifier. With very few excitation turns the reactance is relatively small and the regeneration slight. If turns are increased, reactance and regeneration will increase until the amplifier goes into self oscillation and the crystal control is lost. The presence of such regeneration would account for the increased plate current noted.

If this interpretation is correct, increasing the excitation turns should greatly increase the efficiency and output of the amplifier, and the change should produce a noticeable increase in grid current. The curves of Fig. 3 show decidedly higher efficiencies and outputs with increased excitation turns. Accompanying these higher values a radio-frequency current in the amplifier grid circuit of two and three amperes was noted instead of one-tenth to five-tenths ampere as observed with few excitation turns. This verification seems to indicate beyond all doubt that practical frequency multiplication in this type of circuit depends largely upon regeneration in the amplifier. This regeneration is obtained for the most part through internal feed-back capacity of the tube and can be varied by changing the grid-circuit reactance. By proper adjustment of this reactance the efficiency of the multiplier can be made to approach the efficiency of the ordinary balanced amplifier. It will be noted from Table I that an efficiency of 70 per cent was obtained for tripling frequency as compared to 75 per cent for singling.

TABLE I

Frequency	Input	Plate Dissipation	Output	Efficiency
4000 kc	326 watts	81 watts	245 watts	75 per cent
(Singling)	412 "	121 "	291 "	71 "
8000 kc	433 "	154 "	279 "	64.5 "
(Doubling)	570 "	206 "	364 "	63.8 "
12000 kc	256 "	76 "	180 "	70.4 "
(Tripling)	507 "	267 "	240 "	42.3 "

The same efficiency for doubling could not be obtained by the method used, for the required number of excitation turns is too great for sufficient energy transfer from the master oscillator.

In the light of these conclusions, reasons for the inferiority of the screened grid tube for frequency multiplying are obvious. The extremely small effective plate-grid feed-back capacity reduces the regeneration to a minimum, while the low grid-ground capacity reduces the inductive reactance of the grid circuit. Values obtained with the quarter-kw screened-grid tube type AT671 are given in Table II. Operation of the circuit with this type of tube can be considerably improved by increasing the excitation turns and adding a small capacity between plate and grid. At best, however, it can only approach the conditions of the triode, and always with lower efficiency due to shield dissipation.

When this type of circuit is used in high power transmitters the problem of self oscillation becomes more serious, due to stray coupling between amplifier stages. A reduction in excitation turns accomplishes the double purpose of reducing grid-circuit reactance to prevent self oscillation, and diminishing the reaction of the amplifier back on the crystal oscillator. This does not necessarily mean a sacrifice of regeneration since the stray feed-back may be considerable, but in practice regeneration and efficiency are sacrificed in the interests of stability.

Although high efficiencies were obtained in the amplifier when tripling, the output was less than that obtained when doubling or singling. In order to obtain more output at high efficiency on triple frequency the power of the oscillator must be increased, since in tripling only a small part of this power is useful in driving the amplifier.

TABLE II

Frequency	Input	Plate and Shield Dissipation	Output	Efficiency
4000 kc	574 watts	193 watts	381 watts	66.5 per cent
(Singling)	662 "	245 "	417 "	63. "
8000 kc (Doubling)	539 "	303 "	236 "	44. "
12000 kc (Tripling)	370 "	210 "	160 "	44. "

When singling, the whole output of the oscillator is effective on the amplifier grid. In doubling frequency only about half the output is effective, since the amplifier is blocked during the negative half of every cycle. The output of the oscillator must therefore be practically doubled to get the same effective power delivered to the amplifier grid. For higher orders of multiplication the effective portion of the oscillator output is correspondingly less, so that more output from the oscillator is necessary to produce the same output from the amplifier. The resulting inefficient use of the oscillator output at higher orders places a practical limit on multiplication per stage at about three. Where higher frequencies are desired the system can be extended into two or more multiplying stages.

This work was undertaken under the supervision of A. Crossley, formerly of the Naval Research Laboratory, now of the Steinite Radio Corporation. The writer wishes to acknowledge with thanks the assistance of J. Warren Wright.

Books Received

Elements of Radio Communication, by John H. Morecroft, professor of electrical engineering, Columbia University. Published by John Wiley and Sons, Inc., 1929. 270 pages, illustrated, 6×9 inches, cloth binding. Price, $3.00 Contents: simple laws of the electric circuit; special laws for radio circuits; general idea of radio communication; the vacuum tube and its uses; radio telegraphy; radio telephony; receiving sets; problems.

Introduction to Theoretical Physics, by Leigh Page, Ph.D., professor of mathematical physics, Yale University. Published by D. Van Nostrand Company, Inc.,1928. 587 pages, illustrated. 6×9 inches, buckram binding. Price $6.50. Contents: vector analysis; dynamics of particles; dynamics of rigid bodies; dynamics of deformable bodies; advanced dynamics; hydrodynamics of perfect fluids; hydrodynamics of viscous fluids; classical thermodynamics; statistical mechanics; kinetic theory of gases; electrostatics and magnetostatics; electric currents; electromagnetic theory; geometrical optics; physical optics; origin of spectra.

Radio Manual, 1928 edition revised by Commander F. W. Rockwell, Lieutenant C. W. Brewington, and Professor G. D. Robinson all of the department of electrical engineering and physics, U.S. Naval Academy. Published by U.S. Naval Academy. 176 pages, 7¾×10½ inches, cloth binding. Price $3.50. Contents: wave motion; resistance, inductance, capacity and resonance; simple oscillating circuit; use of simple frequency meter; apparatus for damped wave transmission; transmission of continuous waves; radiation of waves; receiving apparatus; vacuum tube as a detector; vacuum tube as an amplifier; screen-grid tube; regeneration, feed-back; multistate amplification; three-element vacuum tube as transmitter; radio telephone transmitter; antennas; coil antennas; beam transmission; interference and selectivity; naval radio apparatus; standard symbols and definitions (I.R.E.).

Radio—A Study of First Principles, by Elmer E. Burns, Instructor in Physics, Austin High School, Chicago, Ill. Published by D. Van Nostrand Company, Inc., 255 pages, illustrated. Price, $2.00. Contents: simple receiving circuits; electric batteries; magnetic action of an electric current; electric circuits and Ohm's law; electron tubes; alternating currents; detectors and amplifiers; fundamentals of receiving circuits; oscillating and transmitting circuits; radio measurements; appendix.

Storage Batteries—Theory, Manufacture, Care and Application, by Morton Arendt, assistant professor of electrical engineering, Columbia University. Published by D. Van Nostrand Company, Inc., 1928. 285 pages, illustrated. Cloth binding. Price, $4.50. Contents: introduction and history; general theory of the storage battery; lead plates and their manufacture; sulphuric acid electrolyte; factors influencing capacity and efficiency; lead storage cell parts and assembly; installation, operation and maintenance; the nickel-iron-alkaline cell; storage battery testing; storage battery applications.

Practical Television, by E. T. Larner, engineering department, General Post Office, London. Published by D. Van Nostrand Company, Inc., 1928. 175 pages, 5¼×8½, illustrated, cloth binding. Price, $3.75. Contents: introduction; history; selenium and the selenium cell; continental and American researches; researches with the cathode-rays; images and their formation; the Baird televisor; television technique; recent developments; 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 various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R100 Duncan, R. L. and Drew, C. E. Radio telegraphy and telephony (book). Publisher: J. Wiley and Sons, New York, N. Y. 1929.

(A textbook for students of radio.)

R113 Nakai, T. On the difference of East to West and West to East transmission phenomena at sunrise and sunset. Researches Electrotechnical Lab., Tokyo, #241; November, 1928. Original in Japanese. Abstract in *Experimental Wireless and W. Engr.* (London), 6, p. 323; June, 1929.

(From theoretical considerations based on ultra-violet radiation from sun, it was concluded that the ionized layer goes down much more rapidly after sunrise than it rises after sunset. Therefore little difference between sunrise and sunset effects should be found in East-West radio transmissions while sunrise effects should be much larger than sunset effects for West-East transmission. Data is cited in confirmation of this reasoning.)

