VOLUME 16 APRIL, 1928 NUMBER 4

PROCEEDINGS
of
The Institute of Radio Engineers

Published Monthly By
THE INSTITUTE OF RADIO ENGINEERS
Publication Office: 450-454 Ahnaip St., Menasha, Wis.

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

Subscription $10.00 per Annum in the United States
$11.00 in all other Countries

General Information and Subscription Rates on Page 389

THE CHOICE
of
LEADING MANUFACTURERS

For over four years Thordarson transformers have predominated in the receivers and power units of leading radio manufacturers.

Such patronage is not an accident. It stands as a positive proof of a superiority of product. It demonstrates the effectiveness of a policy of service rendered to the n'th degree by an efficient and smooth running organization.

We are at present manufacturing over twelve hundred different types of transformers. Among our customers are more than a hundred radio manufacturers.

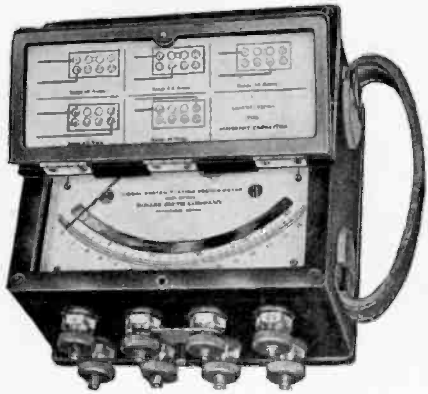
Thordarson engineers always stand ready to help you with your transformer problems.

PROMPT DELIVERY
RIGHT PRICES

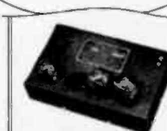
THORDARSON
RADIO
Supreme in Musical Performance
TRANSFORMERS

THORDARSON ELECTRIC MANUFACTURING CO.
Transformer specialists since 1895
WORLD'S OLDEST AND LARGEST EXCLUSIVE TRANSFORMER MAKERS
Chicago, U.S.A.

(3576(



Link Your Tuner to Natural *Reproduction*



THERE are thousands of hours of good operation left in your tuning circuit. In the last three years there has been no progress made in the development of better commercial tuners.

But the Audio! Three years have brought new refinements, new developments which have culminated in the new AmerTran companion units, the AmerTran Push-Pull Power Amplifier and the AmerTran ABC Hi-Power Box — the Power House of Radio Sets.

Link your tuner to Natural Reproduction—transform your old set to one that will astonish even your most critical musical friends. Your imagination cannot exaggerate the difference this combination will make in your set.

Never, in all your experience, have you heard its equal. Send us the coupon for complete information. Your radio experience is incomplete until you have heard this, the crowning accomplishment of AmerTran.

AMERICAN TRANSFORMER COMPANY
Transformer Manufacturers for 28 Years
160 Emmet Street, Newark, N. J.

AMERTRAN
TRADE MARK REG. U.S. PAT. OFF.

The Push-Pull amplifier consists of a first stage AmerTran DeLuxe and second stage AmerTran Push-Pull for two power tubes. Choice of UX-201A or UX-227AC for first stage for DC or AC operation.

The ABC Hi-Power Box is a 500 volt DC plate supply; 110 ma; AC filament current for rectifier, two Power tubes and sufficient 226 and 227 AC tubes to take care of any set. Adjustable negative bias voltages for all tubes.

Both units are licensed under patents owned or controlled by the RCA and may be bought complete with tubes.

Prices
Push-Pull Amplifier $60
ABC Hi-Power Box $95
East of Rocky Mts.
Both without tubes.

AMERICAN TRANSFORMER CO.
160 Emmet St., Newark, N. J.
☐ Kindly send complete information on the AmerTran Push-Pull Amplifier and ABC Hi-Power Box.
Name ....
Address ....
City................ State..........

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 16 April, 1928 Number 4

CONTENTS

GENERAL INFORMATION

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

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.

Subscriptions to the PROCEEDINGS 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. A discount of 25 per cent is allowed to libraries and booksellers.

Entered as second class matter at the Post Office at Menasha, Wisconsin.

Acceptance for mailing at special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, Section 412, P. L. and R. Authorized October 26, 1927.

Publication Office 450–454 Ahnaip Street, Menasha, Wis.
EDITORIAL AND ADVERTISING DEPARTMENTS, 33 WEST 39TH ST., NEW YORK, N. Y.

OFFICERS AND BOARD OF DIRECTION, 1928

(Terms expire January 1, 1929, except as otherwise noted)

President
ALFRED N. GOLDSMITH

Vice-President
L. E. WHITTEMORE

Treasurer
MELVILLE EASTHAM

Secretary
JOHN M. CLAYTON

Editor
ALFRED N. GOLDSMITH

Managers

ARTHUR BATCHELLER

L. F. FULLER

R. H. MARRIOTT

W. G. CADY

A. H. GREBE

R. A. HEISING
(Serving until Jan. 1, 1930)

J. V. L. HOGAN
(Serving until Jan. 1, 1930)

J. H. DELLINGER
(Serving until Jan. 1, 1931)

R. H. MANSON
(Serving until Jan. 1, 1931)

Junior Past Presidents
DONALD MCNICOL
RALPH BOWN

Committees of the Institute of Radio Engineers, 1928

Committee on Meetings and Papers

J. H. DELLINGER, *Chairman*
E. F. W. ALEXANDERSON
STUART BALLANTINE
W. R. G. BAKER
M. C. BATSEL
R. R. BATCHER
ZEH BOUCK
B. RAY CUMMINGS
W. G. CADY
FRANK CONRAD
CARL DREHER
E. T. DICKEY
EDGAR FELIX
H. A. FREDERICKS
W. G. H. FINCH
J. D. R. FREED
VIRGIL M. GRAHAM
KARL HASSEL
C. R. HANNA
SYLVAN HARRIS
LEWIS M. HULL
S. S. KIRBY
D. G. LITTLE
E. L. NELSON
G. W. PICKARD
R. H. RANGER
A. HOYT TAYLOR
PAUL WEEKS
W. WILSON
IRVING WOLFF
W. C. WHITE

Committee on Admissions

R. A. Heising, *Chairman*
H. F. Dart
Lewis M. Hull
Leonard F. Fuller
H. E. Kranz
F. H. Kroger
A. G. Lee
C. L. Richardson
E. R. Shute
F. K. Vreeland

Committee on Publicity

W. G. H. Finch, *Chairman*
H. W. Baukat
Zeh Bouck
C. E. Butterfield
David Casem
Orrin E. Dunlap
Fred Ehlert
Edgar Felix
E. H. Hansen
A. H. Halloran
L. W. Hatry
J. F. J. Maher
Hugh S. Pocock
J. J. Rieger
J. G. Uzmann
Willis K. Wing
R. F. Yates

Committee on Membership

H. F. Dart, *Chairman*
W. R. G. Baker
M. Berger
F. R. Brick
I. S. Coggeshall
H. B. Coxhead
C. M. Jansky
R. S. Kruse
Pendleton E. Lehde
C. L. Richardson
John Stroebel

Committee on Institute Sections

Donald McNicol, *Chairman*
Quinton Adams
Arthur Batcheller
M. Berger
W. G. Cady
F. E. Eldredge
L. F. Fuller
H. C. Gawler
Earle D. Glatzel
E. I. Green
F. P. Guthrie
L. C. F. Horle
W. A. Kleist
Harvey Klumb
John R. Martin
John H. Miller
A. M. Patience
George W. Pierce
E. R. Shute
L. Taufenbach
J. C. Van Horn
Walter Van Nostrand

Committee on Standardization

L. E. Whittemore, *Chairman*
M. C. Batsel
Edward Bennett
William R. Blair
E. L. Chaffee
J. H. Dellinger
C. P. Edwards
General Ferrie
A. N. Goldsmith
J. V. L. Hogan
W. E. Holland
L. M. Hull
C. M. Jansky
F. A. Kolster
R. S. Kruse
George Lewis
Elmore B. Lyford
R. H. Manson
Alexander Meissner
Gino Montefinale
E. L. Nelson
H. S. Osborne
H. B. Richmond
W. J. Ruble
Carl E. Scholz
H. M. Turner
A. D. G. West
C. A Wright
Hidetsugu Yagi

INSTITUTE SECTIONS

ATLANTA SECTION

Chairman
Walter Van Nostrand

Secretary-Treasurer
George Llewellyn, Room 524, Post Office Bldg., Atlanta, Ga.

BOSTON SECTION

Chairman
George W. Pierce

Secretary-Treasurer
Melville Eastham, 30 State St., Cambridge, Mass.

BUFFALO—NIAGARA SECTION

Chairman
L. C. F. Horle

Secretary
C. J. Porter, 141 Milton Street, Buffalo, New York

CANADIAN SECTION

Chairman
A. M. Patience

Secretary
C. C. Meredith, 110 Church St., Toronto, Ontario

CHICAGO SECTION

Chairman
John H. Miller

Secretary
H. E. Kranz, 4540 Armitage Ave., Chicago, Ill.

CLEVELAND SECTION

Chairman
John R. Martin

Secretary-Treasurer
B. W. David, 3223 Ormond Road, Cleveland Heights, Ohio

CONNECTICUT VALLEY SECTION

Chairman
W. G. Cady

Secretary-Treasurer
George W. Pettengill Jr., P.O. Box 551 Ludlow, Mass.

DETROIT SECTION

Chairman
Earle D. Glatzel

Secretary-Treasurer
W. R. Hoffman, 615 West Lafayette Blvd., Detroit, Mich.

LOS ANGELES SECTION

Chairman
Don C. Wallace

Secretary
W. W. Lindsay, Jr., 927 La Jolla Ave., Hollywood, Cal.

PHILADELPHIA SECTION

Chairman
J. C. Van Horn

Secretary
John C. Mevius, 1533 Pine St., Philadelphia, Pa.

ROCHESTER, N.Y. SECTION

Chairman
Harvey Klumb

Secretary
F. W. Reynolds, 1060 University Ave., Rochester, N. Y.

SAN FRANCISCO SECTION

Chairman
L. F. Fuller

Secretary-Treasurer
D. B. McGown, 435 Pacific Bldg., San Francisco, Cal.

SEATTLE SECTION

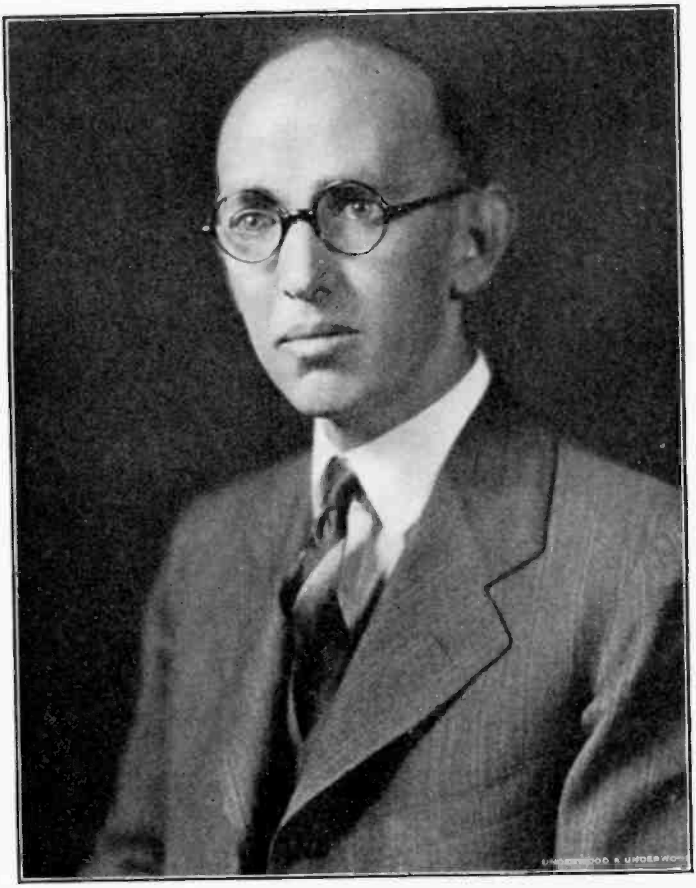
Chairman
W. A. Kleist

Secretary-Treasurer
Oliver C. Smith, 820 Dexter-Horton Bldg., Seattle, Wash.

WASHINGTON SECTION

Chairman
F. P. Guthrie

Secretary-Treasurer
A. Crossley, Naval Research Laboratory, Bellevue, D. C.



Laurens E. Whittemore
Vice-President of the Institute, 1928.

Laurens E. Whittemore

VICE-PRESIDENT OF THE INSTITUTE, 1928.

Laurens E. Whittemore was born in Topeka, Kansas, August 20, 1892. He was educated at Washburn College, Topeka, Kansas (A.B. degree in 1914) and University of Kansas from which he received the M.A. degree in 1915.

Mr. Whittemore was an instructor in the Department of Physics of the University of Kansas from 1915 to 1917. He left the University to join the Radio Laboratory Staff of the U. S. Bureau of Standards where he remained until 1923. From 1923 to 1924 he was Secretary of the Inter-Departmental Radio Advisory Commission of the U. S. Department of Commerce.

Since 1925 Mr. Whittemore has been an engineer in the Department of Development and Research of the American Telephone and Telegraph Company in New York City.

Mr. Whittemore was appointed to the Board of Direction of the Institute in 1926 and has served as Chairman of the Committee on Standardization of the Institute from 1926 to date. He is a Fellow in the Institute.

He is the author of several Bureau of Standards publications and was the joint author of the "Lefax Radio Handbook."

CONTRIBUTORS TO THIS ISSUE

Ballantine, Stuart: Born at Germantown, Pennsylvania, September 22, 1897. Radio amateur 1908– ; operator, Marconi Co. summers 1914–15, H. K. Mulford Co., bacteriologists, 1916; Bell Telephone Co. of Pennsylvania, 1917; Expert Radio Aide, U. S. Navy, in charge of research and development of radio direction-finder apparatus, Philadelphia Navy Yard, 1917-20; organized Philadelphia Section of the Institute, 1920 and served as Chairman until 1926; studied mathematics Drexel Institute, Phila., Pa. 1919, and mathematical-physics in Graduate School, Harvard University, 1920-21; with L. M. Hull organized research work at Radio Frequency Laboratories, Inc., Boonton, N. J., 1922–23; John Tyndall Scholar in Mathematical Physics, Harvard University, 1923–24; privately engaged in miscellaneous research work in radio, spectroscopy, astrophysics, propagation of electric waves in the upper atmosphere, at White Haven, Pennsylvania, 1924–27; in charge Research Division, Radio Frequency Laboratories, Inc., 1927– . Mr. Ballantine has been a frequent contributor to the PROCEEDINGS, and is an Associate member of the Institute.

Cady, W. G.: Born at Providence, Rhode Island, December 10, 1874. Received Ph.B. degree, 1895, M.A. 1896, Brown University; Ph.D., 1900, University of Berlin. Instructor in mathematics, Brown University, 1895-1897. Magnetic observer, U. S. Coast and Geodetic Survey, 1900–02. Instructor in physics, 1902–1903, associate professor, 1903–1907, professor physics since 1907, Wesleyan University, Middletown, Connecticut. Dr. Cady has been elected a member of the Board of Direction of the Institute of Radio Engineers for the year 1928, is a member of the Meetings and Papers Committee, and has frequently contributed technical papers to the PROCEEDINGS. He is a Fellow of the Institute.

Crossley, Alfred: Born at Newark, New Jersey, June 2, 1892. Special course in radio engineering at University of North Dakota under Dr. A. Hoyt Taylor. Associated with various radio activities since 1910 in U. S. Navy, Tropical Radio Company, and Dupont Company. During world war was Lieutenant (j.g.) U. S. Navy, in research work on special trans-oceanic receiving sets and submarine radio equipment. In 1919 became Expert Radio Aide U. S. Navy having duties in connection with direction of naval radio research. Since 1923 associated with Naval Research Laboratory doing work in connection with frequency standardization, piezo-electric crystal control and receiving sets. He is a Member of the Institute of Radio Engineers and of the American Society of Naval Engineers.

Dreher, Carl: Graduated from the College of the City of New York, 1917, having specialized in electric and radio engineering courses. From 1917 to date has been associated with the Marconi Wireless Telegraph Company of America, The General Electric Company, the Radio Corporation of America, and National Broadcasting Company. From 1923 to 1927 was Engineer-in-charge of Stations WJZ and WJY of the Radio Corporation of America. Is now Staff Engineer of the National Broadcasting Company, conductor of the "As the Broadcaster Sees It" Department in *Radio Broadcast*; director of the Radio Club of America and business manager of its *Proceedings*; expert examiner in radio for the Municipal Civil Service Commission of New York. He is a Member of the Institute of Radio Engineers.

Hanna, C. R.: Born at Indianapolis, Indiana, December 17, 1899. Received the B.S. degree in E.E. from Purdue University in 1922 and the E.E. degree in 1926. Since July of 1922 he has been associated with the Westinghouse Electric and Manufacturing Company. Since January, 1923 he has been in the Research Department of this organization working on radio and acoustic problems.

Hoch, E. T.: Received the B.S. degree in E.E. from the Case School of Applied Science in 1914; with the Western Electric Company, Manufacturing and Installation Department, 1914–1915; Engineering Department of the Western Electric Company, 1915–1924; Bell Telephone Laboratories, Inc., 1925 to date. Engaged in dielectric studies and condenser development, and in high-frequency coil design.

Sutherlin, Lee: Born in Putnam County, Indiana, July 11, 1889. Graduated from Central Normal College, Danville, Indiana, with B.S. degree, 1909; studied at Indiana University, Bloomington, Indiana, 1909–1912; received the A.B. degree in 1912; University of Chicago during the summers of 1915–1916–1917, received the M.S. degree in 1917. Head of Physics Department Muncie High School, Muncie, Indiana, 1912–1916. Instructor in Applied Mathematics, Culver Military Academy, Culver, Indiana, 1916–1917. Served as enlisted man and officer in Signal Corps, U. S. Army, December 12, 1917 to September 9, 1919. Radio engineer with Miller-Reese-Hutchison, Inc., New York City, 1919–1920. Radio research engineer, Westinghouse Electric and Manufacturing Company, October 1920 to date. He is an Associate member of the Institute.

Terman, Frederick Emmons: Born at English, Indiana, January 7, 1900. Received the A.B. degree from Stanford University, 1920; E.E. degree, Stanford University, 1922; Sc. D. Massachusetts Institute of Technology, 1924. Now Assistant Professor of electrical engineering at Stanford University, and in charge of communication and analytical work. He is an Associate member of the Institute.

Terrell, William D.: Born at Golansville, Virginia, August 10, 1871. Entered telegraph service in 1889; became radio inspector, Department of Commerce, July 1, 1911 at New York City; transferred to Washington, D.C. and placed in charge of the Radio Division, March 1, 1915, in which capacity he has served to date. Charter associate member of the Institute.

Upp, Charles B.: Born in Highland County, Ohio, March 5, 1893. Graduated from grade schools, Rainsboro, Ohio, and high school, Greenfield, Ohio. Received the B.S. in E.E. degree from Ohio State University, 1919, and the M.S. degree in 1923. During the world war served in the Coast Artillery Corps. From 1919 to 1922 was an engineer with the General Electric Company Fort Wayne, Ind. in transformer design. From 1923 to date has been in the Research Department of the Westinghouse Electric and Manufacturing Company.

Walsh, Lincoln: Born November 3, 1903. Foreman, manufacturing, J. Walsh & Brother, Elizabeth, New Jersey, 1919–1921. With Bell Telephone Laboratories in summers of 1923–24–25. Received the M.E. degree Stevens Institute of Technology, 1926. Engaged in receiver development work, Hazeltine Corporation, 1926–1927. 1927 to date, consulting engineer. He is an Associate member of the Institute.

Wheeler, Harold A.: (See PROCEEDINGS for January, 1928.)

INSTITUTE ACTIVITIES

March Meeting of the Board of Direction.

At the meeting of the Board of Direction of the Institute held on March 7, 1928, in the offices of the Institute, 33 West 39th Street, New York City, the following were present: Alfred N. Goldsmith, President; Melville Eastham, Treasurer; Ralph Bown, Junior Past President; Donald McNicol, Junior Past President; Arthur Batcheller, W. G. Cady, J. H. Dellinger, R. A. Heising, R. A. Manson, R. H. Marriott, and J. M. Clayton, Secretary.

The following were transferred or elected to the higher grades of membership in the Institute: Transferred to the grade of Fellow: A. A. Oswald, J. C. Schelleng, W. Wilson. Transferred to the grade of Member: F. A. Cobb, A. C. Hofmann, E. M. Ma-Dan, F. J. Marco. Elected to the grade of Member: Quinton Adams, F. H. Amis, C. G. Cadman, J. P. Johnston, W. L. Krahl, Cecil McQuillan, L. C. Herndon.

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

Licensing of Radio Engineers

The following letter from Everett N. Curtis, Counsellor-at-Law and a member of the Institute, regarding the requirement of the laws of the State of New York for licensing of practicing radio engineers is printed for the information of the membership of the Institute:

February 18, 1928.

The Institute of Radio Engineers,
33 West 39th Street,
New York City.