R113.1 Parkinson, T. Some observations of short period radio fading. Proc. I. R. E., 17, pp. 1042–1061; June, 1929.

(Causes of fading are investigated by means of graphic fading records made simultaneously with different types of receiving antennas. Evidences are found of fading due to interference; to direction shifts; to rotation of plane of polarization and to varying intensity of indirect rays; to multiple rays.)

R113.2 de Wardt, R. G. Variations in signal strength from Australia. *Post Office Elec. Engrs. Jnl.* (London), 22, pp. 52–58; April, 1929.

(Data from systematic records of 11,660-kc transmissions from Australia as received in England are presented in graphic form. Average diurnal and seasonal variations of signal strength are shown for the twelve months of the year. Daylight-darkness effects on different portions of two transmission paths are noted.)

R113.4 Mirick, C. B. and Hentschel, E. R. A new method of determining height of the Kennelly-Heaviside layer. Proc. I. R. E., 17, pp. 1034–1041; June, 1929.

(Periodic variations of fairly constant frequency over a considerable time interval are shown in graphic records of radio signals transmitted from a high-frequency aircraft transmitter. From geometric considerations of this frequency, the ground speed of the plane, and the transmitting distance, the effective height of the layer is computed.)

R113.5 Maurain, Ch. Sur l'origine de certains parasites. (On the origin of certain atmospherics) *L'Onde Electrique*, **8**, pp. 131–134; April, 1929.

(The value of making observations of the connection between radio disturbances, electromagnetic phenomena, and meteorological conditions as a study of the relations between the meteorological and electrical properties of the atmosphere. is stressed.)

R113.5 Bureau, R. Sur l'origine de certains parasites. (On the origin of certain atmospherics) *L'Onde Electrique*, **8**, pp. 135–142; April, 1929.

(Arguments in favor of a meteorological origin of night atmospherics are summarized. The theory is offered that atmospherics of the afternoon are the effect of a strong meteorological situation and not of the storm itself.)

R113.5 Maurain, Ch. Sur l'orage magnetique du 7 au 8 Juillet, 1928 et les phenomenes connexes. (On the magnetic storm of July 7–8, 1928 and connected phenomena). *L'Onde Electrique*, **8**, pp. 170–172; April, 1929.

(Reports concerning sunspots, radio transmission and aurora displays attending the magnetic storm of July 7–8, 1928 are summarized.)

R131 Average characteristics of amplifier tubes with a.c. filament supply. *Radio* (San Francisco), **11**, p. 46; July, 1929.

(Data on tubes.)

R132 Brainard, J. C. Mathematical theory of the four-electrode tube. Proc. I. R. E., **17**, pp. 1006–1020; June, 1929.

(The mathematics of the four-electrode tube including in the most general case expressions for the plate and two grid currents in terms of the applied voltages in the two-grid circuits and the impedances of all three circuits, are given. To avoid complexity the general expression is reduced to illustrative specific cases.)

R132 Aughtie, F. Push-pull amplification—The use of resistance-capacity coupling. *Experimental Wireless and W. Engr.* (London), **6**, pp. 307–309; June, 1929.

(A circuit is described in which use is made of the phase reversal of a simple resistance-capacity coupled stage to feed the grid of the second tube of the output pair of a push-pull amplifier. A transformer is therefore not needed and adjustment for maximum power output is simple.)

R134 Reed, M. The problem of turn-over. *Experimental W. and Wireless Engr.* (London), **6**, pp. 310–315; June, 1929.

(A mathematical explanation of the difference in output currents from a rectifier with the same a.c. input but with connections reversed is given. Conditions for a minimum difference are summarized and the application of the results to the design of vacuum-tube voltmeters is pointed out.)

R150 Beauvais, G. A. Sur les ondes de 10 a 20 centimetres. (On waves of 10 to 20 centimeters). *Bull. de la Soc. Française des Electriciens*, **9**, pp. 503–510; May, 1929.

(Production of very high frequencies by means of a circuit arrangement by Pierret is given, with difficulties encountered in the generation of such frequencies. Application of these frequencies to radiotelephony and radiotelegraphy is discussed.)

R190 Carson, J. R. Reciprocal theorem in radio communication. Proc. I.R.E. **17**, pp. 952–956; June, 1929.

(An analysis of Rayleigh's reciprocity theorem and the Sommerfeld-Phrang reciprocity theorem shows them to be distinct in their practical field of application. The latter theorem is shown to have restrictions seriously limiting its field of applicability.)

R190 Pelabon, H. Application dela theorie electronique aux mauvais contacts. (Application of electron theory to bad contacts). *L'Onde Electrique*, **8**, pp. 160–170; Apr., 1929.

(With the help of the electron theory the expressions for the intensity of a direct current and of an alternating current in a circuit containing an imperfect contact are deduced. Rectification by a contact between identical metals in which one electrode is movable is explained. A study of effects of electromagnetic impulses shows the phenomena of coherence with an imperfect contact to be due to the displacement of the electrodes. An idea on Branley's negative coherence in PbO_2 is given.)

R200. Radio Measurements and Standardization

R220 Bligh, N. R. Measurements of the grid-anode capacity of screen-grid valves. *Exp. Wireless and W. Engr.* (London), **6**, pp. 299–300; June, 1929.

(Measurements of the grid-anode capacities of the screen-grid tubes of the S625 and S215 type give an average for the former of 0.022 $\mu\mu f$ and for the latter of 0.014 $\mu\mu f$.)

R220 Loughren, A. V. and Parker, H. W. The measurement of direct inter-electrode capacitance of vacuum tubes. Proc. I. R. E., **17**, pp. 957–65; June, 1929.

(A method of measuring direct capacitance in the range of 10^{-10} to 10^{-15} farads by a charging current at radio frequencies is described. The circuit is arranged to provide apparatus giving results measured visually by the substitution of a standard.)

R270 Hollingworth, J. and Naismith, R. A portable radio intensity measuring apparatus for high frequencies. *Exp. Wireless and Wireless Engr.* (London), **6**, pp. 316–318; June, 1929.

(Circuit for apparatus to measure radio field intensities in the range 12000 to 4547 kc (25–66 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.)

R300. Radio Apparatus and Equipment

R325.1 A new direction finder for naval vessels. *Jnl. Scientific Instruments* (London), **6**, pp. 201–202; June, 1929.

(Type D.F.M.4 direction finder developed by Research Dept. of Marconi Co. for use on naval vessels. Set is used for taking bearings on CW, ICW, spark or phone stations and has a frequency range of 75–1000 kc (300–4000 meters)).

R330.4 Hodgson, B., Harley, L. S., and Pratt, O. S. The development of the oxide-coated filament. *Jnl. I. E. E.* (London), **67**, p. 762; June, 1929.

(Reviews development of oxide-coated filament. Describes in rough outline present day methods of manufacture for commercial purposes and indicates most recent views on mechanism of electron emission from alkaline earth oxides.)

R341 Gas-filled rectifying valves. *Experimental Wireless and W. Engr.* (London), **6**, pp. 291–292; June, 1929.

(The tubes developed by A. W. Hull of the General Elec. Co. for the rectification of large alternating currents are described and an explanation of the thermionics involved is given.)

R342 Engel, F. H. Engineering features of the UX-245. *Radio Broadcast*, **15**, pp. 167–168; July, 1929.

(Characteristics of tube as power amplifier.)

R342.15 Radio-frequency transformers as applied to screen-grid valves. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 293–298; June, 1929.

(Under simplified assumptions expressions giving (1) the overall voltage amplification, and (2) the conditions for stability, are derived for a screen-grid tube between a tuned circuit and a r-f transformer with its secondary tuned. If the primary turns of the transformers are reduced to give the requisite stability, results comparable with those from a neutralized triode may be obtained from a good commercial screen-grid tube without the complications of a neutralized circuit.)

R342.5 Spitzer, E. E. Grid losses in power amplifiers. Proc. I. R. E., **17**, pp. 985–1005; June, 1929.

(The experimental results of a study of the driving power of a power-amplifier at 60 cycles are presented. The power input to the grid is shown to be proportional to the d-c grid current raised to the 1.34th power and to be practically independent of grid bias voltage if grid current is kept constant. The study extends to six types of commercial air-cooled transmitting tubes. Effects of primary and secondary electron emission by the grid on the driving power are considered.)

R343 Colebrook, F. M. A selective 8-valve receiver for medium and long wave telegraphy. *Jnl. Scientific Instruments* (London), 6, pp. 177–183; June, 1929.

(A receiving set which was designed for the Meteorology Department of the National Physical Laboratory, London, for recording of time signals on frequencies of 200 to 15 kc is described. The principal requirements were met in this set and were: (a) comparative ease of manipulation; (b) sufficient sensitivity and selectivity for the signal operation of a relay for recording purposes.)

R500. Applications of Radio

R520 Dellinger, J. H. and Diamond, H. Radio developments applied to aircraft. *Mechanical Engineering*, 51, pp. 509–514; July, 1929.

(Description of work done by Bureau of Standards on development of a radio-beacon system which serves eight courses.)

R522 Freeman, R. H. Radiotelephony aloft. *Radio* (San Francisco), 11, pp. 39–41; July, 1929.

(Description of work done by the Boeing Air Transport Inc. on successful plane-to-plane and plane-to-ground communication system.)

R526.1 Etudes des radiophares par le "Bureau des Standards." (Study on radio-beacons by Bureau of Standards). *L'Onde Electrique*, 8, pp. 143–159; April, 1929.

(A summary of the work on radio beacons for aircraft carried on at the Bureau of Standards up to November 6, 1928.)

R550 Eckersley, P. P. and Howe, A. B. The operation of several broadcast stations on the same wavelength. *Jnl.* I. E. E. (London), 67, pp. 772–789; June, 1929.

(Consideration is given to the advantages to be derived from operation of several broadcasting stations on one wavelength and to means whereby such operation may be attained. A brief outline is given of theory of production of distortion of various types inherent to single wavelength operation. A theory is elaborated to account, quantitatively, for amount of interference from a distant station likely to be experienced when listening to a local station operating on the same wavelength. Conditions under which distortion introduced by such interference becomes negligible are determined, together with approximate service range of individual single-wave stations.)

R582 Mesny, R. Phototelegraphie d'amateur. (Amateur phototelegraphy). *Bull. de la Soc. Française des Electriciens*, 9, pp. 511–524; May, 1929.

(Description of Belin system of phototelegraphy.)

R582 Ranger, R. H. Photoradio developments. Proc. I. R. E., 17, pp. 966–984; June, 1929.

(A description of recent developments in photoradio apparatus is offered. Among them are: (1) a push-pull relay making possible increased speeds in transmission; (2) a reverse lead-screw for giving continuous operation of the analyzing head; (3) an air speed control eliminating certain local electrical disturbances, and (4) a hot-air recorder for use with heat sensitive paper.)

R800. Non-radio Subjects

510 Ballantine, S. Reciprocity in electromagnetic, mechanical, acoustical, and interconnected systems. Proc. I. R. E., 17, pp. 929–951; June, 1929.

(New proof under more general assumptions than those of previous treatments, of the extension of Rayleigh's reciprocity theorem to an electromagnetic system is offered. The consideration of reciprocity is carried further into mechanical, acoustical, and interconnected systems. The concept of a transduction coefficient for use in treating interconnected systems is introduced.)

CONTRIBUTORS TO THIS ISSUE

Anderson, Clifford N.: Born September 22, 1895 at Scandinavia, Wis. Graduated from Wisconsin State Normal School, 1913. From 1913 to 1917, Supervising Principal of Schools, Amery, Wis. Served as ensign, U.S.N.R.F. in aviation section during World War. Received Ph. B. degree, University of Wisconsin, 1919, and M.S. degree, 1920. Instructor in engineering physics, University of Wisconsin, 1919–1920; with General Eectric Co., Lynn, Mass., 1920–1921; Fellow, American Scandinavian Foundation to Norway, 1921–1922; with Department of Development and Research, American Telephone and Telegraph Co., doing work in connection with transatlantic radio telephony, 1922 to date. Associate member, Institute of Radio Engineers, 1919.

Breit, G.: Born July 14, 1899 in Russia. Radio Section, Bureau of Standards, 1918–1919, 1920–1921. Received Ph. D. degree, Johns Hopkins University, 1921; national research fellow, Leiden and Harvard Universities, 1921–1923; assistant professor, University of Minnesota, 1923–1924; mathematical physicist, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1924 to date. Junior member, Institute of Radio Engineers, 1919; Associate, 1922.

Chaffee, E. L.: Born April 15, 1885 at Somerville, Mass. Received B.S. degree, Massachusetts Institute of Technology, 1907; A.M. degree, 1908; Ph.D. degree, Harvard Graduate School, 1911. Instructor, Harvard College, 1908–1917; assistant professor, 1917–1923; associate professor, 1923 to date. Engineer for John Hays Hammond, Inc., 1913. Secured several patents on methods of radio signaling and apparatus. Member, Franklin Institute and American Optical Society; Member, Institute of Radio Engineers, 1917; Fellow, 1921.

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Goldsmith, Alfred N.: Born September 15, 1887 in New York City. Received B.S. degree, College of the City of New York, 1907; Ph.D. degree, Columbia University, 1911. Associate professor and professor, College of the City of New York for a number of years; consulting radio engineer for U.S. Department of Commerce, Atlantic Communication Company, and General Electric Company; director of research, Marconi Wireless Telegraph Company of America. Appointed director of research upon formation of the Radio Corporation of America; chief broadcast engineer, R.C.A., 1923; vice president, R.C.A. Photophone, Inc., April, 1928; vice president and general engineer, R.C.A., January, 1929. Member, Institute of Radio Engineers, 1912; Fellow, 1915.

Hafstad, L. R.: Born June 18, 1904 at Minneapolis, Minn. With Northwestern Bell Telephone Company, 1920–1927. Received B.S. in E.E. degree, University of Minnesota, 1926. Graduate student in physics, University of Minnesota, 1926–1928; assistant physicist, Department of Terrestrial Magnetism, Carnegie Institution of Washington, 1928 to date. Associate member, Institute of Radio Engineers, 1928.

Hooper, S.C.: Associated with radio work of the Navy since its inception. Served as fleet radio officer and head of radio division of the Bureau of Engineering, Navy Department. During Arms Conference in Washington served on advisory committee; also technical advisor to the American delegation of the International Radiotelegraph Conference in Washington, 1927. At present director of naval communications and technical advisor to the Federal Radio Commission. Associate member, Institute of Radio Engineers, 1913; Member, 1915; Fellow, 1917.

Horton, J.W.: Received B.S. degree in electrochemistry, Massachusetts Institute of Technology, 1914; Instructor, M.I.T., 1914–1916. Member, technical staff, Bell Telephone Laboratories (Western Electric Co.), 1916–1928. On leave of absence from Western Electric Co. as technical expert with the U.S. Navy at experimental station in this country and at Naval Headquarters in London, engaged in work relating to submarine detection. Chief engineer, General Radio Co., 1928 to date. Associate member, Institute of Radio Engineers, 1920.

Hulburt, E. O.: See PROCEEDINGS for March, 1929.

Jenkins, C. Francis: Born 1868 near Dayton, Ohio. Attended Earlham College. Secretary to Sumner I. Kimball, U.S. Life Saving Service, Washington, D.C., 1890–1895. Built prototype of motion picture projector; developed spiral-wound paraffined all-paper container; produced first photographs by radio, mechanism for viewing distant scenes by radio, and radiomovies for home entertainment. Secured numerous patents, foreign and domestic. Maintains private laboratory in Washington, D.C. Member of the Franklin Institute, American Association for the Advancement of Science, National Aeronautic Association, founder of the Society of Motion Picture Engineers, Associate member, Institute of Radio Engineer, 1928.