Gentlemen:

Replying to yours of the 15th inst., I beg to advise you that, in my opinion, a member of the Institute, who is practicing or offering to practice radio engineering in the State of New York, either in a consulting capacity or as an engineer in a manufacturing organization, is required, under the law relating to Engineers and Surveyors, to submit to the State Board of Licensing evidence that he is qualified so to practice and to obtain a certificate of license to practice before he can lawfully engage in professional engineering. Under Section 1466 a person practices "professional engineering" where he holds himself out as able to do, or who does, the work that an engineer does in the planning, designing, constructing, inspecting and supervising of engineering work or appliances involved in public or private projects, or in making investigations for proposed engineering projects.

Under Section 1463 a non-resident of the State of New York is exempted from the operation of the Law, where he has no established place of business in the State, and where his practice does not exceed thirty days in any calendar year, provided he is legally qualified in his own state or country. He is also exempted for a reasonable time, where he has filed an application for a license and paid the fee. There are also exempt, under Section 1463, employees or pupils acting under the direction of a licensed professional engineer, and not in responsible charge or supervising as principal; officers and employees of the United States acting solely as such; and the practice of professional engineering solely as an officer or employee of a corporation engaged in interstate commerce.

Very truly yours,
(signed) Everett M. Curtis

Research Fellowships at Wisconsin

Two research fellowships in Engineering are to be appointed on April 30th by the University of Wisconsin. Candidates must be graduates of engineering colleges of recognized standing, and, preferably, should have had one or two years of graduate study, of teaching, or of engineering experience. Applications will be received up to April 15th. Information and application blanks can be obtained from Dean F. E. Turneaure, College of Engineering, Madison, Wisconsin.

The appointments will be for a period of two years, subject to satisfactory service, and the salary will be $900 for the first year and $1100 for the second year. A fellow will be expected to devote not less than half time to assigned research in the College of Engineering, but will be given an opportunity to complete the requirements for a master's degree within the two-year period. The period of service will be the usual academic year, including the short vacations.

Changes of Address

On page XXVI of this issue of the Proceedings, in the advertising section in the rear, will be found a list of members, mail for whom has been returned to the offices of the Institute on account of incomplete addresses or changes of locations. It will be helpful if members of the Institute knowing the present address of any persons listed therein will notify this office of their current address so that copies of the Proceedings may reach them promptly.

Institute Meetings

New York Meeting

At the New York meeting of the Institute, held on March 7, 1928 in the Engineering Societies Building, 33 West 39th Street, a paper by C. R. Hanna, L. Sutherlin, and C. B. Upp of the Westinghouse Research Laboratory, entitled "Development of a New Power Amplifier Tube" was presented by Mr. Sutherlin.

The paper is published in this issue of the PROCEEDINGS.

In the discussion which followed the presentation of the paper the following, among others, took part; Messrs. Sutherlin, Crom, Batsel, Hull, Goldsmith, and Herbst. Over three hundred members and guests attended this meeting.

BOSTON SECTION

A meeting of the Boston Section was held in Cruft Laboratory on March 16th. Dr. G. W. Pierce presented a paper on "Control of Radio Audio Frequencies by Means of Magneto Striction."

On March 30th there will be a joint meeting between the local section of the American Institute of Electrical Engineers and the Boston Section of the Institute to hear a paper by Dr. E. J. Burg, of Union College, Schenectady, N. Y.

BUFFALO-NIAGARA SECTION

On February 15th in Foster Hall, University of Buffalo, a meeting of the Buffalo-Niagara Section was held. Dr. L. G. Hector presided.

Carl Dreher, staff engineer of the National Broadcasting Company, presented a paper "Problems of Broadcast Operation." The paper is being published in this issue of the PROCEEDINGS.

Messrs. Eichman, Hector, Pickett, and others participated in the discussion which followed.

Forty-three members of the Institute attended the meeting.

CHICAGO SECTION

On January 30th, in the Monadock Building Auditorium, Chicago, C. W. Horn, of the Westinghouse Electric and Manufacturing Company, presented a paper, "Some Short Wave Experiences." J. H. Miller presided.

This was a joint meeting with the local section of the American Institute of Electrical Engineers, the Western Society of Engineers, and the Chicago Section of the Institute.

The attendance at this meeting was over one hundred and thirty.

On February 17th a meeting of the Chicago Section was held in the auditorium of the Western Society of Engineers. J. H. Miller presided.

Professor R. R. Ramsey of Indiana University presented a paper "Radiation from Aerials."

Messrs. Miller, Wilcox, Kranz and other participated in the discussion.

Twenty-four members of the Institute attended.

Cleveland Section

A meeting of the Cleveland Section was held on March 2nd in the Physics Building of the Case School of Applied Science. Professor John R. Martin presided.

Two papers were presented. The first, by George H. Mills, instructor in electrical engineering, Case School of Applied Science, was on "The Electrodynamic Loudspeaker and Associated Power Amplifier."

The various sources of distortion in radio reproduction were discussed, such as the pick-up and broadcasting at the station, in the receiver, and especially in the loudspeaker. The shortcomings of the horn type of speaker were pointed out and comparison made to the cone type. It was stated that the cone type of usual commercial design would handle more volume without distortion than the usual horn type.

The type of driving unit used in the two types were discussed. The usual horn type uses an iron armature drive in many cases, similar to the usual cone type—both having their limitations as to the volume they can handle. The later moving coil or electrodynamic driving unit has many advantages over the other type of drive. A pronounced advantage is its ability to handle great volume without distortion.

The details of construction—mounting of moving coil, suspension of cone, and design of field coil—were pointed out. Diagrams of Kolster and R.C.A. 104 Amplifiers, together with moving coil speakers, were shown and explained. An interesting point was the use of the speaker field as a choke coil. A Kolster Speaker and Power Amplifier was demonstrated both on phonograph records with a magnetic pick-up and on broadcast reception with a receiving set.

The second paper by C. B. Hamman, of the Department of Physics, East Technical High School, was a review of a recent paper "A New High Efficiency Horn Type Loudspeaker," published in rhe Bell *Technical Journal*. This talk was confined entirely to a teview of the paper in which the speaker used lantern slides made from illustrations in the *Journal.* The speaker described the use of the electrodynamic type of driving unit in combination with an exponential horn. The moving coil is attached to a small corrugated metal diaphragm. The energy is transmitted to the air column in a very novel manner.

The above papers were discussed by Professor Martin and Messrs. Worden, Leonard, and Kintner.

On April 6th there will be a meeting of the Cleveland Section in the Case School of Applied Science. Dr. Miller and Professor Martin of the Case School will present a paper on "Loudspeaker Analysis with the Phonodike."

Connecticut Valley Section

On February 20th a meeting of the Connecticut Valley Section was held in the auditorium of the Hartford Electric Light Company. Dr. K. S. Van Dyke presided.

Professor C. M. Jansky, Jr. presented a paper on "Some Studies of Radio Broadcast Coverage in the Middle West."

On February 29th a meeting of the Section was held in the auditorium of the Hartford Electric Light Company. Dr. W. G. Cady presided.

Professor Hidetsugu Yagi of Japan presented a paper "Beams of Ultra Short Waves." The paper explained the directional properties of waves over the use of reflectors or directors, or both, and defined these terms. Many curves were displayed showing the received energy from different locations of the sending and receiving antenna with and without reflectors and directors for both vertical and horizontal polarized waves.

Polar diagrams were also displayed showing the energy distribution with reflectors both with and without directors. Conclusions drawn were that any radiating system now devised can be improved upon by the use of wave directors.

The second part of the paper dealt with the use of a magnetrone for the generation of radio frequencies from twelve to forty centimeters wavelength. Circuit diagrams were shown, and curves giving the effect of anode voltage and magnetic field were explained.

It is hoped that this paper can be published in full in a forthcoming issue of the Proceedings.

Fifty-two members of the Section attended this meeting.

Detroit Section

Dr. Phillip Thomas, of the Research Department of the Westinghouse Electric & Manufacturing Company, presented a paper before the Detroit Section of the Institute on February 24th in the West Engineering Building of the University of Michigan, Ann Arbor.

The paper, entitled "Radio and the Transmission of Power by Radio," showed by demonstrations the close analogy between mechanical and electric vibration and standing waves, using a pendulum, a vibrating rope, and an oscillating system giving about thirty-five watts at a wavelength of 2.4 meters. After showing how small and simple such apparatus becomes on waves of 2 meters or less, Dr. Thomas discussed the difficulties incident to generation of very short wavelengths, and described a line of attack which it is hoped will result in the generation of power of the order of kilowatts associated with a twenty-centimeter wavelength. The possibility of ionization of the air by a beam radiated at this wavelength, and some useful applications of such a "weightless wire" were touched upon. Dr. Thomas concluded his address with the statement that his company hoped shortly to produce such a wave and test its characteristics.

In the discussion which followed it was brought out that the energy density in this contemplated beam of radiation would be about twenty times as great as that of sunlight, at high noon, at the earth's surface. E. T. Glatzel presided at the meeting.

Over four hundred and twenty-five members and guests attended the meeting. Thirty-five persons attended the dinner preceding the meeting.

Los Angeles Section

An informal dinner preceded the meeting of the Los Angeles Section held on February 20th in the Elite Cafe, 633 S. Flower Street, Los Angeles. Thirty-three members attended the dinner.

The new feature of Section meetings, "Timely Topics," consisted of a short paper on the Radio Ray read by A. P. Hill.

J. Clement, of San Diego, gave a short technical description of KFSD.

E. W. Butler of Cunningham, Inc. presented a paper on vacuum tubes covering the tubes in use today.

The latter paper was freely discussed by all members present. Sixty-five members attended the meeting.

Philadelphia Section

A meeting of the Philadelphia Section was held on February 24th in the Bartol Laboratories. J. C. Van Horn presided.

The paper of the evening by Knox McIlwain and W. S. Thompson was entitled "Radio Field Strength Survey of Philadelphia."

The paper was discussed by Messrs. Babcock, Wilson, Van Horn, and others.

Following the technical session, the election of 1928 took place. J. C. Van Horn was re-elected Chairman of the Section and J. C. Mevius, Secretary.

San Francisco Section

The San Francisco Section held a meeting on February 15th in the rooms of the Engineers' Club, 206 Sansome Street, San Francisco. Dr. L. F. Fuller presided.

George T. Royden, of the Mackay Radio Company, presented a paper on "The Development of the Kolster A-C. Radio Receiver." The paper was accompanied by a demonstration of the operation of the receiver and included a technical description of the constructional and engineering features.

A general discussion on the part of the fifty-five members present followed.

Seattle Section

On February 25th in the Club Room of the Telephone Building, Seattle, a meeting of the Seattle Section was held. W. A. Kleist presided.

A motion picture film showing the apparatus employed in television was presented. This film gave an indication of the equipment required and an idea of the method used in accomplishing television.

L. D. Robinson presented a paper on "Transformer Design" in which the fundamental or primary characteristics of transformers were discussed and the method of cutting the laminations and annealing the iron was illustrated. The exciting current was discussed and mention was made of the harmonics which resulted. Core losses were analyzed and methods of reducing them were discussed.

A second paper by T. M. Libby and W. A. Kleist on "The Importance of Various Frequency Bands in the Voice and Music Spectrum" demonstrated by means of a set of phonograph records the importance of these bands. Records were prepared by eliminating certain bands of frequencies by means of electrical filters. It was pointed out that certain of the records, from which all frequencies except a narrow band in the middle of the range had been eliminated, sounded very much like the radio sets of a few years ago.

Washington Section

A meeting of the Washington Section was held on March 8th in Picardi's Cafe, 1417 New York Avenue, Washington, D.C. Dr. A. H. Taylor presided.

A paper by L. C. Young and Dr. A. H. Taylor on "A Study of Short Wave Propagation with special reference to Round the World Signals" was presented by Dr. Taylor. It is expected that this paper will be published in a forthcoming issue of the PROCEEDINGS.

Messrs. Dellinger, Whittemore, Robinson, Pratt, Blair, Stewart, Merryman and others participated in the discussion which followed.

Fifty-three members and guests attended the informal dinner which preceded the meeting and sixty attended the meeting. Following the technical session the election of 1928 officers took place with the following results:

Chairman—F. P. Guthrie
Vice-Chairman—Dr. C. B. Jolliffe
Secretary-Treasurer—Alfred Crossley

The next meeting of the Washington Section will be held on April 12th at Picardi's Cafe.

Institute Committees

Committee on Meetings and Papers

A meeting of the Committee on Meetings and Papers was held in the offices of the Institute on March 6th at 2 P.M. The following members were present: J. H. Dellinger, Chairman; W. R. G. Baker, M. C. Batsel, Zeh Bouck, W. G. Cady, E. T. Dickey, Carl Dreher, Edgar Felix, W. G. H. Finch, H. A. Fredericks, V. M. Graham, C. R. Hanna, Sylvan Harris, D. G. Little, E. L. Nelson, G. W. Pickard, W. C. White, W. Wilson, and Messrs. Marriott and Clayton.

The general plans and policies covering the activities of this Committee for the ensuing year were discussed. It is planned that the work of the Committee for 1928 will, in the main, be handled through correspondence. Various plans looking to increased participation in discussions of papers presented before meetings were outlined.

Several suggestions were brought forth tending toward more intimate contact with the Meetings and Papers Committees of Sections.

Committee on Membership

A meeting of the Committee on Membership was held in the offices of the Institute on the evening of March 1st. The following were present: H. F. Dart, Chairman; F. R. Brick, J. M. Clayton.

The "Aims and Activities" booklet of the Institute was revised for 1928 and a number of matters relative to increase in membership were discussed.

Committee on Sections

On March 13th at 2 P.M. a meeting of the Committee on Sections was held in the offices of the Institute. The following members of the Committee were present: Donald McNicol, Chairman; E. R. Shute, Quinton Adams, M. Berger, Arthur Batcheller, Harvey Klumb, and H. C. Gawler.

Material for a booklet to be used in the guidance of members interested in the organization and operation of Sections, as submitted by the 1927 Committee on Sections, was approved and is to be transmitted to the Board of Direction with the recommendation for adoption and printing.

Various other important matters regarding the operation of Sections were discussed.

Committee on Admissions

At the meeting of the Committee on Admissions of the Institute held on March 7th, the following were present: R. A. Heising, Chairman; E. R. Shute, Louis M. Hull, Frederick Vreeland.

The Committee considered twenty-five applications for admission or transfer to the higher grades of membership, acting favorably upon fourteen of them. A number of applications had to be held over to the next meeting of the Committee due to the quantity on hand for consideration.

Personal Mention

C. H. Nordhaus is now in the Engineering Department of Grigsby-Grunaw-Hinds Company of Chicago.

J. M. Davidson, formerly with the African Theatres, is now head of his own radio engineering organization at Salisbury, Rhodesia.

George T. Royden, Radio Engineering Department of the Mackay Radio and Telegraph Company, has been transferred from San Francisco to Honolulu.

B. A. Halfpap has resigned from the Radio Corporation of America and is now connected with the Federal Railway Institute of Milwaukee, Wisconsin, in the capacity of Radio Instructor.

V. Ford Greaves has resigned from the staff of the Magnavox Company of Oakland, California, to become associated with Newcombe-Hawley, Inc. of St. Charles, Ill., in the Engineering Sales Division.

W. S. Fithian has recently become associated with the Victor Talking Machine Company of Camden, New Jersey. Mr. Fithian was formerly in the Supply Department of the Philadelphia Electric Company.

THE INTERNATIONAL RADIOTELEGRAPH CONFERENCE OF WASHINGTON, 1927*

By

W. D. Terrell

(Chief of Radio Division, U. S. Department of Commerce)

THE International Radiotelegraph Conference which held its sessions in Washington from October 4th to November 25th of this year was composed of delegates from 79 countries including those colonies and possessions whose delegates affixed separate signatures to the treaty which was drawn up. There were nearly 300 government delegates and in addition about 75 representatives of communication companies and other interested international agencies.

The specific purpose of the conference was to revise the International Radiotelegraph Convention or Treaty which was signed at London in July, 1912. It may be stated broadly that the general purpose of the conference was to formulate such provisions as are appropriate for international agreement, in order to minimize interference between radio stations engaged in international service or which are international in their interfering capabilities.

The delegation of the United States to this conference consisted of 15 men commissioned for this duty by President Coolidge. These delegates came largely from government departments, but there were also several from private life and from the communication companies. Herbert Hoover, Secretary of Commerce, was Chairman of the American Delegation and President of the Conference. It is interesting to note in passing that the chairmen of the two largest and quite important delegations were engineers, Herbert Hoover, Chairman of the American delegation, and Col. T. F. Purves, Chairman of the British Delegation. Col. Purves is the Chief Engineer of the British General Postoffice.

The conference was organized into committees under the chairmanship of delegates from the various countries. The conference was provided with the necessary staff for the publication and distribution of proposals, the preparation of reports and

* Original Manuscript Received by the Institute, December 21, 1927.

* Presented at the Annual Institute Convention, January 9, 1928.

A detailed account of the activities of the Conference published in book form can be obtained from the United States Government Printing Office at Washington, D. C. for 40 cents, the exact title being "International Radiotelegraph Conference, and General and Supplementary Regulations Relating Thereto."

making of arrangements for entertainment, and the conduct of other business of the conference. Officers of the International Bureau of the Telegraph Union coöperated with the American Delegation on matters of this kind.

It had been customary at previous International Radiotelegraph Conferences to conduct all proceedings in the French language alone. Through the efforts of the American Delegation, an agreement was reached whereby English was used for the discussions as well as French. Interpreters were provided by the American Delegation. The official texts of the convention, regulations and other documents were in French. English texts were prepared and distributed by the American Delegation.

The treaty which was drawn up consists of three parts known as the Convention, the General Regulations, and the Supplementary Regulations. The Convention is based largely on that which was signed at London in 1912. The Regulations are based to some extent on a draft of regulations for mobile radio service which was formulated at an Interallied Conference in Washington in 1920, the technical features having been revised at an Interallied Conference in Paris in 1921.

The Department of State of the United States Government had submitted to the International Bureau at Berne, Switzerland, in 1926, the American proposals for the convention and regulations and had forwarded in addition the proposals of American Radio Companies for management regulations or operating rules which would be the subject of agreement between the radio operating agencies engaged in international communication. The decision to divide the regulations into two parts, General Regulations and Supplementary Regulations, was made by the conference at the request of the United States. Those provisions which are of a managerial nature and relate to the operation of radio services, particularly those operated by private companies, could in this way be put into the supplementary regulations which would not be signed by the delegates from the United States. This supplementary set of regulations also contains a provision making applicable to radio the provisions of the International Telegraph Regulations to which the United States is not a party. No difficulty is involved in this, however, since the United States did not sign the supplementary regulations. The delegates of Canada and Honduras also refrained from signing the supplementary section.

The provisions of the Convention cover such matters as the licensing of radio transmitting stations and operators, the secrecy of messages, intercommunication between coastal and ship stations, the mutual exchange of information necessary to facilitate international radio communication, the settlement of accounts in the mobile service, the establishment of an international consulting committee on radio communication, the allocation of blocks of call letters to countries, and the settlement of disputes by arbitration. The Convention contains no article on the question of voting. The decisions on the questions before this conference were so nearly unanimous that on only one occasion was a roll call required at a plenary session. It was agreed that the next conference would determine its own rules governing voting.

Perhaps the most important article of the regulations is Article 5 which deals with the allocation of frequency and wavelength bands to radio services. In the allocation waves are designated in the first instance by their frequency in kilocycles per second. Following this designation there is given the approximate wavelength in meters. The conversion factor used is 300,000.

The frequency allocation adopted is not an allocation to countries. It is entirely an allocation to services, the stations of all countries having equal rights to the use of the bands designated for a particular service.

There are several provisions of the regulations which give a tacit recognition to the rights of priority of radio stations which have been in operation—for example, in paragraph 16 of Article 5, it is provided that the frequencies assigned to all new fixed, land or broadcasting stations must be chosen in such a manner as to prevent as far as possible interference with international services carried on by existing stations, the frequencies of which have already been notified to the International Bureau. Another provision of this article requires that notice be sent in advance to the International Bureau of the establishment of stations using frequencies below 37.5 kilocycles per second (wavelengths above 8000 meters) in case the use of this frequency might cause international interference over broad areas. Similar notice must be given the International Bureau regarding the operation of short wave stations intended to carry on a regular service and which are likely to cause international interference.

The frequency allocations to the various services conform in their major divisions to the assignments which have been used in the United States under the recommendations of the 4th National Radio Conference. The band from 10 to 100 kilocycles (30,000 to 3000 meters) is assigned to stations engaged in point-to-point service, chiefly of course the trans-oceanic service. The band from 100 to 550 kilocycles (3000 to 545 meters) has been designated primarily for ship to ship, ship to shore, and aircraft services. This includes radio beacons on a band at about 300 kilocycles (1000 meters) and provides for a radio compass service on a band around 375 kilocycles (800 meters). The 500-kilocycle frequency (600 meters) is the international calling and distress wave and may be used for message traffic only on condition that interference with call signals and distress signals will not result. The band between 194 and 285 kilocycles (1550 and 1050 meters) was one on which it was somewhat difficult to secure agreement. The difficulty arose from the fact that many of the European countries desired to utilize this band for broadcasting. It was finally agreed that part of this band may be used for broadcasting in Europe only, and that the rest of the band will be used by mobile and aircraft services and by fixed stations not open to public correspondence.

The band from 550 to 1500 kilocycles is now universally recognized as the broadcasting band. Permission is given to use one frequency in this band, namely 1365 kilocycles (220 meters) for small ships. The entire band may be used by mobile service in any part of the world where its use will not interfere with broadcasting.