Page, Robert M.: Born June 2, 1903 at St. Paul, Minn. Received B.S. degree in physics, Hamline University, St. Paul, Minn., 1927. Engaged in radio research and precision measurements, U.S. Naval Research Labroatory, 1927 to date. Associate member, Institute of Radio Engineers, 1927.

Ranger, R. H.: See PROCEEDINGS for June, 1929.

Rockwood, Warren Robert: Received B.S. degree, Rose Polytechnic Institute, Terre Haute, Ind., 1927. Student engineer, General Electric Co., 1927–1928; research laboratory, 1928 to date.

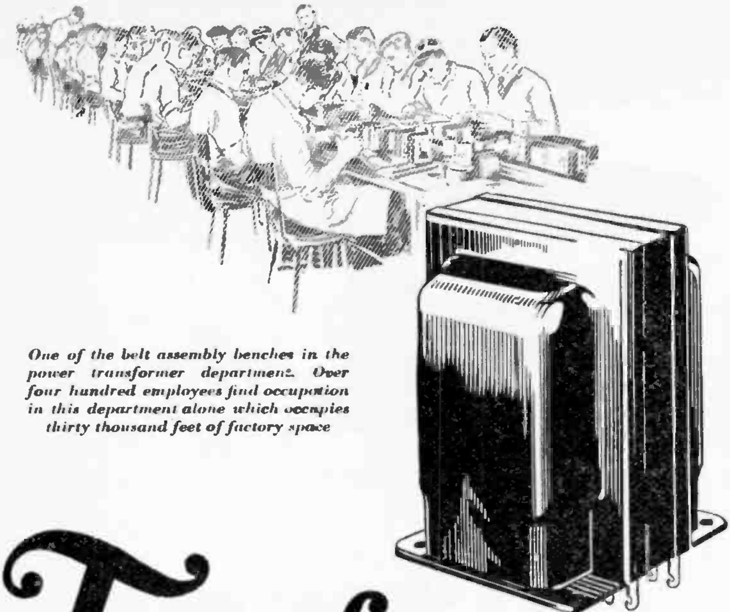
Rodwin, George: Born September 4, 1903 in New York City. Received A.B. degree, Columbia University, 1923; E.E. degree, 1925. With Radio Corporation of America doing research work in connection with fading recorder equipment, standard receiver test methods, receiver development and general broadcast station equipment, 1925 to date. Associate member, Institute of Radio Engineers, 1925.

Smith, Theodore A.: Born February 17, 1905 at Brooklyn, N.Y. Received M.E. degree, Stevens Institute of Technology, 1925. With Radio Corporation of America engaged in work on fading recording, short-wave reception, field intensity measurements, and miscellaneous work on broadcast station engineering, 1925 to date. Junior member, Institute of Radio Engineers, 1925; Associate, 1926.

Taylor, A. Hoyt: Born January 1, 1879 at Chicago, Ill. Received B.S. degree, Northwestern University; instructor, Michigan State College, 1900; instructor, University of Wisconsin, 1903. Received Ph.D. degree, University of Göttingen, Germany, 1908. Professor and head of physics department, University of South Dakota, until 1917. Lieutenant, Naval Reserve, 1917; lieutenant commander, 1918; in charge of aircraft radio laboratory, Washington, D.C., 1919; promoted to Commander, remaining in active service until 1922. Upon organization of the Naval Research Laboratory was made superintendent of its radio division. In 1927 awarded the Morris Liebmann Memorial Prize by the Institute. Member, Institute of Radio Engineers, 1916; Fellow, 1920.

Weinberger, Julius: Born July 22, 1893 in New York City. Received B.S. degree, College of the City of New York, 1913. Public Service Commission of New York, 1913–1914; radio laboratory, Bureau of Standards, 1914–1916; research assistant to Dr. A. N. Goldsmith, 1916–1917; research department, Marconi Wireless Telegraph Company of America, 1917–1919; Radio Corporation of America, 1919 to date. At present engineer in charge, research department, Radio Corporation of America. Associate member, Institute of Radio Engineers, 1913; Fellow, 1925.

Young, L.C.: Born January 12, 1891 at Danville, Ill. Amateur experimental work, 1909–1917. Telephone and Telegraph Dept., Western Division of Pennsylvania Railroad, 1912–1917. Experimental radio work, 1917–1919, under Lt. Comdr. A. H. Taylor. Aircraft radio section, Bureau of Standards, 1919; research work, radio section, Naval Research Laboratory, 1919 to date. Associate member, Institute of Radio Engineers, 1919; Member, 1929.



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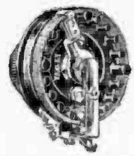

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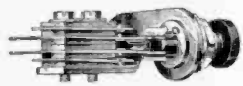

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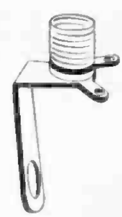

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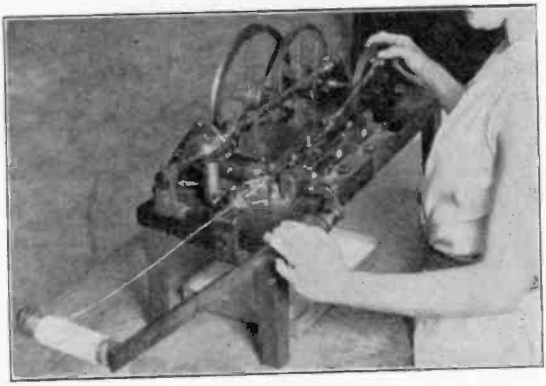

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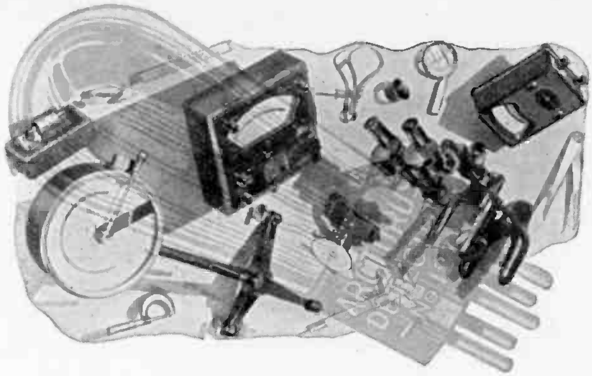

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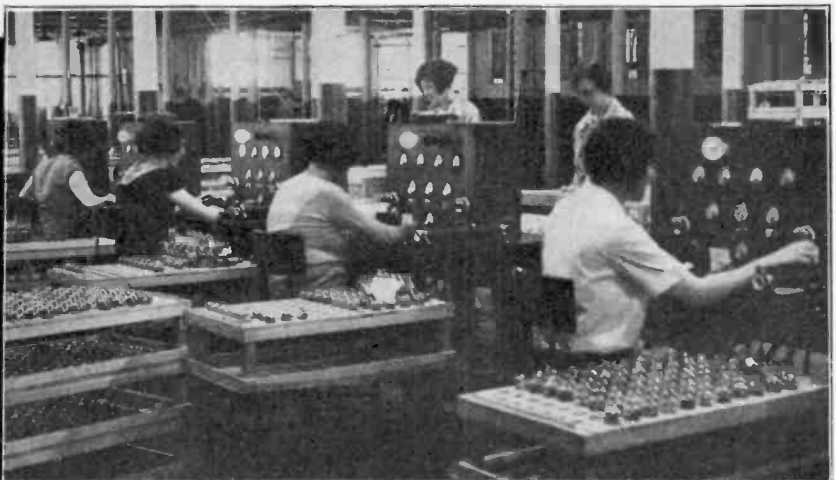

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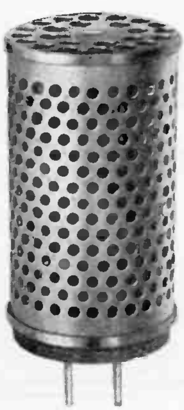
Mr. Radio Engineer: Alibis are bad things to fall back on. Your engineering skill is judged by just one standard: the ultimate public acceptance of your products. Therefore, don't take a chance on line voltage. When you include the line ballast in your assembly, you are removing the last *variable* in the socket-power radio set. At least provide a socket for the line ballast cartridge, and be sure that your descriptive literature tells of the necessity of inserting this device in place before using the set.