The band from 1500 to 60,000 kilocycles (200 to 5 meters) has been divided into 40 smaller bands and apportioned between mobile services, communication between fixed stations, broadcasting and amateur stations. This allocation of the short waves involves some change from the 4th National Radio Conference allocation, but has the advantage of giving some assurance that stations of a given type which begin operation in this band will be able to continue in operation subject only to the adjustment of interference with other stations engaged in a similar service.

The Conference gave definite recognition to the amateur in international radio communication. The allocation to amateur service of four exclusive bands and two non-exclusive bands was secured through the efforts of the American Delegation with the support of the delegates from Canada and New Zealand. The result is to give the amateurs much greater assurance of making contact with one another internationally.

While the Conference recognized that the allocation of frequency bands to specific services was necessary in order to minimize interference, there was a corresponding desire to leave to each country or to any group of countries in a certain region as much freedom as possible in making assignments to stations which are not international in their effect. Only international stations therefore must comply with the allocation. Freedom is left for the assignment of any frequency to stations which do not cause international interference.

It was recognized as inadvisable to write into the regulations definite provisions of a technical or engineering nature which might become obsolete during the next few years. Instead, general provisions calling for the maintenance of a high technical standard were adopted. It is provided, for example, in Article 4 of the General Regulations, that the wave emitted by a station must be maintained upon its authorized frequency as closely as the state of the art permits, and its radiation must be as free as practicable from all emissions not essential to the type of communication carried on. The interested administrations shall fix the tolerance allowed between the mean frequency of emissions and the recorded frequency; they shall endeavor to take advantage of technical improvements progressively to reduce this tolerance. The width of a frequency band occupied by the emission of a station must be reasonably consistent with good current engineering practice for the type of communication involved.

In considering the use of damped wave transmitters, the Conference felt that definite dates must be set on which certain restrictions would go into effect. The Regulations provide that upon adoption, no more damped wave sets are to be installed at fixed or land stations; that after January 1, 1930 sets of this type to be installed on ships shall, when working on full power, use less than 300 watts measured at the input of the supply transformer. The use of existing damped wave transmitters is to be discontinued by all land stations on January 1, 1935. It is provided, however, that no restriction shall be placed upon the means which an operator of a mobile station in distress may use of attracting attention, indicate his position and obtain assistance.

The regulations annexed to the London Convention were applicable exclusively to ship-to-ship and ship-to-shore services. In the new Washington Regulations most of the provisions are applicable to mobile service which now includes aircraft as well as ships. In addition to provisions regarding the use of traffic frequencies other than the calling frequency there are regulations providing for the necessary control of traffic by land stations, the routing of messages by mobile stations and other related matters.

Provision is of course made in the regulations for absolute priority in the mobile service for distress calls, messages and traffic. In addition to SOS as a distress call, there is now established a radio telephone distress call which consists of the spoken expression "may day." This corresponds to the pronunciation in French of the expression which means "help me." Provision is made for the use of an alarm signal which has as its purpose the setting into operation of an automatic apparatus to give an automatic alarm and to warn someone on the ship in which it is installed that a distress signal is about to follow. The alarm signal consists of a series of 12 dashes sent in one minute, the duration of each dash being 4 seconds and the duration of the interval between dashes one second.

Two new urgency signals, *XXX*, and in the case of aircraft *PAN*, are established for indicating that urgent messages are on hand concerning the safety of the ship or aircraft or of persons on board or in sight from them. A safety signal, *TTT*, is established to be used as a preamble to a message concerning the safety of navigation or containing meteorological warnings.

Article 6 of the General Regulations contains provisions relating to the issuance of operator's certificates. These provisions differ but little from the present practice of the United States except for the provision that in order to secure a place as a Chief Operator on a vessel of the first class it will be necessary for an operator to have had a year's experience under a first class license.

Provisions are included in the regulations designating the hours of service of ships having one or two operators respectively. Complete revised lists of abbreviations or *Q* signals are included, applicable to aircraft communication as well as other situations.

Regulations are included applicable to special services such as meteorological services, time signals, notices to navigators, radio compass, and radio beacon service. Rules are included covering the settlement of accounts in the mobile service.

The Conference, throughout its work, endeavored to keep before it the principle that its conclusions should be of such a nature as not to interfere with the development of the art. It is generally felt that the Convention and Regulations adopted occupy a safe middle ground between avoidance of restriction and the maintenance of orderly communication. The Convention and Regulations become effective on January 1, 1929 for all of the governments which ratify it. The Conference accepted an invitation from the Government of Spain to meet next in Madrid in 1932. Egypt and Holland had also extended invitations.

The outstanding impression left by the Conference is perhaps the fact that every effort was made by all of the delegates to secure the correct solution of the problems under discussion. The technical questions in particular were usually discussed and the conclusions arrived at from a technical rather than a nationalistic standpoint. The general attitude was one of coöperation and of realization that the problems should be solved on their technical merits.

MODES OF VIBRATION IN PIEZO-ELECTRIC CRYSTALS*

By

A. Crossley

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

Summary—*The presence of nodes and antinodes on the surface of oscillating quartz crystals have been discovered. The symmetrical arrangement of these nodal points permits a study of the modes of vibration in the crystal plate and the use of the following formulas for determination of the velocity of sound waves through quartz and Young's modulus.*

$$V = F2T \qquad e = V^2D.$$

where V is the velocity, F the frequency, T the thickness of the plate, e Young's modulus and D the density. The value obtained for V was 5733 meters per second while 8.785×10^{11} *C.G.S. units represents Young's modulus for plane parallel to X-axis dimension.*

THE piezo-electric crystal and its application for frequency control of vacuum-tube transmitters has held the attention of radio engineers for the last four years and the major activities along these lines have been devoted to the practical application of this means of frequency control. The practical application of the piezo-electric crystal has been such that no appreciable time has been devoted to the study of modes of vibration in the crystal. In view of this condition there is presented in this paper information which has been obtained at the Naval Research Laboratory which will shed some light on this interesting and important subject. It is hoped that this information will stimulate an interest among investigators in this phase of the piezo-electric crystal art and lead to more knowledge of this phenomenon.

The major part of the data presented in this paper was obtained with zero angle or the "Curie" cut type of quartz crystal when this crystal was oscillating at a frequency which corresponds to the thickness or X axis.[1] The crystals employed in this experiment were approximately 25 millimeters square and of different thickness from 0.6 to 6 mm.

It has been known that it is possible to increase or decrease the piezo-electric response characteristic of a quartz crystal, when oscillating at radio frequencies, by adjusting the several dimensions of the crystal. An increase in piezo-electric response

* Original Manuscript Received by the Institute, Feb. 20, 1928.

[1] "Piezo-Electric Crystal-Controlled Transmitters," A. Crossley, Proc. I.R.E., Jan. 1927.

is obtained when the several dimensions are integrally related to each other, while a decrease is obtained when this condition is departed from.

The proper dimensioning of crystals for maximum piezo-electric response was thought to have a definite relation to the phenomenon of resonance from a mechanical and acoustical stand-point. This was found to be true and evidence was obtained which showed the presence of nodes and antinodes on the surfaces of the crystal. The presence of the nodes and antinodes was noted in an experiment which was intended to determine whether or not the vibrating crystal would evaporate water. For this

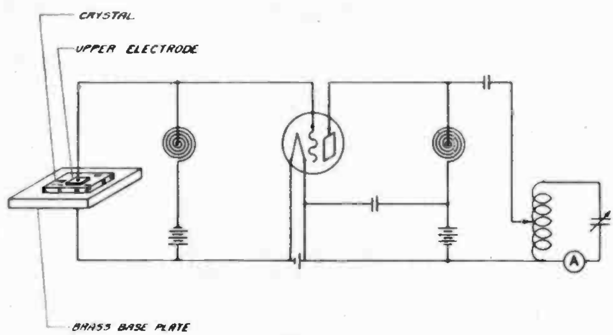


Fig. 1

experiment a crystal-controlled vacuum-tube oscillator of approximately 30 watts output was employed. The crystal was placed on the brass base plate, shown in Fig. 1, and a small brass electrode made contact with the upper surface of the crystal. A portion of the upper surface of the crystal (4000 kcs. fundamental frequency), was exposed and when the system was oscillating a small drop of water was placed on the exposed part of the crystal. As soon as the water came in contact with the crystal the greater part of it rose in a column of vapor while the remaining portion split up into small particles and assumed definite positions, and then disappeared, presumably by a process of evaporation. The various particles referred to arranged themselves in a group of squares, each particle separated from the others by a definite distance.

The water particles were hard to observe, and resort was made to the use of various solutions and suspensions such as ink, potassium permanganate, ferro ferricyanide, cupric ferricyanide, and red lead and alcohol for obtaining a permanent pattern on the surface of the crystal. Of the different indicators cited the ferro ferricyanide produced the best record. The potassium permanganate when mixed with water evaporated quickly and returned to the crystalline form. Blue ink was fair, but had such a surface tension that it would not readily break up into the particles and separate without leaving clouded areas around the particles.

Following the classical experiments of Chladni and Kundst resort was made to the use of lycopodium powder, flowers of sulphur and red lead to note whether these materials would form patterns on the crystal surface. The lycopodium powder when

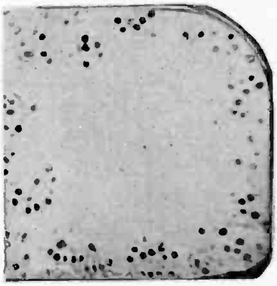


Fig. 2

placed on the oscillating crystal was thrown off and no trace of the powder remained on the crystal. The flowers of sulphur and red lead were treated the same way, but some of the heavier particles remained on the surface of the crystal and became heated. Some particles which were of the right area, say 1 mm. in diameter, started whirling around, and kept whirling until a wind current carried them off the crystal surface.

A small globule of amalgamated mercury was placed on the crystal, and it immediately heated up and started boiling and after a period of time the mercury evaporated and a solid metallic deposit was left on the surface of the crystal. This deposit could not be brushed off and only by grinding could it be removed. It is thought that this deposit was therefore an alloy of copper and zinc, because the mercury had been previously placed in a brass thermometer well.

There are submitted (Figs. 2 and 3) enlarged photographs of the patterns produced on crystals using ferro ferricyanide. When a pattern was obtained on one part of the surface of the crystal the upper electrode or plate was shifted over to another position on the crystal thus exposing a new surface for another portion of the pattern. This procedure was kept up until the greater part of the surface was covered with the pattern. During the experiment care should be taken so that no liquid will creep in between the crystal and upper electrode, which condition causes the crystal to stop oscillating.

It was not possible to obtain a perfect reproduction of the position of the dots for as soon as the circuit stops oscillating the particles would roll out of line or they would recombine with other particles as can be noted from the photograph. A slight change in the fundamental frequency due to the loading of the

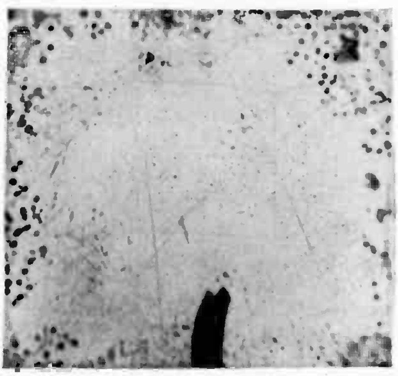


Fig. 3

crystal, which is apparent during the evaporation process, also causes the dots to move away from and back to the original position. This latter condition can be observed very definitely by listening to the beat note obtained from a local heterodyne for as soon as the beat note changes there is a simultaneous change in the position of the dots. This change in the position of the dots in most cases causes a blur or irregular alignment of the dots.

The best reproductions can be observed along the edge of the crystal. A very vivid demonstration of the nodes and antinodes can be had by submerging the crystal in transformer oil to a depth of approximately ¼ inch, and driving the crystal by use of a self-oscillating circuit. When a frequency equivalent to one of the crystal frequencies is impressed on the crystal and part of the surface of the crystal is exposed to the oil a multitude of eruptions are observed. The picture presented on the surface of the oil resembles a flat plane with numerous little hills situated at definite distances from each other. The hill tops represent point of maximum movement in the quartz plate while the low areas are minimum movement. The oil phenomena is opposite in observed effect to the ink-spot phenomena for in the case of the ink spot only the point of no movement is shown while in the other case the maximum movement is indicated.

A study of these photographs and numerous other ink-spot patterns obtained with different crystals shows us that there are spots of no movement represented by the deposits and places of maximum movement which are indicated by the absence of any kind of a deposit. The distance between nodes is equal to one-

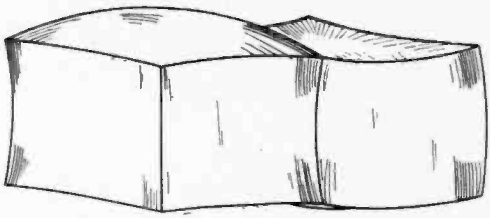


Fig. 4

half a wavelength of sound in the crystal and is also equal the thickness of the crystal. Measurement on two crystal specimens of the average distance between indicated nodal points or ink spot showed that this distance checked to within less than one per cent of the thickness of the crystal. This check is of great interest as it ties in very accurately with our integral relation law.

A further study of results obtained during these experiments suggests the following explanation of the mechanism of oscillation or vibration observed in the crystal. Let us assume from a vibration standpoint that the crystal is of a mosaic form, having numerous crystal cubes which when assembled make up the crystal plate. Each cube will have all three dimensions equal to the thickness of the crystal plate, which we also can assume is equal to one-half a wavelength of sound in the crystal. Now, let us examine the sketches shown in Figs. 4 and 5, which are intended to show graphically the distortion which takes place in the respective suggested cubes of the crystal plate when the plate is oscillating. It is, of course, understood that the distortion is greatly exaggerated in these sketches for the purpose of explaining the vibration phenomenon. In Fig. 4 two cubes have been drawn from data obtained by the summation of the vector forces due to stresses in the three dimensions and also from data obtained from the crystal patterns previously described. The figure upon inspection suggests a flexural vibration. Sufficient data are not on hand to state definitely whether or not it is a flexural or longitudinal vibration.

We note from these sketches when the surface of one cube is rising the surface of the next cube is falling like that of sections of a tent which are subjected to gusts of wind. We also note that the boundary points such as the four corners of the upper and lower surfaces of the cube are points of no movement, which checks with our observed deposits at the nodal points of the crystal. Fig. 5 shows the same two cubes as depicted in Fig. 4, but

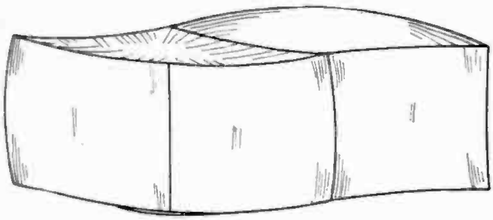


Fig. 5

under the influence of the opposite mechanical force, therefore, these two figures show the two extreme mechanical distortions which exist in a crystal when oscillating at one of its natural periods.

Another way to consider this oscillating phenomenon in the crystal is to consider the crystal as a checker board which has the alternate red and black squares on its surface. In such a form let us visualize the instantaneous oscillation effect by considering for one moment that the black squares are moving upward while the red squares are moving downward, and the next moment the red squares start moving upward while the black squares are moving downward. The maximum movement is at the center of each square tapering off to no movement at the corners as shown in the sketch.

The whirling of the particles of sulphur and red lead previously mentioned can be easily explained by the fact that there is a spot of no motion at the corner of the squares and the alternate rising and falling of the portions of quartz surrounding this point can impart the whirling or circular movement to the particle.

Assuming that the suggested phenomena of the oscillating condition of the crystal is correct it is possible to obtain data on the velocity of sound waves through quartz and also Young's modulus or the coefficient of elasticity of quartz. The velocity of sound waves through quartz was obtained by measuring the frequency and the thickness for the X-dimension of 18 crystals ranging in thickness from 0.6 to 6 mm. and averaging the values obtained by use of the following formula:—

$$V = F\lambda \text{ or } V = F2T$$

where V is the velocity, F the frequency, λ the wavelength of sound in quartz and T is the thickness for the X-dimension. The thickness of the crystal as previously stated is equal to one-half wavelength of sound in quartz for the X-axis oscillation. The average value obtained for the velocity is 5733 meters per second.

Knowing the velocity and assuming the density to be equal to 2.67 grams per cc. and substituting these values in the following formula we have:—

$$e = V^2 D$$

where e is Young's modulus and D the density. The value of Young's modulus thus obtained is equal to 8.785×10^{11} C. G. S. units.

The value obtained for Young's modulus of quartz in the oscillating state applies only to the zero-angle crystal and for the oscillation corresponding to the X or thickness dimension. Different velocities and Young's moduli will be obtained with 30 degree crystals and also for the longitudinal mode of oscillation. The value of Young's modulus herein quoted lies between values obtained by other experimenters[2] who employed the conventional mechanical method for determining this elastic constant. The latter values are as follows: 10.3×10^{11} C.G.S. units for a plane parallel to the optical axis and 7.85×10^{11} when at right angles to optical axis. Considering the two entirely different methods of measurement of Young's modulus and the small difference noted between the radio-frequency measurement and either of the mechanical values it is reasonable to assume the suggested theory of crystal oscillation merits consideration.

The author wishes to express his appreciation to Drs. L. P. Wheeler, H. B. Maris, Messrs. H. D. Eisenhauer and J. W. Wright for their assistance in this investigation.

[2] Handbook of Chemistry and Physics, page 443.

The following publications are quoted as having some bearing on the subject matter of this paper:

A. Hund. Proc. I. R. E. August, 1926.
A. Crossley, Proc. I. R. E., January, 1927.
A. Meissner, Proc. I. R. E., April, 1927.
E. P. Tawil, *Comptes Rendus*, December, 1926.
E. P. Tawil, *Comptes Rendus*, July 11, 1927.

SOME CHARACTERISTICS AND APPLICATIONS OF FOUR-ELECTRODE TUBES*

By

J. C. Warner

(Research Laboratory, General Electric Company)

Summary—*Four-electrode tubes may be classified by their designs and uses as "screen-grid" tubes, "space-charge-grid" tubes, and "double function" tubes. In the screen-grid tube the inner grid is the control electrode and the outer or screen-grid is kept at a fixed potential. The capacity between plate and control-grid is thereby reduced to an almost negligible value. A second result of the screen-grid is a large increase in amplification factor and plate resistance without reduction of mutual conductance. This permits high amplification in connection with high impedance coupling circuits, without undesired regeneration or oscillation. The screen-grid principle has been applied to transmitting tubes as well as receiving tubes. Characteristics of these tubes are given in detail.*

In the space-charge-grid tube the outer grid is the control electrode and the inner grid is maintained at a fixed potential. The purpose of the inner grid is to reduce the effect of the space-charge around the filament and thereby reduce the plate resistance of the tube. The space-charge-grid tube performs the same functions as ordinary three-electrode tubes, but in general has higher mutual conductance than a three-electrode tube of similar design.

Several double function tubes and circuits are described in which both grids act as control-electrodes or in which one grid acts as control electrode and the other as a combination space-charge-grid and control or output electrode. These circuits are sometimes useful but are subject to certain definite limitations.

SEVERAL forms of vacuum tubes have been made with four electrodes, but the one which perhaps is the best known and of the greatest present interest is that containing a cathode, two grids, and an anode. The purpose of this paper is to discuss briefly some of the important characteristics of the two-grid tube and to show some of the relations between the tube constants and the performance of the tube in typical circuits.

The uses and types of two-grid tubes may be divided into three general classes depending upon the functions of the two grids; and to a considerable extent the use to which the tube is to be put influences the details of the design. These classes include the "screen-grid" tube, the "space-charge-grid" tube, and various "double function" and miscellaneous tubes and uses.

* Original Manuscript Received by the Institute, December 14, 1927.
* Presented at the Annual Institute Convention, January 11, 1928.

THE SCREEN-GRID TUBE†

The earliest work on the screen-grid tube[1,2,3,4] was done by W. Schottky in Germany. A. W. Hull[5,6] has further developed the tube by providing more complete shielding and present commercial examples of this tube, Radiotron UX-222, and Cunningham Type CX-322 as well as the larger transmitting tubes are the outgrowth of Dr. Hull's work.

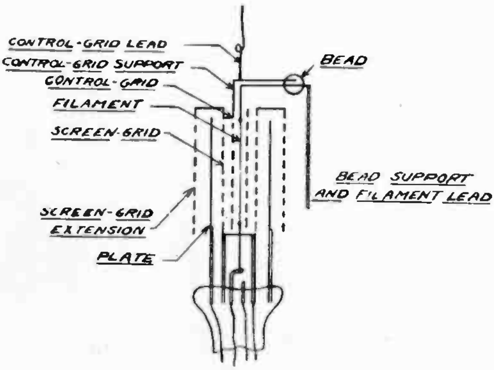


Fig. 1

Figs. 1 and 2 show the arrangement of electrodes in a typical screen-grid tube (UX-222). The inner grid is the control electrode and is similar to the grid of a three-electrode tube. It is supported

† (Author's note:—A number of names for this type of tube have appeared recently in various publications. Some of these are "shield-grid," "shielded-grid," "screened-grid," "shielded-plate," "screened-plate." These terms are obviously not all synonymous although they all have some technical justification. The last four have the disadvantage of not indicating directly that the screening or shielding is accomplished by the use of a fourth electrode. Also, there is some question as to whether the grid or the plate is screened since the screen is interposed between the two. "Screen-grid" and "shield-grid" refer directly to the fourth electrode, which is the distinguishing feature of the tube. Of these two, the name "screen-grid" has the advantage of implying both the form and function of the fourth electrode, while "shield-grid" gives the idea of a solid metal plate such as commonly is used for shielding of circuits, and in fact such as is often used around the outside of the tube. "Screen-grid" is in keeping with the idea of allowing the electrons to pass through but tending to obstruct the electrostatic field. "Screen-grid" furthermore can, without confusion or misunderstanding, be shortened to "screen" in speaking of "screen voltage" or "screen current," and the name of the tube shortened to "screen tube.")