Mr. Service Man: More and more you are going to come across socket-power radio sets employing the line ballast, or at least provided with a socket for this device. And when you find a line ballast socket, always be sure to insert the proper cartridge. Remember, such a set has a low-voltage primary for the power transformer, and if no cartridge is used, the applied voltage will be excessive. NEVER short out the cartridge. To do so is to apply a serious overload on the tubes, which are certain to burn out in short order. And if you have trouble with line voltage variations or fluctuations, write your manufacturers so they may know that a line ballast is essential in your territory.



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APPLICATION FOR ASSOCIATE MEMBERSHIP

To the Board of Direction
Gentlemen:

I hereby make application for Associate membership in the Institute.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

....
(Sign with pen)

....
(Address for mail)

....
(Date) (City and State)

References:
(Signature of references not required here)

Mr.............................. Mr..............................
Address.............................. Address..............................
Mr.............................. Mr..............................
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Mr..............................
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The following extracts from the Constitution govern applications for admission in the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

(Typewriting preferred in filling in this form) No.________

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

1 Name..

(Give full name, last name first)

2 Present Occupation..

(Title and Name of concern)

3 Permanent Home Address..

4 Business Address..

5 Place of Birth.................. Date of Birth.............. Age.......

6 Education..

7 Degree..

(college) (date received)

8 Training and Professional experience to date..............................

NOTE: 1. Give location and dates. 2. In applying for admission to the grade of Associate, give briefly record of radio experience and present employment.

DATES HERE	

9 Specialty, if any..

Receipt Acknowledged............ Elected............ Deferred...........

Grade.......... Advised of Election......... This Record Filed...........

INCORRECT ADDRESSES

Name	Last Address
Bennett, W. E. D.	c/o Public Works Dept., P. O. Box 266, Bloemfontein, O. F. S., S. A.
Bates, Cyril R.	40 Woodbridge Rd., Knowle, Bristol, England.
Batchelder, S. P.	25 Windemere St., East Springfield, Mass.
Banks, Adrian C.	3714 92nd St., Elmhurst, L. I., N. Y.
Attmore, William B.	California Victor Distributing Co., 948 Santee St., Los Angeles, Cal.
Allen, H. Clifford	4 Grosvenor Sq., Schenectady, N. Y.
Albert, W. V.	1135 I. R. E. c/o General Delivery, Reading, Pa.
Albert, Michael M.	116–53 Suthin Blvd., Jamaica, L. I., N. Y.
Brown, Gilbert G.	4007 67th St., Woodside, L. I., N. Y.
Brose, Fred O.	342 N. Hamlin Av., Chicago, Ill.
Briggs, Perro O.	4340 42nd St., Long Island City, L. I., N. Y.
Borislavsky, Michael A.	91 Tehama St., Brooklyn, N. Y.
Betwinek, Jack L.	Queens Valley Club, Forest Hills, L. I., N. Y.
Bertman, Abe.	1621 East 33rd St. Kansas City, Mo.
Berry, Harold C.	c/o Norton Lilley, 26 Beaver St., New York City.
Bernstein, P.	Station WCGU, 1587 Broadway, New York City.
Cohn, Hans	140 Claremont Ave., New York City.
Clough, Kendall	5930 Newport Ave., Chicago, Ill.
Clauss, Fred W.	602 Chew St., Allentown, Pa.
Clarke, Douglas O.	10 Finsburg Rd., Woodhouse Lane, Leeds, England.
Chittick, K. A.	1642 Rugsby Rd., Scotia, N. Y.
Charbonneau, Allan P.	University of Kentucky, Lexington, Ky.
Byrnes, Walter C.	4734 Ingleside Ave., Chicago, Ill.
Burnside, James H.	150 West 58th St., New York City.
Bur, J. W.	Aikinhead Hardware Store, Radio Department, Toronto, Ont., Canada.
Finter, Capt. C. V.	c/o U. S. Air Service, 159 Victor Ave., Dayton, Ohio.
Fink, William D.	418 S. Orange Ave., Newark, N. J.
Ferrin, Sidney E.	507 Union St., Valparaiso, Ind.
Ferguson, Arthur F.	Hydro, Ont., Canada.
Ellsworth, William C.	209 E. Fifth Ave., Muscatine, Iowa.
Davis, Charles E.	211 Auburn St., Auburn, R. I.
Crossland, Henry A.	1843 Kipling Ave., Houston, Tex.
Colwell, F. E.	6421 Greenview Ave., Chicago, Ill.
Garretson, Oliver S.	c/o General Delivery, Burbank, Cal.
Gardiner, Paul C.	1454 36th Ave., Oakland, Cal.
Galea, Vincent	640 E. 12th St., New York City.
Gail, Preston C.	SS *Greater Detroit*, RCA Great Lakes Transit 223 Erie Co., Buffalo, N. Y.
Fraser, G.	3112 S. Catalina, Los Angeles, Cal.
Fox, Leon J.	Radio Engineering Co., 113 Franklin St., Buffalo, N. Y.
Flory, Carl L.	144 Roosevelt Ave., Flushing, L. I., N. Y.
Fisher, E. H.	P. O. Box 2287, Stanford University, Cal.
Henry, Charles C.	1355 N. Custom Blvd., Chicago, Ill.
Heinley, Paul P.	937 N. Western Ave., Hollywood, Cal.
Haugh, A. T.	25 Leighton St., Rochester, N. Y.
Harvey, Vernon L.	P. O. Box 730, Stockton, Cal.
Harness, Sam A.	WFIW The Acme Mills, Hopkinsville, Ky.
Hansen, Leland S.	4721 N. Maplewood Ave., Chicago, Ill.
Gray, D. R.	1211 Bedford Ave., Brooklyn, N. Y.
Gordon, George	509 Park Ave., West Orange, N. J.
Geloso, John	331 Rodney St., Brooklyn, N. Y.
Lara, Albino	c/o Director of Posts, Manila, P. I.
Kent, Oliver C.	6631 Angeles Mesa Dr., Los Angeles, Cal.
Kemper, Guy A.	2718 Moss Ave., Los Angeles, Cal.
Kasner, Henry P.	1370 E. 35th St., Brooklyn, N. Y.
Jurgensen, Louis	701 N. 7th St., Forest City, Iowa.
Jenkins, L. A.	5042 11th Ave., Seattle, Wash.
Irving, Herbert W.	500 E. End Ave., Pittsburgh, Pa.
Hume, A. A.	217 Kasota Bldg., Minneapolis, Minn.
Holland, Francis L.	518 S. Main St., Tulsa, Okla.
Mickelson, C. D.	88 Livingston St., Brooklyn, N. Y.
McCargar, S. Harold	381 E. 60th St., Portland, Ore.
May, Samuel	George Washington Hotel, Washington, Pa.
Mauro, Oswald G.	Marconi Sta., Drummondville, P. Q., Canada.
MacLaren, Wallace E.	1756 Chapman Ave., E. Cleveland, Ohio.
Lighty, Russell D.	Ludington, Mich.
LaBeau, George B.	170 Hughes Ave., Pawtucket, R. I.
Lathrop, F. A.	3200 Chicago Blvd., Detroit, Mich.
Larrowe, Harvey F.	Dodge's Institute, Valparaiso, Ind.
Paggi, Martin M.	Radio KFWO, Avalon, Catalina Island, Cal.
Ostrowski, Walter R., Jr.	6327 S. Richmond St., Chicago, Ill.
O'Day, Arthur C.	c/o Y. M. C. A., New London, Conn.
Nourse, Philip R.	1544 Dearborn Parkway, Chicago, Ill.
Mossman, F. B.	2309 East 53rd St., Seattle, Wash.
Morrow, Granville P.	6020 Normal Blvd., Chicago, Ill.
Morris, Capt. George W.	Signal Corps, U. S. A., 1st Signal Troop, 1st Cavalry Div., Fort Bliss, El Paso, Tex.
Millard, E. L., Jr.	Log House, Highland Park, Ill.