[1] Schottky, *Archiv. fur Elektrotechnik*, Vol. 8, p. 299, Dec. 1919.

[2] Schottky, U.S. Patent No. 1537708, filed Aug. 27, 1919, issued May 18, 1925.

[3] Barkhausen, *Jahrbuch der draht. Tel. u. Tel.* Vol. 14 p. 43, 1919.

[4] Howe, *Rad. Review*, Vol. II, No. 7 pp. 337–340 July 1921.

[5] Hull and Williams, *Phys. Rev.* Vol. 27, No. 4 pp. 432–438 Apr. 1926.

[6] Hull, *Phys. Rev.* Vol. 27, No. 4, pp. 439–454, Apr. 1926.

entirely from the upper end of the tube and the lead is brought through a seal in the top of the bulb to a metal terminal cap. The outer grid is the screen, and it is supported on the main stem as well as by the glass bead above the plate. The plate is supported on the stem only. The screen-grid and its extension on the outside of the plate serve to shield the control-grid from the plate. Since this shield must take the form of a screen in order to allow electrons to pass through it, the shielding is not absolutely perfect, but can with a practical design be made sufficiently good to reduce the grid-plate capacity to a small fraction of the capacity in a three-

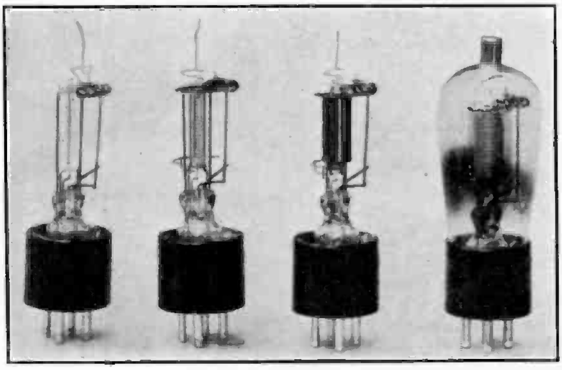


Fig. 2—UX-222

electrode tube. For example, the UX-222 has an effective capacity of about 0.02 $\mu\mu$f. Usually a metal cap should be placed around the outside of the bulb and connected to the filament or screen in order to prevent any stray coupling around the outside of the electrodes. Tinfoil wrapped on the bulb and grounded is equally effective.

Fig. 3 shows the simple circuit connections for a screen-grid tube. The screen-grid is connected directly to a positive voltage somewhat less than the plate voltage. The input circuit is connected to the inner grid in the usual manner. In a typical radio-frequency amplifier circuit the plate supply voltage may be 135 volts and the screen voltage 45 volts. Electrons leaving the cathode and passing through the control grid are accelerated toward the screen and most of them pass through it and are then drawn to the plate since there is negligible space charge between screen and plate. Some of the electrons are, of course, caught by the screen and perform no useful function, but this loss need not be over 25 percent of the total current and is often less than 10 percent. The field at the cathode is not influenced appreciably by the plate voltage on account of this shielding of the screen and is determined by the voltages of the control-grid and the screen.

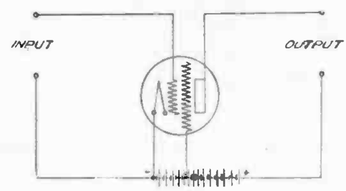


Fig. 3

Also, the amount of control of the grid voltage on the total current, i.e., the mutual conductance, is determined largely by these same voltages. The plate then acts as a collector of the electrons which have passed through the screen and, because of the electrostatic shielding between the plate and the other electrodes, the plate

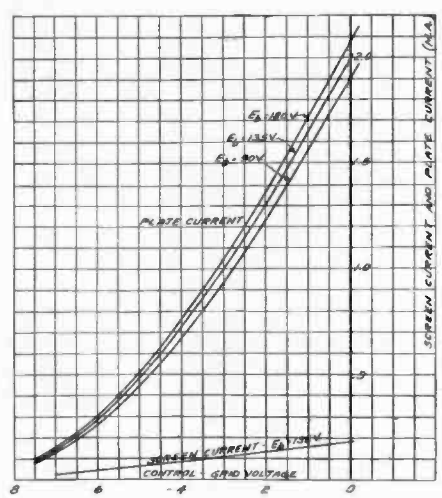


Fig. 4—UX-222 Mutual Characteristics, Screen-Grid Connection. $E_{c_2}=45$ volts.

voltage has very little effect on the plate current. The internal plate resistance is accordingly very high, in typical cases being 500,000 to 1,000,000 ohms. This is an important advantage since, as will be explained later, the effective amplification factor of the tube is increased at the same time as the plate resistance.

Characteristics of Screen-Grid Receiving Tubes (UX-222)

Typical static characteristics of a screen-grid receiving tube are shown in Figs. 4, 5, and 6.‡ The grid-voltage plate-current characteristics of Fig. 4 are similar to ordinary three-electrode tube curves except that as the plate voltage is changed, the position of the curve is only slightly shifted. This is merely another indication of the high plate resistance. The screen current curves show the amount of current which is lost in the screen circuit. In Fig. 5 that part of the curves below the screen voltage (45 in this case)

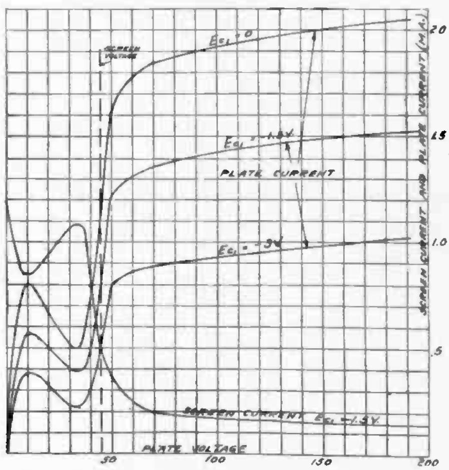


Fig. 5—UX-222 Mutual Characteristics, Screen-Grid Connection. $Ec_2=45$ volts.

is of little practical interest since the tube is ordinarily used at plate voltages considerably higher than the screen voltage. Secondary emission from the plate plays a considerable part in the shape of this section of the curve. Above the screen voltage the plate current curves flatten out and the plate conductance becomes only a few micromhos. If there were perfect shielding and no secondary emission from the screen the curves would be perfectly flat. Fig. 6 shows the effect of the screen voltage on its own current and the plate current. The plate current curves are very similar to the plate characteristics of a three-electrode tube.

These curves illustrate the fact that the plate current and the

‡ (Author's note:—In these figures and others, the subscripts c_1 and c_2 have been used to denote the first and second grids respectively, regardless of their functions. For example Ec_2 refers to the voltage of the outer grid regardless of whether it is being used as a control-grid or as a screen-grid.)

mutual conductance of a given tube are dependent almost entirely upon the voltages of the two grids. In fact these quantities are almost the same as they would be in a three-electrode tube having the same filament and control-grid, but with a plate at the location of the screen and at a potential equal to that of the screen. (In the three-electrode tube, the plate current would be equivalent to the sum of screen and plate current in the screen-grid tube.) The most important characteristic of the tube is the mutual conductance and the amplification factor is not necessarily a

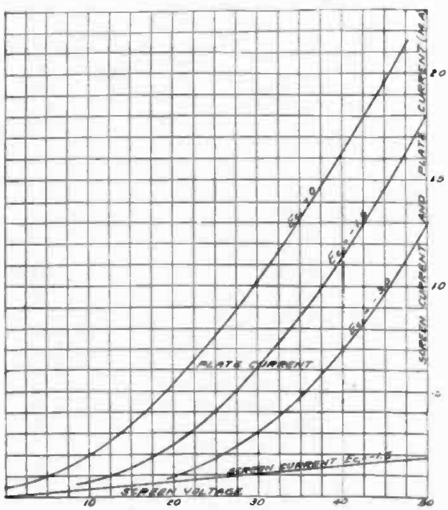


Fig. 6—UX-222 Screen Characteristics. $Eb=135$ volts.

direct function of the geometry of the tube. If there were no secondary emission from the screen, the amplification factor would be dependent upon the diameters of the grids and plate and the mesh of the grids,[7] but even a small amount of secondary emission upsets the usual relations. The effect of this emission is to raise the mutual conductance and to lower the plate resistance since more electrons reach the plate. In the UX-222, the over-all effect is a slight increase in amplification under practical conditions. The mutual conductance of the UX-222 at 135 volts on the plate, 45 volts on the screen, and -1.5 volts bias on the control grid is about 0.35 m.a. per volt and the plate resistance averages about 850,000 ohms. This gives an amplification factor of nearly

[7] Schirmann, *Archiv. fur Elektrotechnik*, Vol. 8 p. 441, March 1920.

300. It should be remembered, however, that while this factor enters into the circuit calculation in the same way as for the three-electrode tube, it is not a constant but varies considerably with the electrode voltages as shown by Fig. 7.

There is a noticeable difference between these amplification characteristics of the screen-grid tube and those of a three-electrode tube having a very high amplification factor. It is, of course,

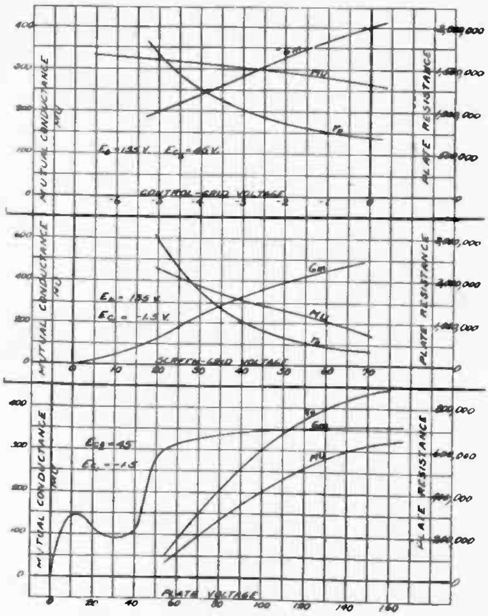


Fig. 7—UX-222 Characteristics, Screen-Grid Connection.

possible to make a three-electrode tube with an amplification factor of 200 or more by using a very close grid mesh or increasing the distance from grid to plate. However, in doing this, the mutual conductance would be reduced to so low a value that the tube would be of little practical use. In addition, the three-electrode tube would have the usual feed-back capacity.

It is perhaps self-evident that the screen-grid tube is particularly well suited to use as a radio-frequency amplifier. The absence of appreciable feed-back capacity makes it possible to use tuned coupling circuits without danger of oscillation provided, of course, that the circuits themselves are properly shielded from each other. At the same time the high impedance obtained by resonance is desirable in order to utilize the high voltage amplification of the tube.

Some examples of the obtainable amplification may be of interest. It will be assumed that the plate resistance of the tube is 850,000 ohms, and the mutual conductance 350 micromhos, giving an amplification factor of practically 300. If the load circuit is tuned to resonance, the impedance becomes a pure resistance and in the broadcast frequency range a well designed load circuit will have an impedance of about 100,000 to 200,000 ohms.

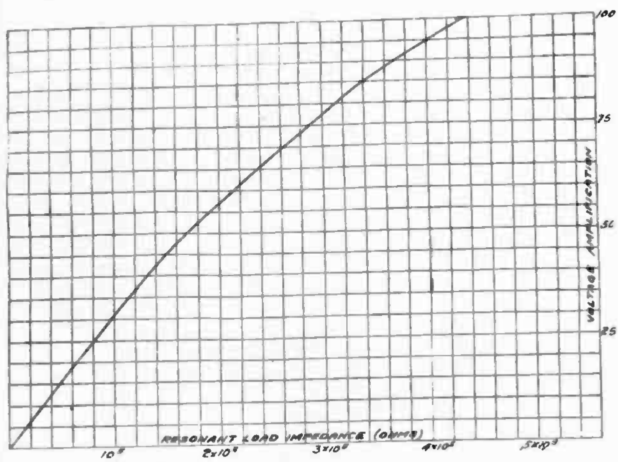


Fig. 8—UX-222 Voltage Amplification with Resonant Loads. Screen-Grid Connection—$Ec_1 = -1.5$; $Ec_2 = 45$; $Eb = 135$.

The usual expression for voltage amplification is

$$A_v = \frac{\mu R_p}{r_p + R_p} \tag{1}$$

where R_p = load resistance

r_p = plate resistance

μ = voltage amplification factor.

However, it has already been pointed out that the mutual conductance of the screen-grid tube is more of a fundamental constant than the amplification factor and the physical significance of this is perhaps better shown by writing Eq. (1) in the form

$$A_v = g_m \frac{R_p r_p}{R_p + r_p} \tag{2}$$

That is, the voltage amplification is equal to the mutual conductance multiplied by the resistance of the load and the internal resistance in parallel.

Assuming the load to be 100,000 ohms, the voltage amplification is 31.3. For a load of 200,000 ohms this is increased to 56.5.

Fig. 8 shows the relation between load resistance and amplification for loads up to 400,000 ohms.

The use of the screen-grid tube is, of course, not limited to radio-frequency amplification, but it must always be remembered

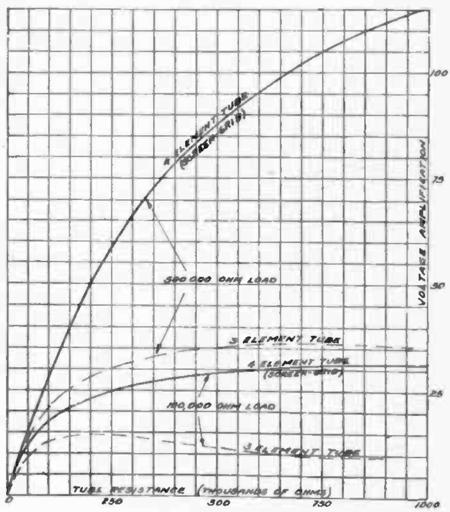


Fig. 9—Variation of Voltage Amplification with Plate Resistance.

that the voltage amplification depends almost entirely upon the load impedance, hence the over-all frequency characteristic of tube and load is very different from what would be obtained with a three-electrode tube having low plate resistance. One way of explaining this difference between the screen-grid tube and the ordinary three-electrode tube is to say that in the three-electrode tube circuit where the load impedance is usually higher than the plate resistance, the current through the load is determined more by the load impedance than by the plate resistance. In the screen-grid tube, the plate resistance is almost invariably higher than the load impedance and the current is determined mostly by the plate resistance instead of the load impedance. In the three-electrode tube it is often considered desirable to have a low plate resistance, but in the screen-grid tube it is made as high as possible. This is simply due to what has already been mentioned, that in the three-electrode tube, an increase in plate resistance is always accompanied by a decrease in mutual conductance. Hence, for any given value of load resistance there is an optimum tube resistance for maximum amplification assuming a definite electrode structure. In the screen-grid tube an increase in plate resistance by improved screening has an inappreciable effect on mutual conductance with the result that *for any value of load resistance* the higher the plate resistance of the tube, the higher will be the voltage amplification. Fig. 9 shows the variation of voltage amplification with plate resistance for a typical three-electrode tube and a screen-grid tube. The curves for the three-electrode tube always go through a maximum at a finite value of plate resistance while the curves for the screen-grid tube rise indefinitely and approach a limit equal to $g_m R_p$.

Dr. Hull has called attention to the fact that with infinite plate resistance the mutual conductance becomes the only parameter of the tube. In the amplification equation already given,

$$A_v = g_m \frac{R_p r_p}{R_p + r_p},$$

if g_m is constant A_v increases as r_p increases until in the limit with r_p infinite, $A_v = g_m R_p$. The current in the output circuit per volt input is equal to g_m regardless of the load impedance. It is possible by means of secondary emission effects to operate a properly designed screen-grid tube under conditions which will give an infinite resistance over a limited range or even to make the resistance negative. Such secondary emission effects comprise an entire field of study in themselves and no attempt will be made to discuss them in this paper.

Screen-Grid Transmitting Tubes

In radio-frequency power amplifier circuits, the problem of preventing self-oscillation of the amplifier tube is much the same as in receiving circuits. With three-electrode tubes, it is usually necessary to employ some means for neutralizing the internal capacity of the tube to prevent oscillation when the plate and grid circuits are tuned to nearly the same frequency. As in receiving circuits the screen-grid provides a means of doing away

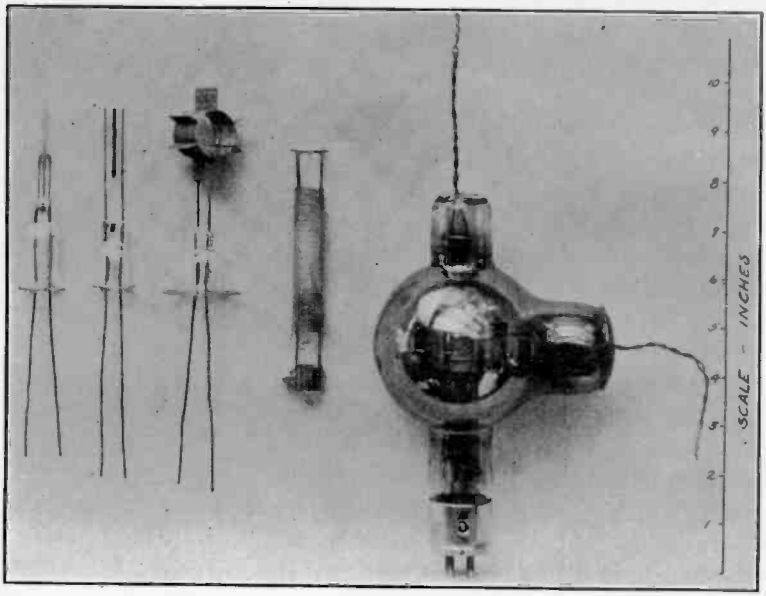


Fig. 10—75-Watt Screen-Grid Transmitting Tube.

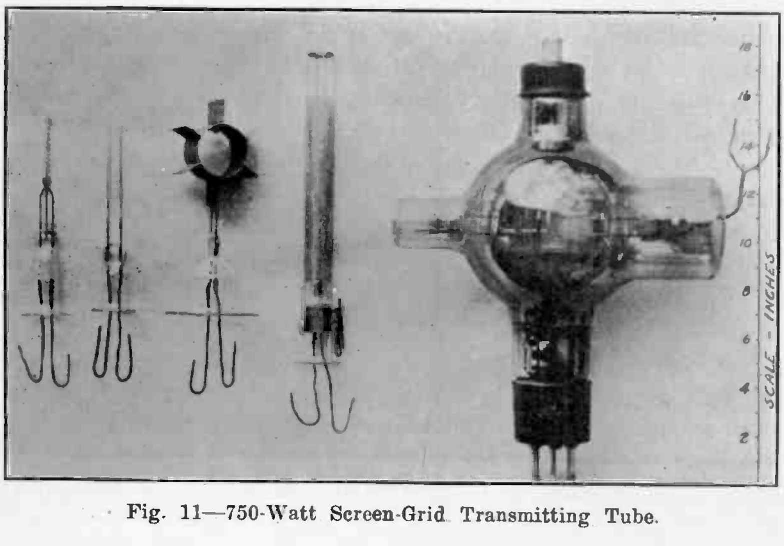


Fig. 11—750-Watt Screen-Grid Transmitting Tube.

with the necessity for neutralization, and screen-grid transmitting tubes with output ratings up to 750 watts are being used successfully. Two of these are shown in Figs. 10 and 11. Such tubes are used in much the same way as the three-electrode power amplifier tubes except that the neutralizing circuits are of course omitted. The grid and plate circuits must be shielded from each other to prevent feedback since the shielding in the tube eliminates only the feedback through the tube itself. The elimination of the neutral-

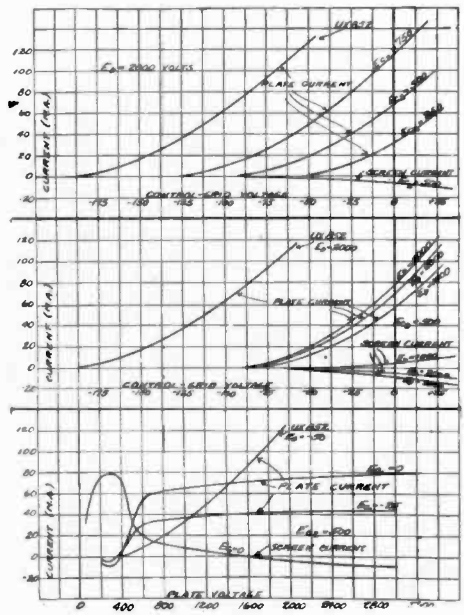


Fig. 12—Characteristics of 75-Watt Screen-Grid Tube.

izing circuits, of course, simplifies the transmitter design and, particularly in the case of transmitters designed to work on a number of different frequencies, often results in a reduction in the number of controls.