Miers, Floyd	149 Palmer Ave., Kenmore, N. Y.
Porter, G. Oliver	R. F. D., Route 1, Box 60, Grand Haven, Mich.
Pond, Edward W., Jr.	712 St. John St., Allentown, Pa.
Polydoroff, W. J.	c/o Johnson-Williamson Laboratory, 601 W. Lake St., Chicago, Ill.
Peterson, Frank M.	4445 S. Broadway, Englewood, Colo.
Pearce, Harry G.	U. S. Dredge *Wm. T. Russell*, c/o U. S. Engineer Office, 1505 Race St., Philadelphia, Pa.
Patterson, C. F.	124 Richmond St., West, Toronto, Ont., Canada.
Pata, Y. J.	1624 Park Place, Oklahoma City, Okla.
Pasayiotis, George N.	64 W. 22nd St., Room 10, New York City.
Shum, J. Merrill	139½ Pier Ave., Ocean Park, Cal.
Shuhart, John H.	R. F. D. 1, Phoenixville, Pa.
Shephard, Maxwell	Box 303A, Post Office, Adelaide, S. Australia.
Schmidt, Erwin	373 East 139th St., New York City.
Sands, W. F.	739 Nobile St., Norristown, Pa.
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Roedell, Leroy W. F.	c/o Brunswick-Balke-Collender Co., 410 W. Lombard St., Baltimore, Md.
Reesor, Delbert A.	P. O. Box 124, Camden, N. J.
Rathbun, Harry	76 Sierra Ave., San Jose, Cal.
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Thomas, W. M.	USS *New York*, c/o Postmaster, New York City.
Taylor, John P.	15 Holworthy Hall, Cambridge, Mass.
Tatreault, Leon E.	544 W. Elk St., Glendale, Cal.
Snyder, Lieut. W. R.	845 N. Alta Vista Blvd., Hollywood, Cal.
Smith, Hugo C.	3172 Main St., Buffalo, N. Y.
Smith, B. J.	125 Pape Ave., Toronto, Ont. Canada.
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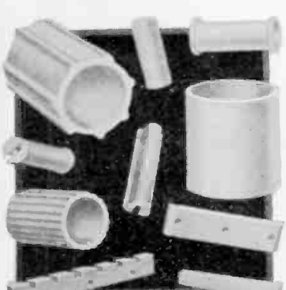
Zeidlik, William J.	U. S. Internal Revenue Lab., 907 W. T. Waggoner Bldg., Forth Worth, Tex.
Zahn, Gilbert L.	376 Claremont Ave., Westmont, P. Q., Canada.
Woods, Michell D.	924 Fullerton Ave., Chicago, Ill.
Wilder, D. R.	520 Lake St., Oak Park, Ill.
Whitney, Chas. L.	Tropical Radio Tel. Co., 321 St. Charles St., New Orleans, La.
White, Newell N.	919 Graham St., Dallas, Tex.
White, Arthur C.	552 Arlington Place, Chicago, Ill.
Walworth, Fred	28 Sherman Ave., New York, N. Y.
Van Doeren, C. A.	3223 East 8th St., Tulsa, Okla.



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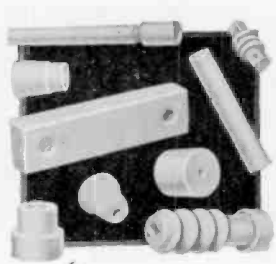

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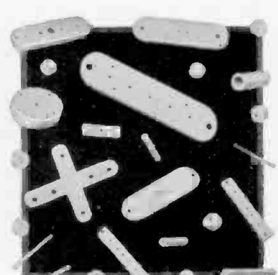

7

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Dear Sir:

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TO NEW ADDRESS

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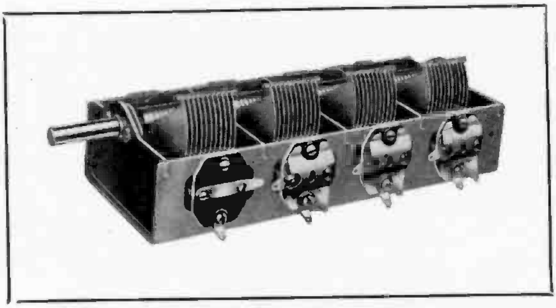
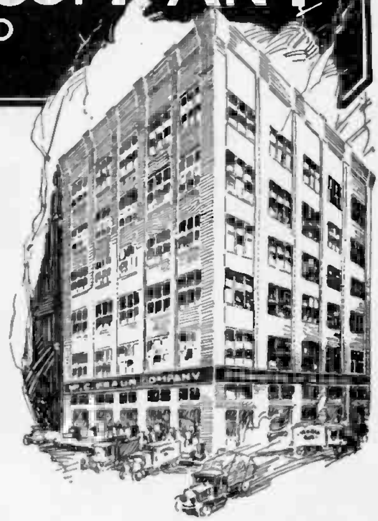


W.C. BRAUN COMPANY
WHOLESALE RADIO HEADQUARTERS



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Manufacturers desiring a distributing outlet furnishing world-wide service, are invited to take up their problems with us. Dealers, custom set builders and engineers will find here an organization keyed to fill their needs promptly and efficiently and a request on their letterhead will bring a copy of the Braun's Radio Buyers' Guide —the bible of the radio industry.

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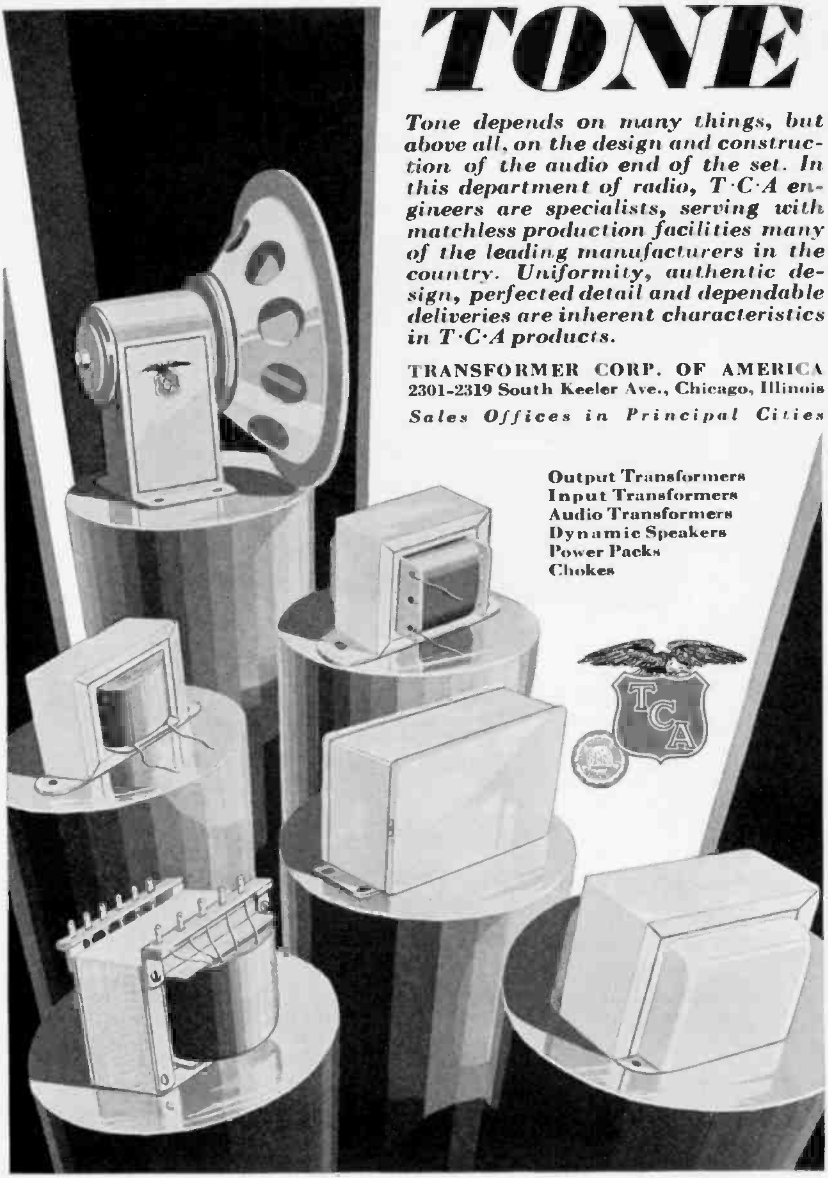
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Tone depends on many things, but above all, on the design and construction of the audio end of the set. In this department of radio, T·C·A engineers are specialists, serving with matchless production facilities many of the leading manufacturers in the country. Uniformity, authentic design, perfected detail and dependable deliveries are inherent characteristics in T·C·A products.
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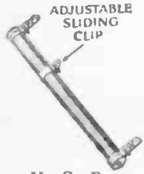