The design of the two tubes illustrated is unique in one respect in that they have been developed from two regular three-electrode transmitting tubes by the addition of the screen-grids. The smaller tube has an output rating of 75 watts and is similar to the UX-852 Radiotron while the larger tube has been derived from a 750-watt short wave transmitting tube. In each case the filament and plate and in fact practically the whole electrode structure are the same in the four-electrode as in the three-electrode tube, the screen being mounted on the regular filament and grid stems.

Static characteristics of the 75-watt tube are shown in Fig. 12 and for comparison some of the curves for the UX-852 have been drawn in also. Similar curves for the 750-watt screen-grid tube are shown in Fig. 13.

The effect of the screen-grid on the feed-back capacity is shown by a comparison of the control-grid to plate capacities of the three

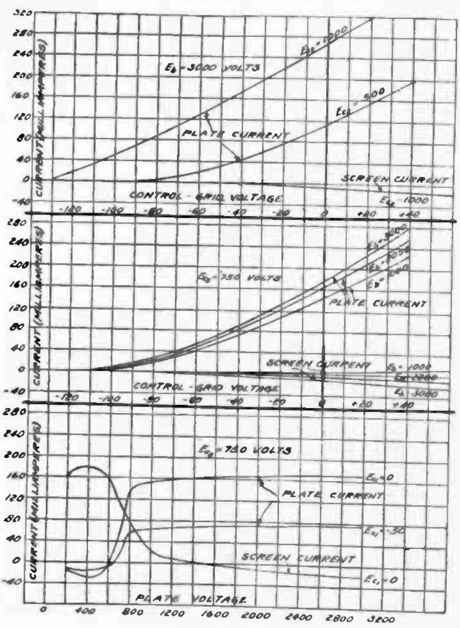


Fig. 13—Characteristics of 750-Watt Screen-Grid Tube.

and four-electrode tubes. In the UX-852 the grid-plate capacity is about 2.5 mmf., which is relatively low for a three-electrode tube since it is designed for short wave use. The screen reduces this to 0.05 mmf. In the 750-watt tubes the screen reduces the capacity from 3.9 mmf. to 0.05 mmf.

The Space-Charge-Grid Tube

The early work on this form of tube was done by Langmuir[8] in this country, and by Schottky[1] and Barkhausen[3] in Germany.

[8] Langmuir. U. S. Patent No. 1558437 filed Oct. 29, 1913, issued Jan. 1, 1924.

The tube takes it name from the fact that the inner grid is used in such a way as to reduce the space-charge around the cathode and thereby reduce the internal plate resistance of the tube. This is done without any decrease in amplification factor, hence, there is an increase in mutual conductance corresponding to the decrease in plate resistance.

The inner grid or space-charge-grid, in its simplest connection, is kept at a fixed positive potential with respect to the filament.

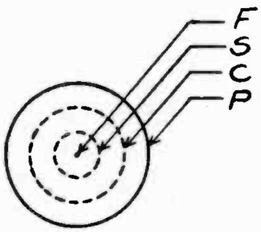


Fig. 14

The outer grid is the control electrode and performs exactly the same function as in a three-electrode tube. The arrangement of the two grids is therefore just opposite to that of the screen-grid tube.

The reduction in space charge is the result of the formation of a virtual cathode in the region between the two grids and very close to the outer one. Fig. 14 illustrates a cross section of the tube

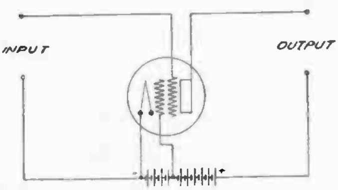


Fig. 15

and Fig. 15 shows the simple circuit connections. The positive voltage on the space-charge-grid is usually about $\frac{1}{4}$ to $\frac{1}{2}$ the plate voltage. Electrons leaving the cathode F, (Fig. 14) are accelerated by the force exerted on them by the first grid S. Some of them strike S and comprise part of the current flowing in the space-charge-grid circuit. Others pass through the meshes of the grid and since they are now travelling against the electrostatic force they come to rest in a region close to the control-grid C. Some are now drawn back to S, but since others take their place there is a continuous supply of electrons which are at rest or nearly so in the region close to the control grid. The effect is much the same as if an actual cathode had been placed very close to the outer grid—much closer than could be done by mechanical means. In this way the plate resistance is reduced just as it would be in a three-electrode tube if the grid were placed very close to the filament. Of course in

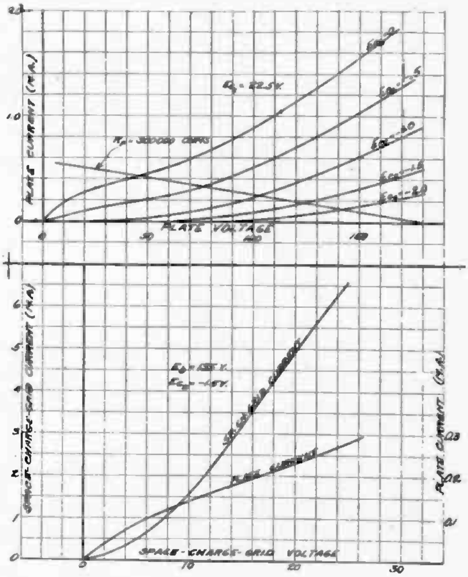


Fig. 16—UX-222 Characteristics, Space-Charge-Grid Connection.

designing a space-charge-grid tube the amplification factor and plate resistance may be made high or low as desired just as in a three-electrode tube. However, the greatest gain in mutual conductance, as compared with a three-electrode tube having the same amplification factor, occurs in a tube with a medium or high amplification factor.

Characteristics of the UX-222 as a Space-Charge-Grid Tube

The UX-222 is primarily designed to be used as a screen-grid amplifier but by proper connections to the grids it may be used as a space-charge-grid tube. Since the outer grid has a very close mesh it is obvious that the tube will have a relatively high amplification factor (compared with common three-electrode tubes) when used in this way although not nearly so high as when used as a screen-grid tube. Under usual operating conditions the amplification factor is about 60 to 80. Naturally, the plate resistance will be high also, and the tube is therefore most useful with high impedance coupling circuits such as in resistance-coupled amplifiers.

Figs. 16 and 17 show the static characteristics of the tube with space-charge-grid connection. The plate current curves have the same general form as those of a three-electrode tube. The current to the space-charge-grid, Ic_1, is higher than the plate current at negative values of control grid voltage Ec_2, but as Ec_2 is made

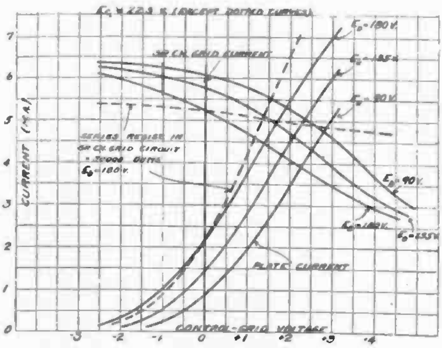


Fig. 17—UX-222 Mutual Characteristics, Space-Charge-Grid Connections, $Ec_1=22.5$ v. (except dotted curves).

more and more positive, Ic_1 decreases and eventually becomes less than the plate current. This is explained by the fact that at low values of plate current most of the electrons which pass through the space-charge-grid eventually return to it and comprise a relatively high current, but as the control-grid voltage is made more positive the plate takes more and more electrons from the space between the two grids and fewer are left to return to the inner grid. If the control-grid is made sufficiently positive, all of the electrons passing through the inner grid go on to the plate (or outer grid) and the inner grid current reaches its minimum value.

The amplification factor, plate resistance and mutual conductance of the UX-222 used as a space-charge-grid tube are shown in Fig. 18.

Using this tube in a resistance-coupled audio amplifier with a coupling resistance of 300,000 ohms, grid bias of -0.75 volt, and 180 volts plate supply voltage the actual plate voltage at the tube is 90 volts (See load line on Fig. 16). The amplification factor is approximately 80 and plate resistance 160,000 ohms. The increase in mutual conductance due to the space-charge-grid is very apparent here. A three-electrode tube of the same general size with an amplification factor of 80 and worked at a plate voltage of 90 would have a mutual conductance of about 125 or only one-fourth as much as the space-charge-grid tube.

One of the limitations in the use of tubes with very high amplification factor in resistance-coupled amplifier circuits is that

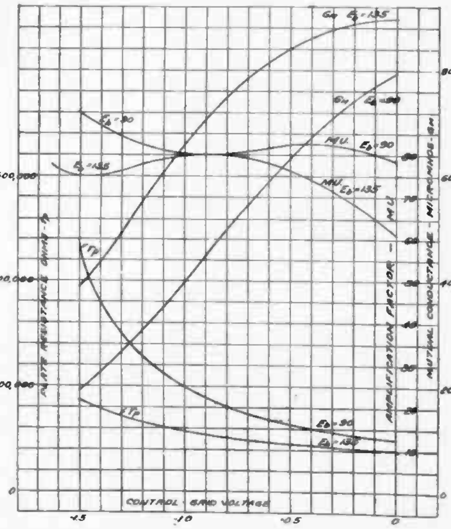


Fig. 18—UX-222 Characteristics with Space-Charge-Grid Connection. $Ec_1 = +22.5$ volts.

their effective input capacity is apt to be very high. This results in a falling off of amplification at the higher audio frequencies. The higher the amplification of the stage, the more serious this effect becomes because the input capacity is

$$Cg = Cgf + Cpg(A_v + 1). \tag{3}$$

where Cgf = direct grid-filament capacity
Cpg = direct plate-grid capacity
A_v = voltage amplification of stage.

This same limitation applies to the space-charge-grid tube having high amplification factor. As will be shown later the screen-grid tube used with resistance coupling does not have this high input capacity although it does have another sort of limitation.

Before leaving the subject of the space-charge-grid characteristics it may be well to repeat that all that has been said about the high amplification factor and plate resistance applies only to the UX-222 and not to all space-charge-grid tubes. These tubes can be made with any desired amplification factor, the same as a three-electrode tube. Tubes with a factor of 6 to 10 have been used quite extensively in Europe for a number of years. European practice has been to design and use the tubes in such a way as to permit very low plate voltages, of the order of 6 to 20 volts. Some work has been done in England with no plate voltage except the

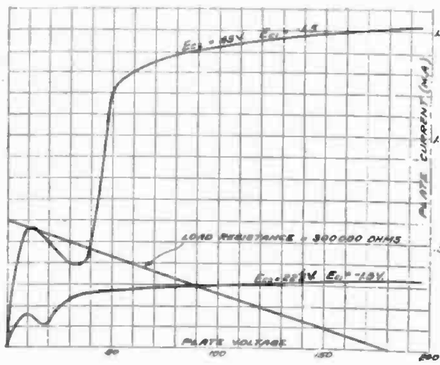


Fig. 19—UX-222 Characteristics with Resistance Coupling.

filament drop, but the performance in this case is not as good as when at least 6 or 8 volts are used. It might seem that a space-charge-grid could be used to raise the mutual conductance of a power amplifier tube but this has not yet been done very successfully. A power amplifier tube must ordinarily work with high bias and high a-c. input voltage. In a tube containing a space-charge-grid the curvature of the plate-voltage plate-current curves at high negative grid voltages is such that the distortion is abnormally high. Hence, the increase in power output is not as great as might be expected from the large increase in mutual conductance which occurs at lower negative grid bias and with small amplitudes.

The Screen-Grid Tube as an Audio Amplifier

An examination of the characteristics of the screen grid tube indicates that while the tube cannot be used as an audio amplifier in the ordinary way with transformer coupling on account of its high plate resistance, it may be used with resistance coupling. It has already been pointed out that when the UX-222 is used as a space-charge-grid tube with resistance coupling the voltage amplification is high but falls off at the higher frequencies. The screen-grid tube has a grid-plate capacity of only 0.02 mmf. hence, even when multiplied by a voltage amplification of 40 is only a small part of the total input capacity, which is therefore practically equal to the grid-filament capacity itself. However, the amplification given by the screen-grid tube is not as great as might be expected. This is explained by reference to Fig. 19. If it is assumed that the supply voltage is 180, a series load will give a load characteristic as shown by the straight line passing through the 180-volt point and having a slope equal to the reciprocal of the resistance.

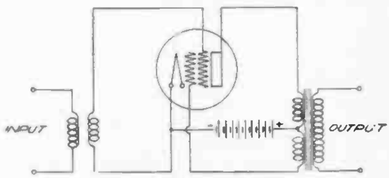


Fig. 20

This intersects the plate current curves for $Ec_1 = 0$ and $Ec_1 = -1.5$ at points far outside the normal operating range, and off the flat part of the plate characteristic. There are two ways of correcting this condition—the screen voltage may be lowered or the control-grid voltage made more negative. Either procedure will lower the mutual conductance but this cannot be avoided. Referring again to Fig. 19, the lower curve represents proper operating conditions and here the voltage amplification for small swings is about 40.

Double Function and Miscellaneous Uses

Most of the four-electrode tube applications of this class may be divided into two groups—first, those in which one of the grids is made to serve as a space-charge-grid and at the same time as a control electrode or as an output electrode, and second, those in which the two grids are control electrodes only. Numerous varieties of tubes and circuits have been proposed and no attempt will be made to describe all of these in this paper. Only a few will be discussed in order to illustrate some of the general principles involved.

An examination of the static characteristics of a space-charge-grid tube immediately suggests the possibility of making use of the variation of space-charge-grid current with control-grid voltage, and a large number of schemes for doing this have been proposed. The variations in grid current are of course opposite to the variations in plate current and it is a simple matter to combine the output of both circuits. For example, an output transformer with a tapped primary connected as shown in Fig. 20 will combine the two outputs in correct phase relation.[9] A similar result may be obtained with resistance coupling as in Fig. 21. In the latter case there is an added advantage in that no direct current need flow through the load if the resistances are properly balanced. This is sometimes important when the tube is used for measurement

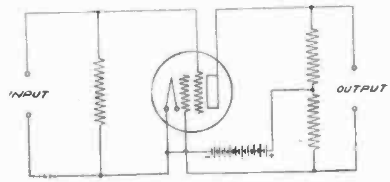


Fig. 21

purposes and also permits the amplification of d-c. voltages. Another sort of push-pull arrangement for radio-frequency amplification has been proposed in France[10] in which the space-charge-grid performs its usual function and at the same time acts as a neutralizing condenser. The adjustment of this circuit is apt to be somewhat critical because the alternating voltage at the space-charge-grid which is used for neutralizing is partially dependent upon the electron emission of the filament. Hence, a close adjustment of filament temperature is required.

All of these schemes have been shown with common battery for plate and space-charge-grid. If, as is usually the case, the best space-charge-grid voltage is less than the plate voltage a series resistance may be used to reduce this voltage to the right value, which introduces another effect of some interest. The circuit arrangement is shown in Fig. 22. When the control-grid voltage is varied the current flowing through the resistance varies in a direction opposite to that of the plate current, that is, when the plate current rises the space-charge-grid current falls and conse-

[9] VanderBijl, U.S. Patent No. 1479779, filed July 20, 1920, issued Jan. 1, 1924.

quently causes the voltage between space-charge-grid and filament to rise. This voltage exerts a certain amount of control upon plate current and although less in magnitude, it is the same in direction as the control of the control-grid voltage, hence, the rise in space-charge-grid voltage aids the original change in control-grid voltage. The amplification is therefore somewhat greater with the resistance in the inner grid circuit even though the mean space-charge-grid voltage is the same. The dotted curves in Fig. 17 show the effect of using this resistance. The space-charge-grid current varies only slightly with varying control-grid voltage while the plate current changes more rapidly than without the resistance.

Another method of making use of the variation in space-charge-grid current is to couple this grid circuit back to the input and produce regeneration. Obviously, the reverse effect may be

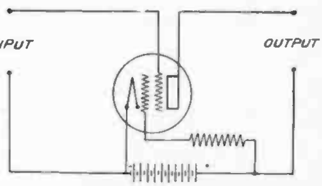


Fig. 22

used to counteract any undesirable regeneration which may already exist due to coupling from the plate circuit to the input.

At first thought it might seem that by virtue of the variation of space-charge-grid current this type of tube should give the same results as two three-electrode tubes in any of the balanced circuits such as the push-pull circuit. This is not the case, however, because the a-c. power which may be drawn from the space-charge-grid circuit is strictly limited. That is, while the control-grid may produce large current changes in the space-charge-grid circuit when the latter contains no external impedance, the current changes become much smaller when a load circuit is connected. Otherwise stated, the voltage amplification factor of the control grid with respect to the space-charge-grid $\left(-\frac{\partial e_{g_1}}{\partial e_{g_2}}\right)_{i_{g_1}\ \text{const.}}$ and the internal output resistance of the space-charge-grid circuit $\left(\frac{\partial e_{g_1}}{\partial i_{g_1}}\right)$ are low even though the mutual conductance $\left(\frac{\partial i_{g_1}}{\partial e_{g_2}}\right)$ is relatively high.

In the second group of double function circuits in which both grids act as control electrodes alone may be mentioned the many reflex circuits, regenerative and super-regenerative circuits, frequency changers, etc., which have appeared in foreign publications.[10–18] The number of combinations of electrode functions is almost unlimited and many of them have a certain degree of usefulness although few have come into common use. This is probably due to the two limitations to which practically all of this group of double function schemes are subject. In order to act as control electrodes, the two grids must be operated at a mean potential of zero or slightly negative so as not to load the input circuit. With the two grids between filament and plate and at this low potential the plate resistance is relatively high and the control of either grid is relatively low, and less than would be obtained in a three-electrode tube under corresponding conditions. The other limitation applies to circuits in which both grids have radio-frequency voltages impressed upon them, as for example, one grid excited by antenna and the other coupled to the plate circuit for regeneration. This limitation is the electrostatic capacity between the two grids which ordinarily makes it impossible to vary the potential of one grid without also affecting the other.

One other type of double function circuit uses the plate as one of the control electrodes and the output is taken from one of the grids.[19]

Conclusion

Particular attention should be called to the foreign publications on four-electrode tubes. Those which have been given as references represent only a small part of all that have appeared and they have been chosen merely as representative of the work which has been going on for a number of years. Strangely enough the screen-grid tube although developed from Schottky's early work has been mentioned very little in the foreign literature until very recently,

[10] Barthelemy, *L'Onde Electrique*, No. 64, pp. 152–160 Apr. 1927.
[11] Scott–Taggart, *The Electrician*, Jan. 21, 1921 pp. 97–98.
[12] De Mare. *La T. S. F. Moderne*, No. 28, pp. 494–500 Oct. 1922.
[13] deVoogt, *Radio Nieuws*, 4, p. 99, Apr. 1921.
[14] Corver, *Radio Nieuws*, 4, p. 104, Apr. 1921.
[15] Nozieres et Giroud, *L'Onde Electrique*. pp. 583–590 Dec. 1924.
[16] Chauvierre, *QST Fr. et Radioelectricite*, Vol. 8, pp. 8–16, Apr. 1927.
[17] Mittelman, *Der Radio Amateur*, Vol. 4, No. 29 pp. 571–573, No. 30, pp. 595–597, No. 31 pp. 605–607, No. 32 pp. 629–632 1926.
[18] Decaux, *L'Onde Electrique*. No. 61, pp. 1–18 Jan. 1927.
[19] Donisthorpe, Proc. I.R.E. Vol. 12, No. 4, pp. 411–421 Aug. 1924.

apparently much more work having been done on space-charge-grid tubes and on double-function circuits.†

The degree of general usefulness of the various four-electrode tubes and circuits may perhaps be expressed by saying that the space-charge-grid tube performs the same kind of functions as the three-electrode tube but at lower plate voltages or with somewhat higher amplification; the double function circuits while often very interesting in themselves, accomplish with one tube what can often be done almost as simply, as effectively, and sometimes less expensively with two three-electrode tubes; but the screen-grid tube not only permits a degree of radio-frequency amplification much greater than can be obtained with a three-electrode tube but also eliminates the feedback which is so often an unwanted function of the three-electrode tube.

In conclusion, the writer wishes to thank Messrs. O. W. Pike, A. C. Rockwood, and B. J. Thompson for their assistance in the preparation of the data given on the screen-grid tubes.

† (Author's note:—Since the first draft of this paper was written, screen-grid receiving tubes have been placed on the market in England and several excellent articles on the subject have appeared in English publications. See references 20, 21, and 22 below.

[20] McLachlan, *Wireless World*, Vol. XXI pp. 260–263 Aug. 31, 1927 and pp. 307–310 September 7, 1927.

[21] McLachlan, *Exp. Wireless and Wireless Eng.*, Vol. IV pp. 597–600 October 1927.

[22] Beatty, *Exp. Wireless and Wireless Eng.*, Vol. IV pp. 619–625 October 1927

THE INVERTED VACUUM TUBE, A VOLTAGE-REDUCING POWER AMPLIFIER*

Frederick Emmons Terman
(Stanford University, California)

Summary—*By interchanging the functions of the grid and plate of the usual vacuum tube a voltage-reducing power amplifier is obtained. The usual vacuum tube acts as a voltage-increasing power amplifier.*

The static curves of the inverted vacuum tube are similar in form to the corresponding curves of the ordinary vacuum tube, and the theory of the inverted vacuum tube is analogous in all respects to the usual vacuum-tube theory, the only difference being reduction instead of amplification of voltage.

It is relatively simple to construct an inverted vacuum tube with wide clearances between plate and the rest of the tube, so that potentials of hundreds of thousands of volts can be applied to the plate, while the effect of this high voltage stepped down in almost any desired ratio is obtained in a low-potential circuit.