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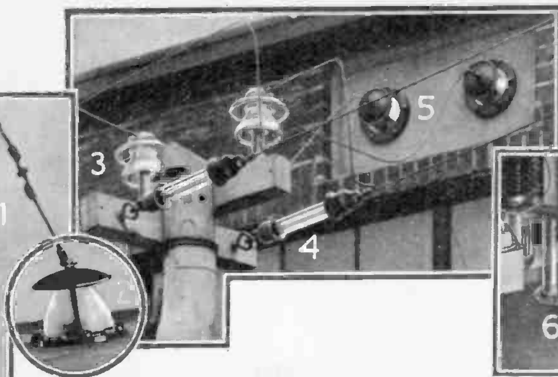

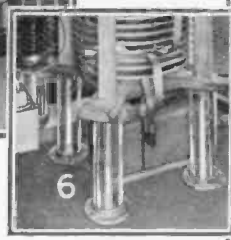

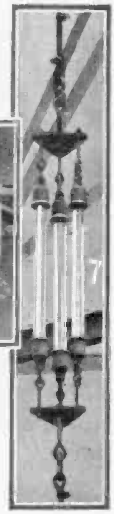

PYREX Insulators at Station WLW

1 and 2. On antenna line and lead in. 3, 4 and 5. On frequency transmission line and lead in. 6. Supports on the tuning coil. 7. On the antenna tension line.

WLW - 50,000 watts

—and a strong believer in PYREX Insulators

THAT PYREX Insulators of antenna, strain, entering, stand-off, pillar and power types have vindicated their right to exclusive use in this fine new station is evident from the following comment by J. A. Chambers, Technical Supervisor: *"We feel that PYREX Insulators have minimum leakage and that they do their part in maintaining quality and range. Our installations have proven unusually strong, durable and free from breakage. The insulating quality is satisfactory in fog, rain, etc."*

An investigation of the 600 American broadcasting stations showed that PYREX Insulators were almost universally used on the antennae, that the larger and new stations favor PYREX Entering Insulators on the lead-in, and that where conditions invite the use of stand-off, pillar and bus-bar types, PYREX Insulators are given the preference.

There is a suitable type and size for every radio service and our PYREX Radio Insulator booklet with all listed and priced, makes the correct selection easy.

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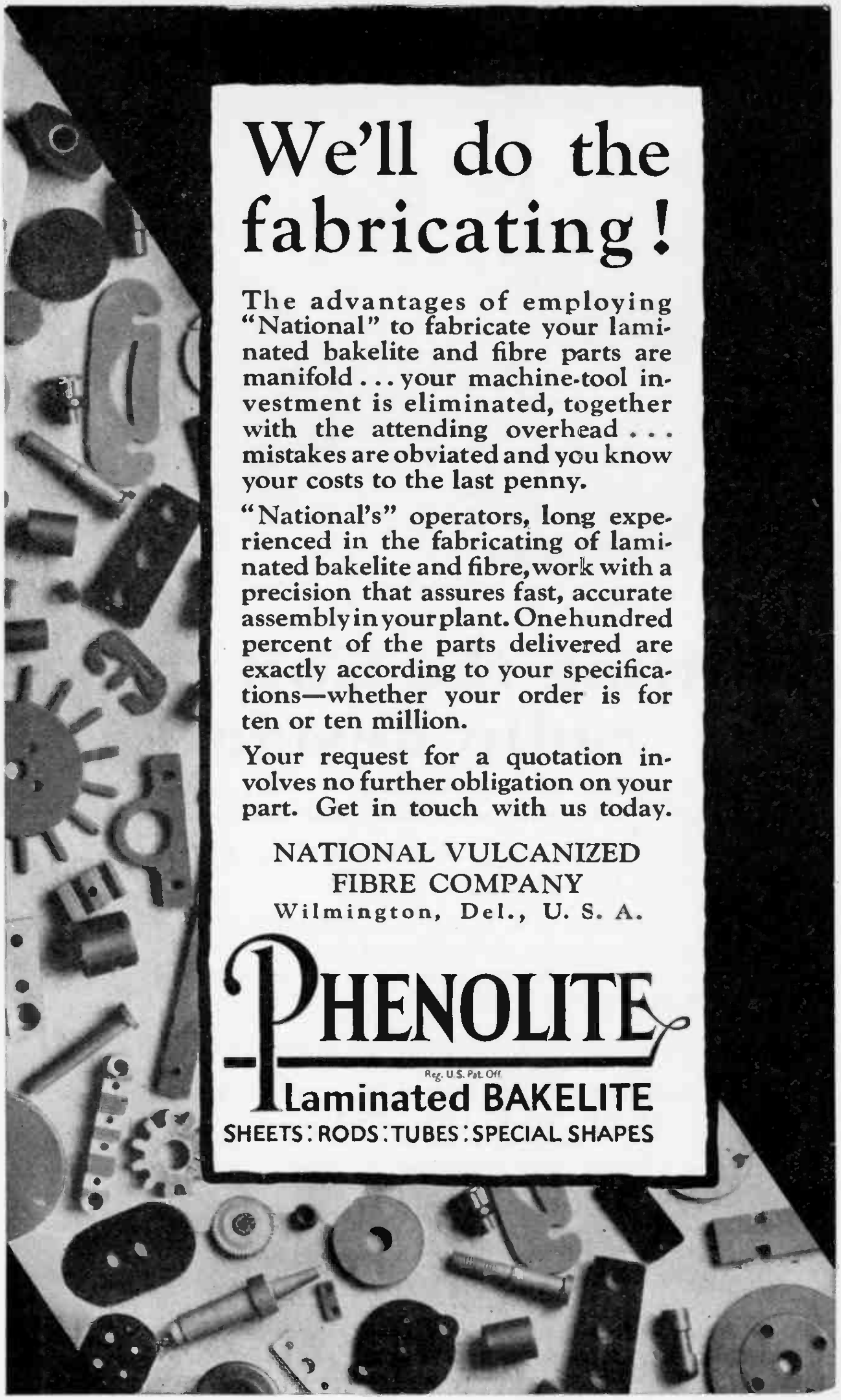
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The advantages of employing "National" to fabricate your laminated bakelite and fibre parts are manifold . . . your machine-tool investment is eliminated, together with the attending overhead . . . mistakes are obviated and you know your costs to the last penny.
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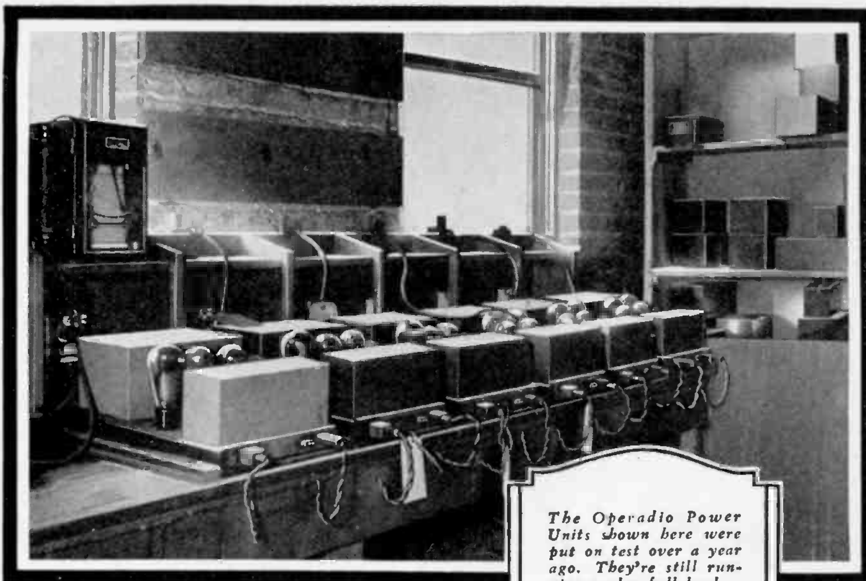

The Operadio Power Units shown here were put on test over a year ago. They're still running under full load.