Introduction

THE inverted vacuum tube is a three-element vacuum tube that has been made to operate as a voltage step-down device by interchanging the grid and plate functions in the ordinary tube circuit. The basic circuit of the inverted vacuum tube is shown in Fig. 1. The essential features of this circuit are: (1) the grid is operated at a positive potential and so draws considerable

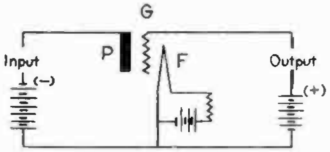


Fig. 1—Circuit of the Inverted Vacuum Tube.

current; (2) the plate is operated at a negative potential and so draws no current; and (3) the input circuit is the plate circuit, while the output circuit is the grid circuit. The inverted vacuum tube is merely an ordinary vacuum tube with the grid doing what the plate usually does, and with the plate carrying on the functions usually performed by the grid.

The inverted vacuum tube acts as a voltage reducer, or voltage step-down device, because a voltage applied at the input, *i.e.*, to the plate, has the same effect on the grid current as though a similar but much smaller voltage had instead been added to the grid battery. If the vacuum tube used has a voltage amplification

*Original Manuscript Received by the Institute December 12, 1927.
* Presented at New York Institute Meeting, February 1, 1928.

factor of μ, the step-down ratio will be approximately μ. The inverted vacuum tube acts as a power amplifier, for with the plate negative practically no energy is consumed in the plate circuit when a voltage is applied to the input, while at the same time this input voltage controls an appreciable grid current, thus controlling considerable energy in the grid, or output, circuit.

The inverted vacuum-tube circuit was developed for the purpose of taking oscillograms of voltages without disturbing the action to be observed by drawing current to operate the oscillo-

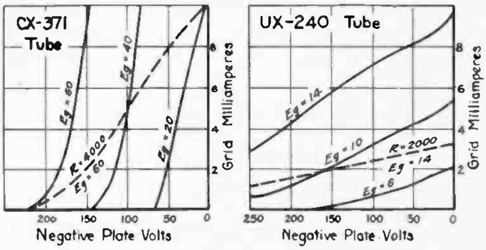


Fig. 2—Relation of Plate Voltage and Grid Current at Constant Grid Volts.

graph vibrator. The device will also function as a generator of either radio- or audio-frequency oscillations, as an amplifier of voltages, as a voltmeter, as a rectifier, etc. These applications are given detailed treatment in a later section of the paper.

Static Curves

The operation of the inverted vacuum tube can best be visualized in terms of curves giving the relation between grid current and plate and grid voltages. A complete set of such curves for two representative tubes is given in Figs. 2, 3, 4, 5, and 6. One of these tubes has a μ of about 3 (step-down ratio of approximately 3) while the other has a μ of about 30 (step-down ratio of approximately 30). As the two companion sets of curves are plotted to the same scales, and apply to tubes very similar to each other in general construction except for the value of μ, the effect of changing the step-down ratio can be readily visualized. All potentials in the figures are measured with respect to the negative filament lead.

The curves of Fig. 2 show the relation between grid current and negative plate voltage for various values of positive grid voltage. The results are seen to have a form similar to the $E_g - I_p$

(grid-voltage, plate-current) curves of the usual vacuum-tube circuit. An important feature is that each curve in Fig. 2 has a straight line portion of more or less length. Variations of plate voltage within the boundaries of this straight line portion give rise to variations in grid current that are directly proportional to the plate voltage changes. When operating on this straight line part

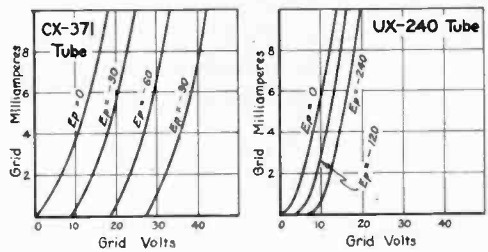


Fig. 3—Relation of Grid Current to Grid Voltage at Constant Plate Volts.

of the characteristic *the grid current variations give a distortionless representation of any a-c. or d-c. voltage applied at the input shown in Fig. 1.*

The dash lines in Fig. 2 give the characteristic when a resistance is inserted in series with the grid. The effect of this resistance is to straighten out the characteristic, and to extend greatly the range of plate voltage over which the grid current is proportional to changes in plate potential.

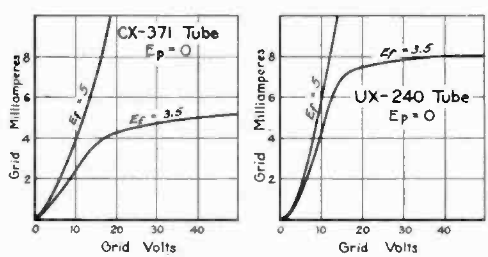


Fig. 4—Static Characteristic Illustrating Effect of Saturation

Fig. 3 gives the same information as Fig. 2 but in another form. The curves of Fig. 3 correspond to the usual $E_p - I_p$ curves of the vacuum tube, and have the same form. The effects of limited electron emission from the filament are shown in Fig. 4. It is seen that as long as the filament temperature is sufficient to emit a small surplus above the number of electrons flowing to the positive grid, the filament temperature is unimportant. Portions of the curves in Fig. 4 where the electron emission is insufficient to furnish the necessary supply of electrons required for normal operation are flattened out as the figure indicates. The departure from normal takes place at lower and lower grid currents as the filament voltage is reduced because the electron emission drops rapidly with reduction in filament heating.

The curves in Fig. 5 are very important in the theory of the inverted vacuum tube, and will be discussed in the next section.

Fig. 6 differs from Fig. 2 only in showing the effect on the grid current of making the plate voltage positive. It is seen that as soon as the plate begins to take current, the grid circuit is robbed

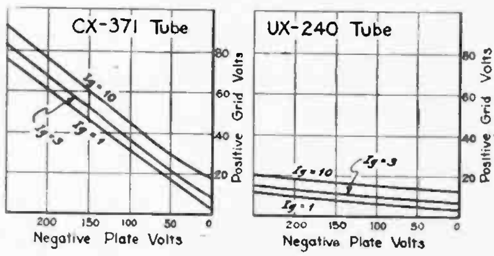


Fig. 5—Relation of Plate and Grid Voltages Required for Constant I_g.

of a large part of its current. The very sudden change of curvature in the characteristics at zero plate volts indicates that this point gives a large rectifying effect.

Theory

The theory of the inverted vacuum tube rests upon the fundamental fact that the current flowing to the positive grid depends upon the electrostatic field existing between filament and grid, and is substantially independent of how the field is produced. Both the grid and plate potentials affect the magnitude of this field. It can be shown from the theory of electrostatics that the actual field is proportional to the quantity (E_g+E_p/m), where E_g and E_p are the potentials of the grid and plate respectively, and m is a constant that is determined by the geometrical proportions of the tube and is not affected by the electrode potentials. Stating that the field intensity between grid and filament is proportional to the quantity (E_g+E_p/m) is equivalent to saying that E_g volts applied to the grid produce the same field intensity as is produced by the application of mE_g volts on the plate. The constant m is usually larger than unity, ranging commonly from 3 to 40. The constant m is larger than unity because the grid is so constructed and located that it is in a better position to produce a high field intensity between filament and grid than is the plate.

The grid current is determined by the field intensity between filament and grid, and this field is proportional to the quantity (E_g+E_p/m). For constant grid current it follows that (E_g+E_p/m) must be constant. Fig. 5 shows a series of curves for different constant values of grid current. These curves are practically straight lines that are substantially parallel. The equation of a straight line in Fig. 5 is:

$$(E_g+E_p/m)=\text{Constant}$$

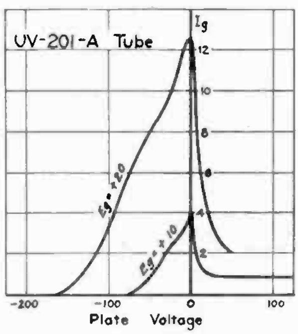


Fig. 6—Complete Static Characteristic of Inverted Vacuum tube.

where $(1/m)$ is the slope of the line. Since the lines are straight it follows that a constant grid current is obtained for all combinations of voltages that keep the quantity (E_g+E_p/m) constant. Since the factor m depends only on the slope of the lines in Fig. 5 and the lines are nearly parallel, it follows that m is a constant substantially independent of the tube voltages and current.

The lines in Fig. 5 depart a slight amount from perfect parallelism, and perfect straightness. To this extent the actual tube behavior departs from the simple theory that makes m a geometrical constant of the tube independent of electrode voltages, and that makes the grid current depend only on the value of the quantity (E_g+E_p/m).

The constant m is the same as the constant μ of the usual vacuum-tube circuit. Tests show that when the tube is used in the inverted manner, m and μ as determined from measurements are not exactly the same, m being in general slightly greater than μ. For this reason the symbol m is used for the μ of the inverted tube.

The constant m is the step-down ratio of the inverted vacuum tube. According to the theory, an increment of ΔE_p in plate potential will have an effect on the grid current equivalent to the effect of adding $\Delta E_p/m$ volts in the grid circuit. *It follows from this that the effect on the grid circuit of an input voltage e_s in Fig. 1 is exactly the same as though this input voltage had been replaced by a fictitious generator of voltage e_s/m acting in the grid or output circuit.*

The equivalent circuit of the inverted vacuum tube is given in Fig. 7. The effect of a signal voltage e_s applied to the input (plate) circuit is as though a generator having a voltage $-e_s/m$ was inserted between the grid and filament of the tube. The minus sign is present because of the direction in which this voltage is assumed to act in Fig. 7 which is the most convenient direction.

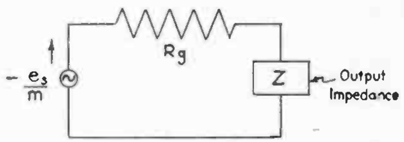


Fig. 7—Equivalent Circuit of the Inverted Vacuum Tube.

The resistance R_g is the dynamic grid resistance, *i.e.*, R_g is the resistance the grid circuit offers to an increment of voltage such as $-e_s/m$. It is the a-c. resistance of the grid circuit, and is analogous to the dynamic plate resistance R_p of the usual tube circuit. The value of R_g depends on the grid and plate-battery potentials, and can be determined by methods given in the next section. The voltage e_s that is applied to the input will generally be an a-c. voltage of magnitude E_s and frequency f. This voltage superimposed on the negative plate battery potential by being introduced at the point marked "Input" in Fig. 1, is equivalent to a voltage of amplitude $-E_s/m$ and of frequency f acting in the equivalent circuit. The current that this equivalent voltage produces depends upon the impedance of the equivalent circuit. This circuit consists of the dynamic grid resistance R_g in series with whatever impedance is inserted in the grid circuit at the point marked "Output" in Fig. 1. The grid current produced as a result of applying the a-c. input voltage of $e_s = E_s \sin \omega t$ is then

$$\text{a-c. grid current} = \frac{-(E_s/m)\sin \omega t}{R_g + Z}$$

where Z is the output impedance inserted in the grid circuit.

An important property of the inverted vacuum tube is the amount of change of grid current obtained with a given change of plate voltage, and with no load or output impedance present in the grid circuit. The constant expressing this property is the ratio dI_g/dE_p, and can be called the reflex mutual conductance of the inverted vacuum tube, and given the symbol g_r. The reflex

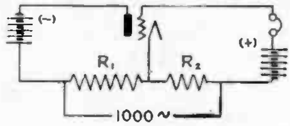


Fig. 8—Circuit for Measuring the Step-down Ratio of the Inverted Vacuum Tube.

mutual conductance of the inverted vacuum tube is analogous in all its properties to the mutual conductance g_m of the usual vacuum-tube circuit. In terms of m and R_g the reflex mutual conductance is

$$g_r = 1/mR_g$$

When there is no load impedance inserted in the grid circuit the application of a small voltage E to the plate circuit causes a change of grid current of Eg_r.

Measurement of Constants of the Inverted Vacuum Tube

The voltage step-down ratio m of the inverted vacuum tube can be measured by means of the bridge circuit shown in Fig. 8.

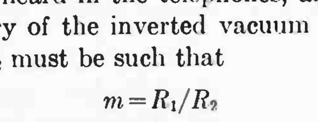


Fig. 9—Circuit for Measuring the Dynamic Grid Resistance of the Inverted Vacuum Tube.

When no sound is heard in the telephones, an elementary application of the theory of the inverted vacuum tube shows the resistances R_1 and R_2 must be such that

$$m = R_1/R_2$$

Resistances for R_2 as low as ten ohms are satisfactory. Either of the resistances may be varied to establish the balance. The actual grid voltage to which the measurement applies is the battery voltage minus the voltage drop of the grid current in flowing through the phones and R_2. To make this correction small, low resistance phones and a moderately small value of R_2 are desirable.

The dynamic grid resistance R_g can be measured by the use of an alternating current bridge, as shown in Fig. 9. The scheme merely consists in making the grid-filament resistance the X arm of the bridge. The grid potential to which the measurements apply is the battery voltage minus the voltage drop in the bridge of the

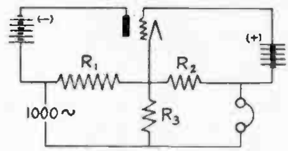


Fig. 10—Circuit for Measuring the Reflex Mutual Conductance of the Inverted Vacuum Tube.

grid current. By proper arrangement of bridge resistances the correction can be kept small.

The reflex mutual conductance g_r of the inverted vacuum tube can be measured by the circuit shown in Fig. 10. When the resistances are such as to give no sound in the phones, an elementary application of the inverted vacuum-tube theory shows that

$$g_r = R_3/R_1R_2$$

Any one of the three resistances may be varied, although R_3 is

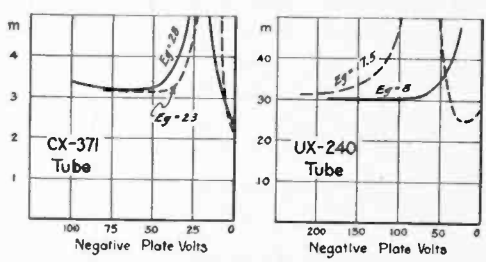


Fig. 11—Step-down Ratio of Inverted Vacuum Tube.

generally most satisfactory for the variable element. Suitable values are $R_1 = 1000$ ohms, $R_2 = 100$ ohms, and R_3 variable up to 100 ohms in tenth ohm steps. Correction for the voltage drop in R_2 due to grid current must be made to get the grid voltage from the battery potential.

In all of these measurements it is desirable to make the a-c. input voltage to the measuring equipment small. With large inputs there is some second harmonic current generated, which masks the fundamental tone for which the bridge is to be balanced. A microphone hummer is a suitable source of audio-frequency energy for the measurements.

The constants of the inverted vacuum tube can also be derived from the static curves by methods analogous to those applied to static curves of ordinary vacuum tubes. The constants can also be determined by adding voltage increments in to the proper batteries, and reading the results on meters.

Constants of the Inverted Vacuum Tube

Results of measurements of m, and R_g for a low and a high μ tube are given in Figs. 11 and 12. Examination of Fig. 11 shows that the voltage step-down ratio m is subject to considerable fluctuations in value. Tests of a large number of tubes under

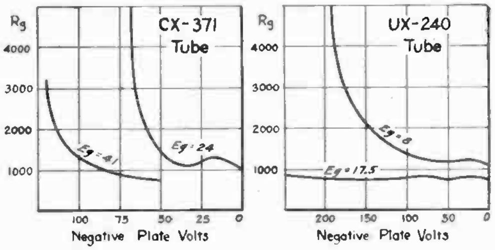


Fig. 12—Dynamic Grid Resistance of Inverted Vacuum Tube.

different conditions indicate that the step-down ratio m varies in an erratic manner when the grid current is large, and particularly when the negative plate voltage is small. For large negative potentials on the plate, and where the grid current is relatively small, the step-down ratio m is practically constant at a value approximately equal to the μ of the tube.

The dynamic grid resistance of the inverted vacuum tube is rather low, even for very low grid voltages. This is because of the proximity of the grid and filament in standard tubes. For ordinary receiving tubes, resistances in the order of 1000 ohms are found for grid potentials of around 25 volts. The dimensions of the grid do not seem to be so very important, for Fig. 12 shows that two tubes with very different grid constructions have grid resistances in the same order of magnitude.

Practical Applications of the Inverted Vacuum Tube

Oscillograph work: The inverted vacuum tube was originally developed as a means of taking voltage oscillograms in vacuum-tube circuits where the voltage was high, and where circuit operation would be affected by even a small consumption of current in the measuring device. The inverted vacuum tube is ideally suited for this purpose. The voltage wave to be photographed is applied directly to the plate using suitable plate bias battery. By the reducing action of the tube this high voltage is transformed into a smaller potential acting in the low impedance grid circuit, developing current variations that can be registered by the oscillograph.

The best circuit for oscillograph work is that given in Fig. 13. The voltage of the plate bias battery should be such as to cause the tube to operate on a straight line portion of its characteristic. The resistance R is to straighten out the characteristic of the tube,

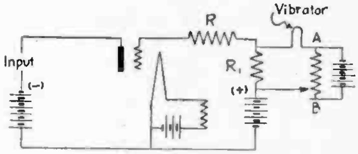


Fig. 13—Circuit for Operation of Oscillograph by Inverted Vacuum Tube.

and should be at least twice the dynamic grid resistance. The resistance R_1 and the potentiometer AB balance the normal steady grid current out of the vibrator. Values of 100 to 1000 ohms are suitable for R_1, while AB should have considerably less resistance than R_1, such as one-tenth as much. In some cases it may be satisfactory to put the vibrator directly in series with the grid circuit, and omit R_1 and the associated potentiometer.

The distortion introduced by the tube can be determined from the static curves, and the oscillograms corrected accordingly. This distortion can be minimized by making use of the straight line portions of the characteristic, and also by inserting a resistance in series with the grid battery, shown at R in Fig. 13. This resistance has the effect of straightening out the characteristic, which becomes practically a straight line if R is two or three times the dynamic grid resistance. When the resistance is used a higher grid battery potential must be employed to make up for the additional voltage drop.

The vibrator of an ordinary oscillograph requires from 50 to 100 milliamperes of current to give a good deflection. This amount of current will generally call for two 7.5-watt tubes in parallel, or a single 50-watt tube, if distortion is to be avoided in the transformation.

By reason of its practically infinite resistance, the plate circuit of the inverted vacuum tube can be safely introduced into any high-voltage low-amperage circuit. By the use of a tube with the proper step-down ratio, and with suitable insulation resistance, the high voltage to be photographed is stepped down without additional apparatus. The oscillograph is in a low potential circuit, and can accordingly be handled easily and safely. In cases where one desires to photograph a wave consisting of an alternating current potential superimposed on a d-c. potential, as in the case of the plate to filament voltage of an oscillating vacuum tube, the plate biasing battery can frequently be dispensed with.

Voltage amplification: In spite of the fact that it is fundamentally a voltage step-down device, the inverted vacuum tube

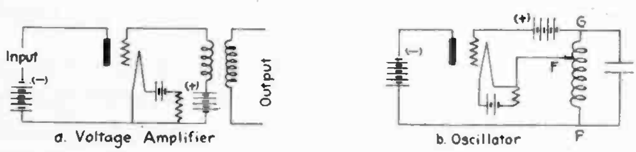


Fig. 14—Circuits for Practical Applications of the Inverted Vacuum Tube.

can function as a voltage amplifier by the use of an out-put transformer of suitable ratio. The circuit for voltage amplification is shown in Fig. 14-a. Amplification of voltage will be obtained when the step-up ratio of the transformer more than offsets the step-down ratio of the tube. High transformer ratios may be used because the dynamic grid resistance R_g that is in series with the primary is much lower than the plate resistance of ordinary amplifiers.

In an actual test using a CX-371 power tube with a step-down ratio shown in Fig. 11, and an RCA 9–1 ratio transformer, a voltage amplification between 2.6 and 2.7 was obtained for the band of frequencies from 300 to 2000 cycles. The flatness of this characteristic is due to the low value of R_g in the inverted vacuum tube.

Oscillator (or power amplifier): Since the inverted vacuum tube is a power amplifier it will act as an oscillator. Using the circuit shown in Fig. 14b, with +66 volts on the grid and −152 volts on the plate of a CX-371 tube, an oscillating current of 200 milliamperes at approximately 36 kilocycles was obtained in a low-resistance circuit. Because of the voltage-reducing action of the plate on the grid circuit, it is necessary that the plate portion of the oscillating coil be many times greater than the grid portion. In the example just mentioned, best results were obtained when the part *FP* had eight times as many turns as *FG*. The oscillator requires a high negative plate potential for satisfactory operation. Inserting a condenser in series with the plate, and omitting all leak other than that furnished by the condenser dielectric will furnish this bias after a fashion, but is not so satisfactory as a battery.

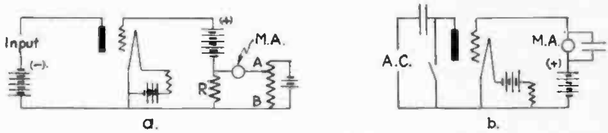


Fig. 15—Circuits for Using the Inverted Vacuum Tube as a Voltmeter.

Detection or rectification: The inverted vacuum tube can be used as a rectifier because of the non-linear properties it possesses. This rectification can be in the grid circuit (equivalent to ordinary anode rectification) or it can take place in the plate circuit with the aid of a condenser in series with the plate with a leak shunted around this condenser. Greatest sensitivity is obtained when the plate leak-condenser method is used, with little or no plate bias. The higher the resistance of the plate leak the more sensitive the detection.

The curves in Fig. 6 show a very sharp peak at the point of zero plate voltage. By operating at this point very sensitive grid circuit rectification can be obtained.

Measurement of high voltages: The inverted vacuum tube will very easily measure high d-c. voltages without drawing power from the d-c. source. The negative terminal of the unknown voltage is connected to the plate, and the magnitude of this potential is determined by the amount of grid current that is registered by a milliammeter in the grid circuit. From the static curves it is obvious that with a given grid voltage the grid current is determined by the negative plate voltage. By using the circuit shown in Fig. 15a, and making *R* rather large, and adjusting the voltage across *AB* until the milliammeter reads zero when the plate and filament are short-circuited, the milliammeter reading is practically direct reading in input volts, and is substantially independent of small variations in grid and filament battery voltages. Using a tube with a step-down ratio in the order of thousands (such a tube could be easily made), d-c. voltages of hundreds of thousands of volts could be easily measured in a safe manner, without drawing any current from the high voltage. The measuring equipment would require a filament battery, and about 90 volts grid battery, and everything except the plate lead could be at low potential.

Alternating current voltages can be measured very conveniently by the circuit shown in Fig. 15b. The procedure is to short-circuit the plate and filament and observe the grid current. The alternating current to be measured is then applied as shown in Fig. 15b, which causes the grid current to decrease. The crest value of the a-c. wave is then the same as the value of negative d-c. voltage that would have to be applied to the plate to produce the observed reduction in grid current. The condenser C must be able to withstand twice the crest value of the voltage to be measured and should have a capacity in excess of the plate-filament tube capacity. The circuit operates by reason of the fact that C accumulates a charge whenever the plate potential becomes the least bit positive. With the application of the alternating current the condenser accumulates charge until the voltage drop across the condenser equals the crest value of the applied voltage, when no more charge accumulates. This type of a-c. voltmeter can be used for large voltages, and consumes practically no power.

Input Impedance of Plate Circuit

The plate circuit of the inverted vacuum tube has practically infinite resistance because the high negative potential at which the plate operates repels all electrons. The input resistance is not appreciably lowered by small amounts of ionization of residual gas in the tube because the positive ions are in the main produced between the filament and grid, and accordingly migrate toward the filament, not to the plate. With a negative plate voltage of 60 volts, a CX-371 tube gave a plate current of less than 2×10^{-8} amperes, corresponding to an input resistance of 3,000,000,000 ohms. This small loss apparently was due to leakage over the glass walls of the tube, for it did not change when the filament current was turned off.

The input capacity of the inverted vacuum tube is likewise small, being substantially the capacity existing between the plate as one side, and the filament and grid connected together as the other side. Since the inverted vacuum tube is a voltage reducer, the input capacity is not appreciably increased by impedance in the output circuit, as is the case with the usual vacuum-tube amplifier.

Possibilities and Limitations of the Inverted Vacuum Tube

While the inverted vacuum tube can be used as an oscillator and voltage amplifier, it is inherently less satisfactory than the usual vacuum tube in the performance of these operations. The practical possibilities of the inverted vacuum tube appear to lie principally in oscillograph work, and in the measurement of a-c. and d-c. voltages of any magnitude without the consumption of power from the unknown potential. The voltages that can be handled directly by such a device appear to be of almost unlimited magnitude. An inverted vacuum tube made with a small plate electrode at one end of a tubular bulb, with the filament and grid at the other end, would stand very high potentials, and could be made to have almost any desired step-down ratio. The construction would be relatively inexpensive even for voltages in the hundreds of thousands.

It is to be noted that an ordinary type vacuum tube with a μ less than unity (obtained by wide spacing of the grid wires) would have the same general properties as the inverted vacuum tube, but would at the same time be somewhat different in its method of operation. In the usual vacuum tube the element controlling the flow of electrons (grid) is placed between the filament and the electrode receiving the electrons, so the electrons must stream through the controlling electrode. In the inverted vacuum tube the controlling electrode (plate) has no electrons going anywhere near it, being situated outside both the filament and the element receiving the electrons (grid). The advantage of the inverted vacuum tube over an ordinary tube with a μ of less than unity is in the ease with which the step-down ratio may be made large, and in the greater insulation clearance distances for the high-potential electrode. The disadvantage of putting the controlling electrode outside is that the electron flow then goes to a grid, which has limited heat-dissipating capacity. Ordinarily the heat that must be handled is relatively small, however.

Conclusions

By interchanging the functions of the grid and plate of the usual vacuum tube a voltage-reducing power amplifier is obtained. The usual vacuum tube acts as a voltage-increasing power amplifier.

The essential constants of the inverted vacuum tube are the voltage step-down ratio m (approximately equal to μ) and the dynamic grid resistance R_g.

The effect on the grid circuit of applying a voltage in the plate circuit is exactly as though this voltage divided by the step-down ratio m had been added to the grid potential. This equivalent voltage acts in a circuit consisting of the dynamic grid resistance and the output impedance in the grid circuit.

The constants of the inverted vacuum tube can be measured by the simple dynamic means indicated in Figs. 8, 9, and 10.

The step-down ratio m is determined primarily by the geometrical properties of the tube, but at low negative plate potentials and at high grid currents it changes somewhat with operating voltages. At higher negative plate potentials and at moderate grid currents the step-down ratio is practically constant, and is approximately equal to the μ of the tube.

The dynamic grid resistance of the inverted vacuum tube is much lower than the dynamic plate resistance of the same tube used in the usual manner. This low resistance is obtained with low grid potentials, and seems to be largely independent of spacing and size of the grid wires.

The inverted vacuum tube can be used as a voltage amplifier, oscillator, rectifier, or as a voltmeter for the measurement of either a-c. or d-c. voltages of high values with practically no consumption of power. Another use is in oscillograph work, for the taking of voltage oscillograms in high-voltage circuits without consumption of power.

The input resistance of the inverted vacuum tube is practically infinite, while the input capacity is very small, ordinarily not over 5 to 20 $\mu\mu$fds.

The static curves of the inverted vacuum tube are similar in form to the corresponding curves of the ordinary vacuum tube, and the theory of the inverted vacuum tube is analogous in all respects to the usual vacuum-tube theory, the only difference being reduction instead of amplification of voltage.

It is relatively simple to construct an inverted vacuum tube with wide clearances between plate and the rest of the tube, so that potentials of hundreds of thousands of volts can be applied to the plate, while the effect of this high voltage stepped down in almost any desired ratio is obtained in a low-potential circuit.

DEVELOPMENT OF A NEW POWER AMPLIFIER TUBE*

By

C. R. Hanna, L. Sutherlin, and C. B. Upp

(Westinghouse Research Laboratory, East Pittsburgh, Penna.)

Summary—A general rule for determining the best operating point and load impedance for any power amplifier when anode voltage and dissipation limits must both be considered is derived.

The effect of varying the voltage factor in a given sized tube by changing the grid structure is also considered with voltage and heating kept within safe limits. The process of determining the desired characteristics for a given application is illustrated by describing the development of a new power tube, Radiotron UX-250.

Introduction

In the several papers which have appeared during the last few years on power amplifiers,[1] the output characteristics of existing standard tubes were considered. This paper has for its purpose to describe the process of development of a new power tube known as Radiotron UX−250 for radio receivers, electric phonographs and other applications requiring greater power than obtainable in previous tubes employing standard receiving tube bases. Although the development of this new tube is the principal consideration of the paper, certain properties and limitations as well as design information which apply to power tubes and their associated circuits in general are shown.

Determination of Best Load Impedance and Operating Point

It will not be out of place first of all to review the methods of determining the load impedance and operating point for obtaining the maximum power from a given amplifier. The only case which will be considered is the one in which the anode voltage and dissipation have fixed upper limits, and the grid bias and load impedance may both be chosen so as to obtain maximum undistorted output from the amplifier circuit. This means maximum power without regard to sensitivity, the only consideration being that the curvature of the dynamic characteristic shall be within a certain limit. This curvature produces distortion which is

* Original Manuscript Received by the Institute, January 5, 1928.

* Presented at New York Institute Meeting, March 7, 1928.

[1] E. W. Kellogg, "Design of Non-Distorting Power Amplifiers" *Journal* A. I. E. E., May, 1925. J. C. Warner and A. V. Loughren, "Output Characteristics of Amplifier Tubes," Proceedings I. R. E., December, 1926.

most objectionable on a combination of several musical tones because the various frequencies modulate one another, producing sum and difference frequencies which are inharmonic. A simple measure of the extent of such modulation is the percentage of second harmonic introduced due to curvature when a single fundamental frequency is applied to the grid. An arbitrary value of 5 per cent as an allowable maximum for the second harmonic has been agreed upon by several workers in this field.

In all of the determinations given in this paper, the circuit of Fig. 1 or its equivalent will be considered. In this circuit all of the direct current in the anode circuit is considered to pass through the low-loss reactor L without appreciable voltage drop. The

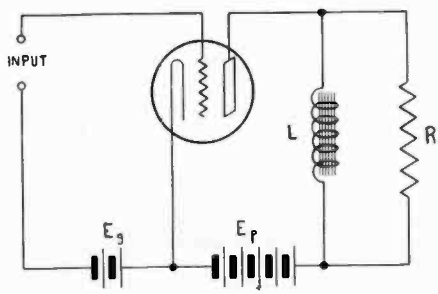


Fig. 1—Power Amplifier Circuit

a-c. output is considered to flow entirely through the load resistance R_L, because the impedance of the reactor to alternating current is very high. A load connected to the tube through a transformer is of course equivalent to the foregoing if the transformer exciting current is very small.[2] If a transformer is used, the equivalent load impedance is the secondary load resistance multiplied by the square of the turn ratio. Because of the comparative ease in obtaining transformers of different ratios, it will be considered that the equivalent load resistance may be made any value desired.

The best load impedance and operating point will now be determined. It was shown theoretically by W. J. Brown[3] that the maximum undistorted output of any tube at a given mean anode

[2] A direct method of designing transformers and reactors capable of carrying considerable direct current and having high excitation inductance is given in a recent paper by C. R. Hanna on "Design of Reactances and Transformers Which Carry Direct Current." *Journal* A. I. E. E., March, 1927.

[3] Discussion, Symposium on Loud Speakers, *Proceedings* of London Physical Society, 36, Part III, April 1, 1924.

voltage will be obtained if the load impedance is equal to twice the tube impedance. In some cases this condition requires that the mean anode current shall be so high as to cause excessive heating of the anode. It will be shown here that under these conditions the maximum permissible anode dissipation should be employed and the load impedance should be greater than twice the tube impedance.

Since the proof given by Mr. Brown that the load impedance should be twice the tube impedance where anode voltage is the only limitation was entirely theoretical, it was thought well to establish this fact experimentally. The curves of Fig. 2 represent the mutual characteristics of a particular tube. Suppose it is

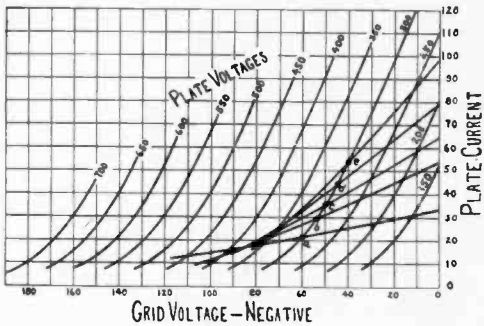


Fig. 2

desired to find the best operating point on the 300-volt curve Through each of the several points, *a*, *b*, *c*, *d*, and *e* on this curve, dynamic characteristics having curvature sufficiently small to prevent the second harmonic from exceeding 5 per cent may be plotted. To do this, a load impedance is arbitrarily chosen and points where the dynamic crosses the various static curves are determined by knowledge of the fact that the change in anode current from one static curve to an adjacent static curve is equal to the difference in anode voltage divided by the load impedance. This fact is seen from the circuit of Fig. 1. When the grid voltage is made more positive the current through the tube must increase. By hypothesis this increase in anode current must all pass through the load resistance, and the drop through this resistance is in such a direction as to lower the anode potential. When the grid is made more negative the anode current is reduced and steady current through the reactor must divide so that part passes through the load resistance in the reverse direction. The voltage drop produced by this current is in such a direction as to make the anode voltage higher than the supply voltage. In reality the reactor causes the voltage at the anode to rise to this value, since any tendency for the reactor current to be less results in a change of voltage which is great enough to keep the reactor current steady. Thus the dynamic curve intersects static curves corresponding to anode voltages both higher and lower than the supply voltage.

The dynamic curve is, of course, extended to the left to a point where the grid voltage is equal to twice that at the operating

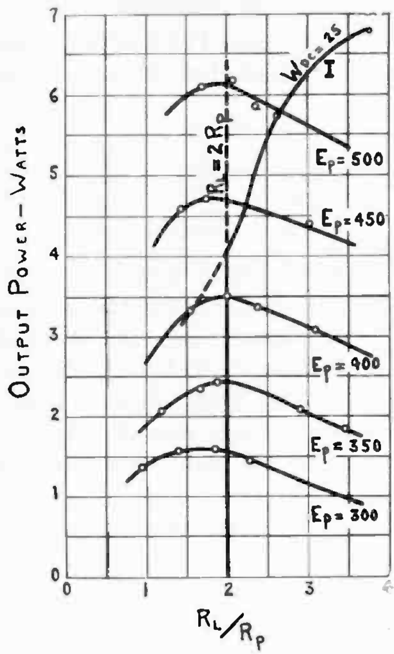


Fig. 3

point and to the right to the point where the grid voltage is zero. Having plotted this dynamic, it remains to be seen whether the curvature is sufficiently small, and this is determined by a calculation of the second harmonic of current using the formula given by Kellogg.[1]

$$\text{Distortion} = \frac{1/2\,(I_{\max}+I_{\min})-I_o}{I_{\max}-I_{\min}}$$

where $I_{\max}$ is the anode current for zero grid voltage, $I_{\min}$ is the anode current at the lower end of the dynamic and I_o is the anode current at the operating point. In case this percentage is greater than 5, a larger value of load impedance should be chosen. After having found the dynamic whose curvature is within the limits of allowable distortion, the power may be calculated with the use of the equation

$$W = 1/8\ (I_{max} - I_{min})^2\ R_L$$

The several dynamic curves shown in Fig. 2 are plotted with the correct value of load resistance so as to make the distortion 5 per cent.

In Table I are given the amounts of power obtainable at each of these operating points. The load impedance and the tube impedance, and their ratio at these various operating points, are also tabulated.

TABLE I

E_p	E_g	I_o	R_p	R	W	R_L/R_p
300	59	0.022	3400	17500	1	5.15
"	53	0.030	2670	6050	1.43	2.26
"	49.5	0.036	2340	4400	1.6	1.88
"	45	0.044	2050	2870	1.56	1.40
"	40	0.0545	1800	1700	1.35	0.945

The 300-volt curve of Fig. 3 shows the variation of power plotted against the ratio of load impedance to tube impedance. It is seen to have a maximum where R_L/R_p is approximately 2. Data similar to that given in Table I were also obtained for other anode voltages, and the curves showing power against R_L/R_p for each of these anode voltages are also shown in Fig. 3. Although these maxima are all quite broad, indicating that close matching is not necessary, they occur where R_L/R_p is approximately 2 and therefore substantiate the theoretical conclusions of Mr. Brown.

Curve 1 of Fig. 4 intersects the various static curves for the same tube at the best operating points if anode dissipation is not limited. Dynamic curves are shown through each of these operating points. As the mean anode voltage is increased, however, the mean anode current also increases and somewhere a limit of anode dissipation will be reached. It might be thought that higher voltages would be undesirable, since the mean anode current must be made less and less if a maximum value is set for the anode dissipation.

Curve II of Fig. 4 intersects the anode voltage curves at points where the anode dissipation is constant and, in this case, is arbitrarily fixed at 25 watts. Dynamic curves plotted through these several points for voltages above 425 require load impedances whose values are greater than twice the tube impedance in order to keep the curvature within the specified limits. It remains to be seen whether the power increases for higher voltages in this region where the mean anode current must necessarily be made smaller and smaller in view of the constant anode dissipation. Curve I of Fig. 3 is for 25 watts anode dissipation and shows that the power

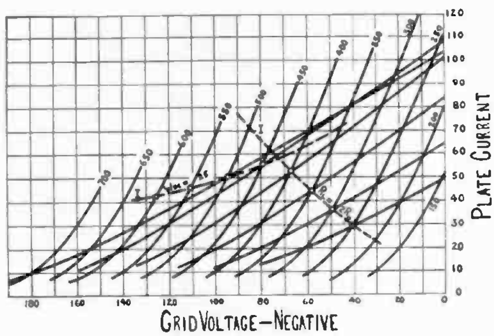


Fig. 4

does steadily increase even under these circumstances, and also shows that R_L/R_p increases with increased anode voltage.

It is seen from the foregoing that in some cases it is desirable to operate at the point which requires that the load impedance shall be twice the tube impedance, and in other cases that the

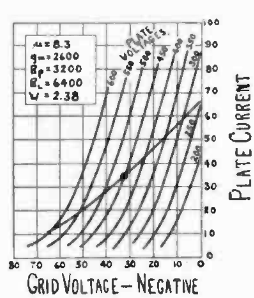


Fig. 5

load impedance shall be greater than twice the tube impedance. A general rule for determining the best operating point where both anode voltage and anode dissipation are limited may be given as follows: On the curve for the greatest permissible anode voltage choose the point where the current is such as to cause the maximum allowable anode dissipation. Plot a dynamic curve by the method previously described, using a value of load resistance great enough to keep the distortion small. If this load impedance is greater than twice the tube impedance at the point the best operating condition will have been determined. In case the load impedance so chosen is less than twice the tube impedance, greater undistorted output will be obtained if the plate current is reduced by the use of greater grid bias, and a larger value of load impedance employed,

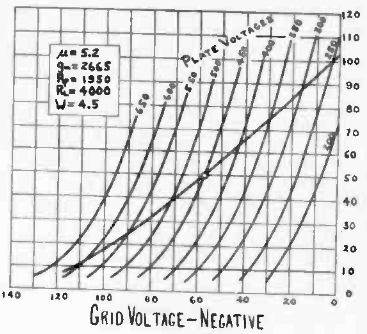


Fig. 6

the best condition resulting when the load impedance is twice the tube impedance.

Variation of Power With Voltage Factor

Having established a simple general rule for determining the best operating point and power output of a given tube where

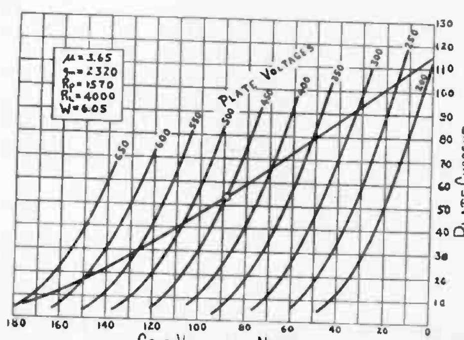


Fig. 7

anode voltage and anode dissipation limits are both taken into consideration, an investigation of the variation in power with voltage factor in a tube of a certain class will be determined. The particular tube under consideration is one with a standard receiving tube base having as large a glass blank as feasible for this size of base and operating at as great an anode voltage and anode dissipation as would be tolerable in a structure of this type. The voltage limitations are determined largely by press and base structure, while the dissipation is determined by the glass envelope and the size of parts that can be enclosed. It was felt that a tube of this class could be made which would be capable of operating at 450 volts mean anode potential and 25 watts dissipation. A number of tubes having a particular anode and filament structure, but different grid pitches, were made up and the best operating points for the 450-volt condition were determined.

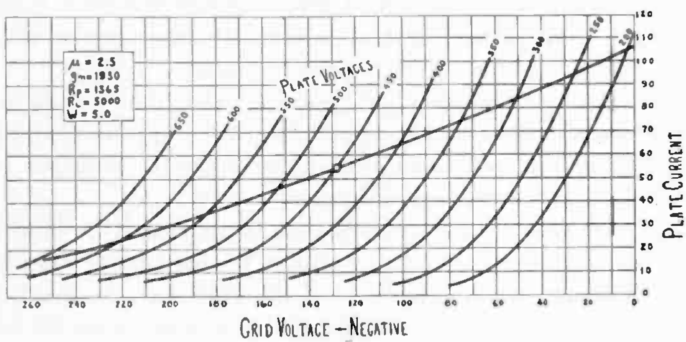


Fig. 8

The curves of Figs. 5, 6, 7, and 8 show the static and dynamic characteristics for four of the tubes, the voltage factors being 8.3, 5.2, 3.65 and 2.5.