The BREAKDOWN TEST!

IT TAKES good "stuff" to stand up these days under the high voltages now employed as standard practice. *The job must be engineered* right. Operadio products stand every test! *They have the "stuff!"* Here's evidence.

In the picture above are six power units designed for 110 volt service which were put on test July 28, 1928. At the end of 500 hours the voltage was increased to 120 volts. At the end of 1000 hours to 135 volts, and all six were still running under full load July 28th, 1929, one year later.

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OPERADIO

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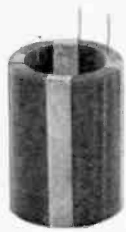

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Compare — for Economy

Centers of wires precisely equidistant. Turns as close together as the dimensions of the wire permit.

Layers exactly alike in number of turns, and in spacing. Turns of the layer above fit with mathematical precision into the valleys of the layer below.

A new and higher factor of space utilization. Smaller coils for the same work to be done. Greater uniformity and higher accuracy both electrically and physically.

These are the unusual characteristics of Rome Precision Heavy Wire Coils. Such improvements are typical of the accuracy of manufacture of all Rome Precision Coils of heavy wire—for any purpose.

To what extent will such coils affect improvements and economies in your product? The best way to determine their net VALUE to you is to ask our engineers to submit a sample built to meet your own specifications.

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Division of General Cable Corporation
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ROME PRECISION COILS

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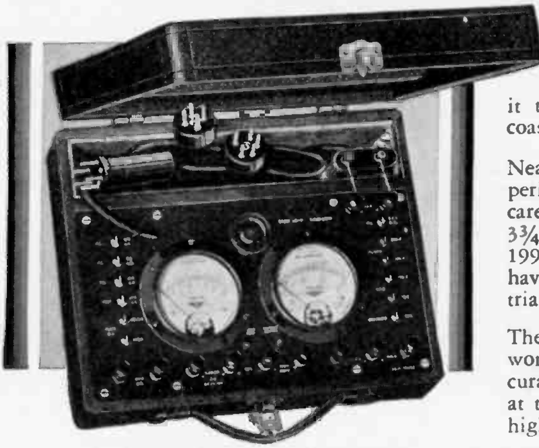

THE inherent accuracy and complete reliability of the Pattern 199 have gained for it the confidence of servicemen from coast to coast.

Nearly thirty years' manufacturing experience, combined with painstaking care in design, has perfected the large 3¾ inch face instruments used in the 199. Thousands of these instruments have been proved in exacting industrial applications.

The Jewell 199 not only makes every worth while radio test, but does it accurately, stands up well in service, and at the same time is the lowest priced, high grade set analyzer on the market.

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Pattern 198 includes the 199 in a large case with compartments for replacement tubes and tools.

The Pattern 199 is designed to give servicemen an instrument of highest quality meeting their requirements perfectly, at minimum expense.

Pattern 409, 4-Instrument Set Analyzer, designed especially for expert radio servicemen, gives plate voltage, plate current, filament, and grid voltages simultaneously. Same high quality throughout as Pattern 199.

Jewell Pattern 210 Tube Tester gives direct reading on all tubes from UV199 to UX250, including half and full wave rectifier and screen grid tubes. Every dealer should have this valuable tube tester.

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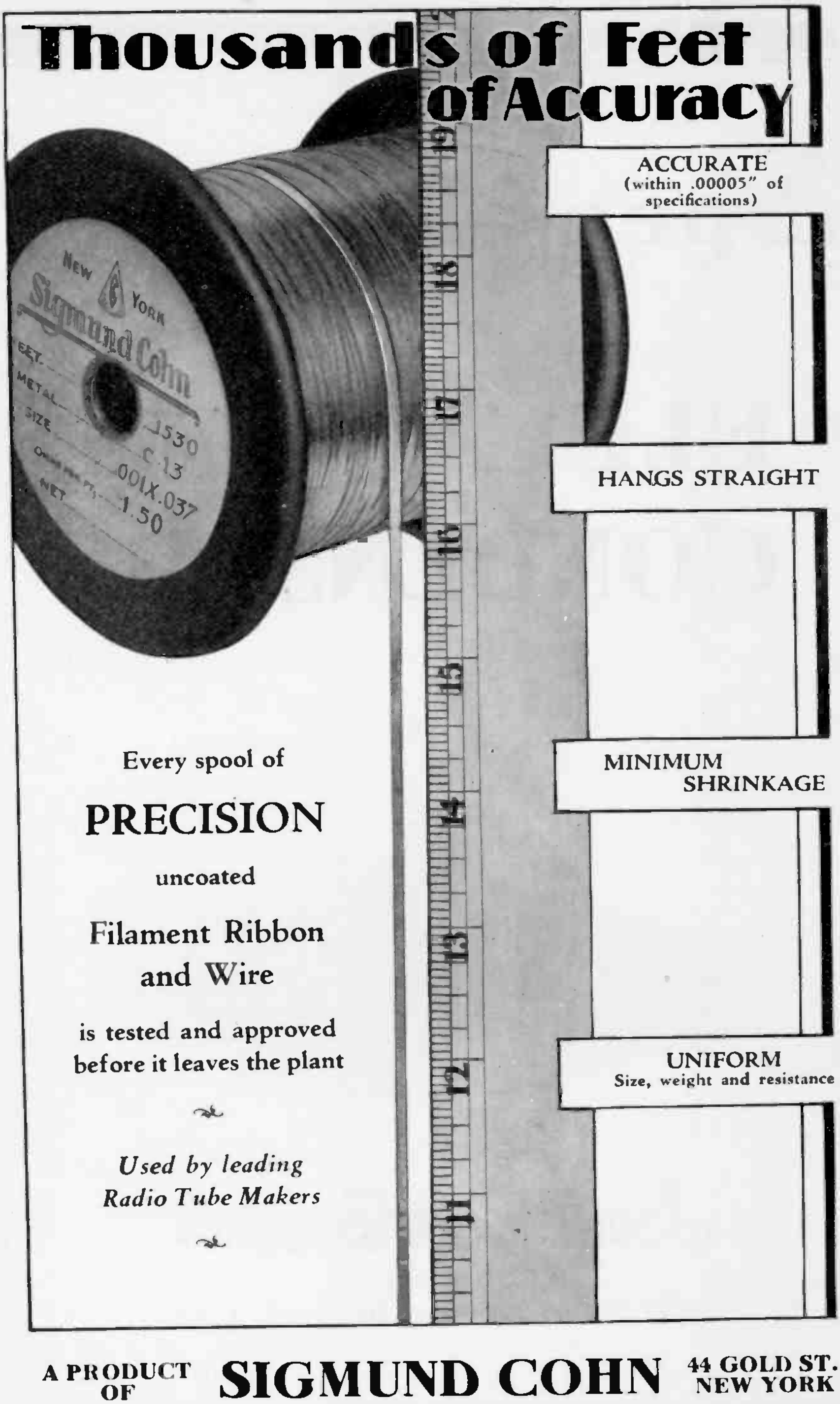
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Many manufacturers are using it for testing tubes on the production line. Others are equipping their traveling representatives so that questions about replacements can be settled in the dealer's presence.

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