A tabulation of data obtained from these and other representative tubes having voltage factors in this range is given in Table II. Several things are apparent from a study of this table. The higher voltage factor tubes operate best with the dissipation well under 25 watts and load impedance equal to twice the tube impedance. As the voltage factor is decreased, the anode dissipation becomes greater and the tubes having voltage factors of 3.65

TABLE II

Amplification Factor	Mutual Cond.	Plate Resist. (Ohms) R_p	Load Resistance R_L	D-C Plate Current (Milliamperes I_p	Anode Dissipation in Watts W_{d-c}	Undistorted Output Watts W_p	Negative Grid-Bias (Volts) E_g	Sensitivity $\frac{M.W.}{E_g^2}$
8.3	2600	3200	6400	35	15.8	2.38	32	2.32
7.4	2780	2660	5320	40	18.0	3.08	38	2.13
6.34	2700	2350	4700	45	20.3	3.62	46	1.71
5.2	2665	1950	4000	50	22.5	4.5	58	1.33
3.65	2320	1570	4000	55	25	6.05	88.5	0.77
3.1	2080	1490	4500	55	25	6.2	106	0.55
2.5	1830	1365	5000	55	25	5.0	127.5	0.31

and below require that the anode current be kept constant at 55 milliamperes in order not to exceed the limit of 25 watts which has been set. It is also seen from the table that the power output is greater for the lower voltage factor tubes, even below the one where the anode current becomes great enough to cause the anode dissipation to reach its limit. For the very low voltage factors, however, the output is considerably less, as will be noted for the tube having a voltage factor of 2.5. This is due to the poor control of the grid at low anode currents, which may be observed from the static curves of Fig. 8. Thus it may be expected that a limitation will always be reached when the grid structure is made more open. The lower limit of practical voltage factor will, of course, be different for different types of tubes.

Another fact which should be pointed out is that for the lower voltage factor tubes, in the region where constant anode dissipation obtains, the best load impedance steadily increases even though the tube impedance decreases.

It is, of course, to be expected that the sensitivity will be less for the lower voltage factor tubes, and in the case under consideration a limit was reached because of the fact that the maximum grid swing available for operating the tube was about 80 volts. This was the value estimated for the undistorted voltage of a detector and one stage of amplification following.

Curve I of Fig. 9 shows the variation of power with voltage factor. Curve II of Fig. 9 shows the peak grid swing required to give maximum output. The vertical line corresponding to the voltage factor of a tube which requires 80 volts grid swing is drawn. The value of μ is 3.8. It is seen that further decrease in voltage factor with corresponding increase in bias causes only small gain in power output. The dotted curve in Fig. 9 shows what the output would be if there were no anode dissipation limit. In this particular case the maximum power is not greatly in excess of that obtainable when anode dissipation is limited, and the drooping in the low voltage factor region still occurs. This experimental fact of an actual loss in power when the voltage factor is decreased below a certain value in a given size tube was not brought out in the curves shown by Messrs. Warner and Loughren in Fig. 10 of their paper.[1] Their curves must have been derived on theoretical grounds with the assumption that the mutual conductance for very low anode currents did not decrease excessively with decrease in voltage factor. In practice, tubes of very low voltage factor have such poor grid control at the lower end of the dynamic curve as to necessitate a higher value of I_{min} in order to avoid excessive curvature. The resulting smaller anode current swing causes a decrease in power output even though the required load resistance is larger.

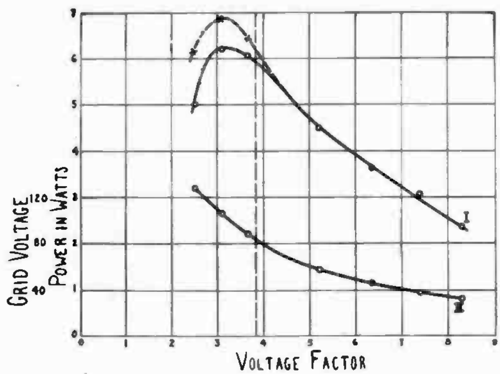


Fig. 9

In view of the 80-volt limitation set for grid swing, the tube finally chosen for the application in mind was one having a voltage factor of 3.8. The average of tubes made in the factory have a

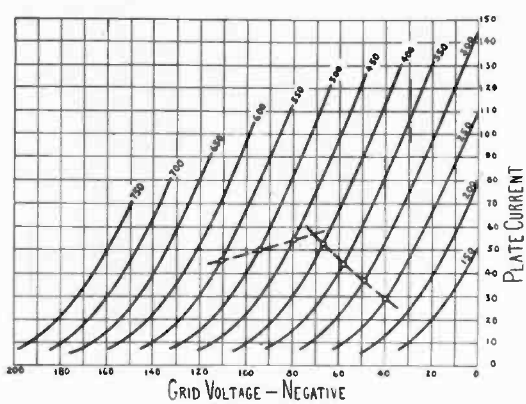


Fig. 10

mutual conductance of 2100 micro-ohms and an anode impedance of 1800 ohms. Fig. 10 shows the mutual characteristics of this tube. Correct operating points at various plate voltages are indicated. Fig. 11 shows power output available at different plate voltages. It will be seen that the power at the normal operating point of 450 volts plate and 80 volts grid is 4.6 watts. This represents an average tube as made in the factory and is known as the UX-250.

Description of the UX-250

The UX-250 tube is shown in Fig. 12. The tube has the large X base, which is standard in receiving sets. A 2–5/8 in. diameter

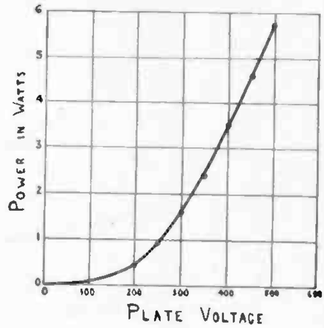


Fig. 11

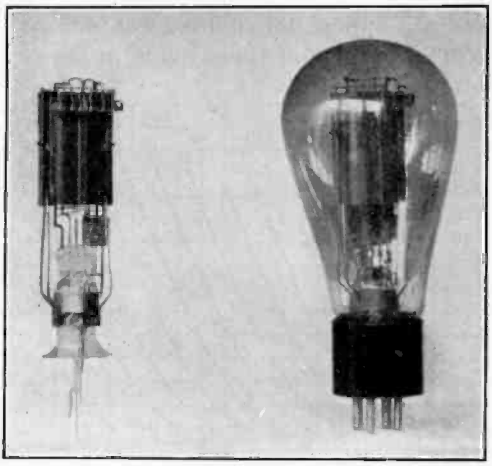


Fig. 12—The UX-250—A New Power Receiving Tube

glass blank is employed, giving an overall height for the tube of 6–1/4 in. The anode is of oval construction with 1/4 in. cooling fins on each of the two flat faces, and in addition has a black surface to facilitate cooling. Its dimensions are 5/16 in. × 13/16 in. × 1–5/8 in. long. The filament is of the oxide-coated type of very high efficiency, requiring only 1.25 amperes at its rated voltage of 7.5. The grid as well as the plate of this tube is black because of a special treatment which makes possible its functioning also as an oscillator.

A tabulation of power output characteristics and operating points for various Radiotron power tubes employing receiving ube bases is given in Table III. The data for the UX-112A and

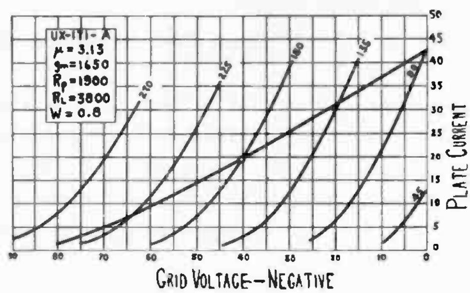


Fig. 13

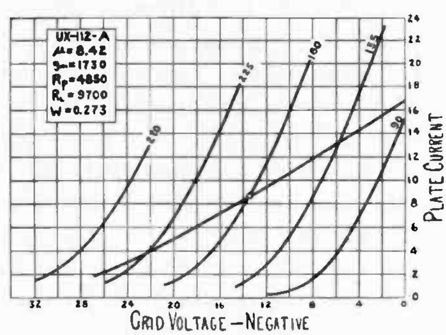


Fig. 14

UX-171A were obtained from the curves of Figs. 13 and 14. Data for other tubes except the UX-250 were taken from the paper by Warner and Loughren.[1]

TABLE III

Tube	Plate Volts E_p	Grid Volts E_g	D-C Plate Current (Milli-amperes) I_o	Plate Dissipation Watts $W_{d\text{-}c}$	Voltage Factor	Plate Resistance R_p	Load Resistance R_L	Max. Output (Watts) W
UX-250	450	80	55	25	3.8	1800	4000	4.6
	400	67.5	52.5	21	3.8	1850	3700	3.5
	350	58.5	44	16.5	3.8	2050	4100	2.45
UX-210	400	35	16	6.4	7.5	5400	11000	1.34
UX-171A	180	40.5	19	3.42	3.1	1900	3800	0.8
UX-112A	180	13.5	8.5	1.54	8.4	4850	9700	0.273
UX-120	135	22.5	7	0.942	3.3	6600	13200	0.105

The high output of the UX-250 is the result of several features, the most important of which are enumerated below:

(1) The use of as large a glass blank as feasible on a receiving tube base so as to allow high plate dissipation.

(2) The use of a large plate with a black surface for good radiation at a safe temperature.

(3) The use of the oxide-coated filament for ample emission without excessive filament power.

(4) The choice of a fairly open grid structure to obtain low impedance.

It is probable that the output of this tube is about as great as may be obtained from a receiving tube of practical structure without requiring greater grid swing or operating at excessive anode voltage or dissipation. The UX-250 is useful in the many applications where very high voltages cannot be used, but large amounts of power are required.

Discussion*

J. C. Warner and A. V. Loughren:† This paper raises the interesting question of the decrease in amplification factor at low plate currents in a given tube. This is particularly noticeable in a tube designed to have a low amplification factor when the grid wires are relatively far apart. If the spacing between the grid wires becomes too large compared with the distance from the grid wires to the cathode, the grid control obviously cannot be uniform at the cathode. This results in a decreased amplification factor when the grid is made more and more negative, since the current coming from parts of the cathode directly opposite the grid wires tends to be cut off first.

In the experiments described in this paper it is stated that the amplification factor was reduced by increasing the distance between grid wires. In this case the distance between the wires becomes equal to the distance from grid to cathode and anode at an amplification factor of about 3.5. Any further increase in spacing is accompanied by serious loss of control. However, if the reduction in amplification factor is accomplished by a reduction in grid-wire diameter instead of spacing, an amplification factor of less than 2 may be reached without making the wire spacing greater than the distance to the cathode.

*Original Manuscript Received by the Institute, March 19, 1928.
†General Electric Company, Schenectady, N. Y.

Of course for practical reasons it is not always possible to use the small grid wires required in the second illustration, but this example is given merely to indicate the possibility of designing a tube, when occasion demands, to have a practically constant value of amplification factor even when this value is relatively low.

In connection with the change in mutual conductance with varying amplification factor (varied by changing design of grid mesh) it should be emphasized that when the plate current is held constant the mutual conductance always decreases with the amplification factor. This shows very clearly that in comparing different tubes the mutual conductance tells nothing whatever regarding the maximum undistorted output which may be obtained.

There is an error in the data given for the UX-120 in Table III. The load resistance should be 6,600 ohms instead of 13,200. This is one of the cases where for practical reasons the tube design and operating conditions are worked out to give maximum output into a load resistance equal to the plate resistance instead of twice as great. The theoretical optimum conditions would require a load resistance rather hard to obtain in practice and the output would be only about 5 per cent greater than before.

MEASUREMENT OF VACUUM-TUBE CAPACITIES BY A TRANSFORMER BALANCE*

By

Harold A. Wheeler

(Hazeltine Corporation, Hoboken, N. J.)

Summary—*A complete, portable equipment is described for the measurement of the direct capacities of vacuum tubes in laboratory or factory testing. The tube capacity is compared with a standard variable condenser by means of a transformer-balance (Neutrodyne) circuit, whose balance is independent of the frequency (about 1500 kc. being preferred). Designs are proposed for the standard condenser and the transformer, and suggestions are made for the further improvement of this equipment.*

MUCH attention is being directed at present to the precise measurement of the small inter-electrode capacities of vacuum tubes, especially the grid-plate capacity, which is on the order of ten micro-microfarads. A method of measuring this capacity is required which will give reproducible results within about one percent when assembled in any laboratory.

This problem has arisen with the commercial development of Neutrodyne receivers, dating from 1923. Prior to this time, amateur and broadcast receivers as a class were designed and built with relatively wide manufacturing tolerances, and vacuum tubes evolved in this class. The Neutrodyne receiver involves in each radio-frequency amplifier tube a *balance* between the grid-plate capacity and the capacity of an added condenser, which is adjusted in the factory. As the earlier sets and vacuum tubes were improved, it was soon discovered that the production variations in grid-plate capacity were large enough to require neutralization for individual tubes. Since this procedure was ruled out by expediency the only alternative was to reduce the amplification to the point where the set could be neutralized for average tubes and subsequently operated with any tubes of a given design. Since this became a serious limitation, the problem was studied from several angles. First, the designing of sets required a knowledge of the range of grid-plate capacities to be met with in tubes on the market. Secondly, the neutralizing of manufactured sets required the selection and use of tubes with average grid-plate capacities. And thirdly, the manufacturing of tubes required the accurate specifications and checking of the grid-plate capacity in order to reject tubes with deviations greater than the specified tolerance.

* Original Manuscript Received by the Institute December 14, 1927.
* Presented at the Annual Institute Convention, January 11, 1928.

Since a tube has three direct inter-electrode capacities (grid-plate, grid-filament, and plate-filament) in a delta connection, it is not easy to measure one of these by a single observation. Three observations would be required unless an arrangement were used in which the effects of the other two capacities could be neglected. Various methods have been proposed to comply with this condition.

It is the purpose of this paper to outline an equipment for measuring the inter-electrode capacities of a tube by means of a tuned radio-frequency transformer balance patterned after the

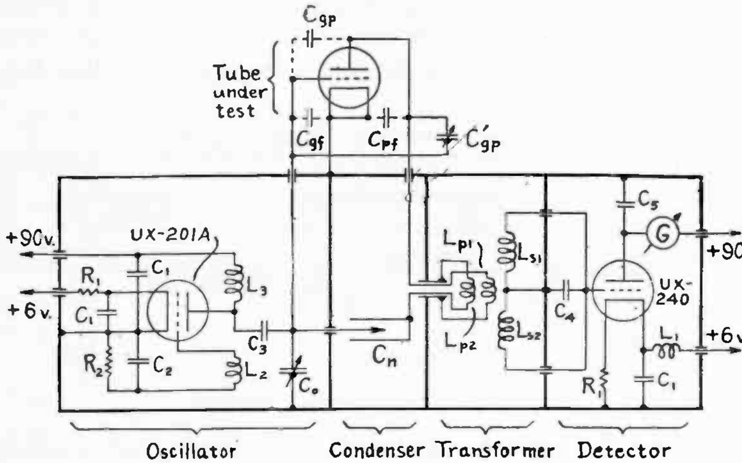


Fig. 1.—Complete Transformer-Balance (Neutrodyne) Circuit

Neutrodyne circuit. This is a logical solution of this problem which arose in the development of Neutrodyne sets, and will be seen to have some advantages over other proposed schemes.

The complete circuit arrangement is shown in Fig. 1. It is housed in a copper box divided into four compartments, and comprises five component parts,—a radio-frequency oscillator, the tube under test with its socket, a standard variable condenser, the radio-frequency transformer, and a detector circuit. These will be described individually in order. The balance circuit comprises the two capacities, C_{gp} and C_n, and the two like transformer primaries, L_{p1} and L_{p2}, which are arranged as in the Neutrodyne circuit. When $C_n = C_{gp}$ the net voltage induced in the transformer secondary is zero. Measurements are made at a frequency of about 1500 kc. The battery circuits are filtered to permit the use of common batteries for oscillator and detector.

The oscillator, located in the first compartment, employs a simple circuit with a UX-201A tube. The power in the tuned circuit is about 50 milliwatts at about 50 volts. The variable condenser C_0 of about 200 $\mu\mu$f. maximum capacity serves to tune the oscillator to resonance with the detector circuit at approximately 1500 kc. The plate coil L_3 consists of 50 turns of No. 24 single-silk enamel wire on a form 3 in. in diameter, while the grid coil has 20 turns on a smaller form just under the ground end of the plate coil. $C_1=1$ μf., $C_2=0.001$ μf., $C_3=0.01$ μf., $R_1=4$ ohms, $R_2=0.1$ megohm.

The tube under test is mounted in a special socket, such as may be agreed upon, conveniently located on top of the box. The incidental capacities between electrodes are kept as small as pos-

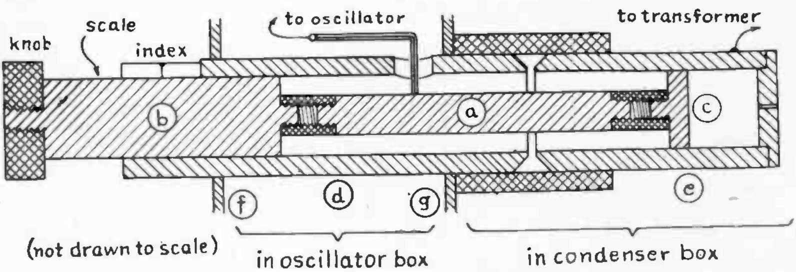


Fig. 2.—Standard Variable Condenser

sible. A small adjustable capacity C_{gp}' may be provided as a zero adjustment when the socket is readjusted for different types of tubes.

The variable condenser C_n, in the second compartment, is the standard of comparison for the measurements. It occupies the position of the neutralizing condenser in the Neutrodyne circuit. This condenser can best be composed of two coaxial cylinders, one sliding to vary the capacity. A proposed design is shown in Fig. 2. A brass rod a is supported by insulating sleeves between two pistons b and c. These pistons slide in two sections of cylindrical tubing, d and e respectively, which are fastened end to end by an insulating sleeve. The tube d extends from outside the box through the wall f into the oscillator compartment and then through the partition g into the condenser compartment. The piston b carries a knob and a scale which passes an index on the outer tube d. Electrical connection from the oscillator to the sliding rod a is made by contact between the rod and an insulated spring brush entering through tube d, which is grounded to the box. The standard variable capacity is between the rod a and the section of outer tube e, which is connected to the transformer. The capacity between e and the box should be kept small.

This condenser design has several desirable mechanical and electrical features. The outside diameter of the rod a and the inside diameter of tubes d and e can be turned to such a ratio (0.573, or approximately 4/7) that one centimeter on the scale represents one micro-microfarad of capacity. The entire assembly is a unit in the outer tubes, and need not be calibrated experimentally except as a check on computations, or for higher accuracy. The computed calibration is realized very closely by avoiding two

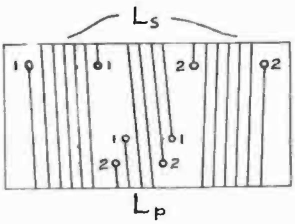


Fig. 3.—Transformer Arrangement

end corrections of the capacity between a and e. First, a radial electric field at the open end of e is secured by the use of d as a "guard cylinder." Secondly, the variable capacity between a and the closed end of e is avoided by closing e on the inside with c, which moves with a. The only remaining error is the distortion of the radial field at the end of a; so that a must remain within e by a distance greater than the diameter of a. By this design, all variations of capacity are completely shielded from effects of outside objects. Another advantage of this design is that the total capacity from a to ground directly and through the transformer, is constant. After the oscillator is tuned to the detector, with the tube in the socket, the condition of resonance is not altered by sliding a to vary C_n. Retuning for different tubes of the same type should be unnecessary, so that the oscillator requires tuning only once.

The transformer is enclosed in the third compartment, and the arrangement of its coils on a single form is shown in Fig. 3. The two primary coils, L_{p1} and L_{p2}, each consist of 10 turns of No. 24 single-silk enamel wire, and their turns are interleaved. The two secondary coils, L_{s1} and L_{s2}, each consists of 50 turns of No. 24 single-silk enamel wire, and they are wound on opposite sides of the primary coils in opposite directions as shown. The winding tube is of clear bakelite, 3 in. diameter by 5 in. long, and should be threaded 18 double threads per inch for primary and 36 threads per inch for secondary coils. The symmetry is maintained as precisely as possible in the coil construction, and the assembly with its connecting wires is located symmetrically in the compartment, as indicated in Fig. 1. The primary leads are brought to the coils in a grounded metal tube, which serves as the return to ground for the primary coils only. The inner secondary terminals are grounded, while the outer terminals are connected in parallel in the detector compartment. This arrangement minimizes all incidental coupling, capacitive or inductive, between primary and secondary coils.

The detector is located in the fourth compartment, as shown in Fig. 1. A UX-240 tube is used, with a grid bias of one volt secured by the filament resistance R_1 of 4 ohms. The grid is connected to the transformer secondaries, which are tuned to about 1500 kc. by a small condenser C_4 of 50 $\mu\mu$f., augmented by incidental capacities. This circuit is tuned to increase the sensitivity only. High selectivity is not desirable here. The galvanometer G has a full scale deflection for about 0.5 milliampere, and indicates relative voltages on the grid. The battery circuits are filtered by $C_5=0.1$ μf., $C_1=1$ μf., $L_1=0.1$ mh.

The total errors of this system as described should be very small, within 1 percent or 0.1 $\mu\mu$f., and can be reduced further if required. The mechanical errors in the standard condenser and transformer can be reduced almost indefinitely. The principal source of electrical errors is in the transformer primary coils, because it is impossible to approach very closely to unity coupling between two coils of so few turns. Any deviation from symmetry between these two coils can be checked by reversing the primary leads in the second compartment. Other errors in the circuit vary with the frequency and can be detected by comparing measurements at different frequencies with the same transformer. These errors can be reduced by decreasing the number of primary turns or working at a lower frequency.

Taken as a whole, this system has several definite advantages which are fundamentally important. The null method of measurement is favored because it obviates the accurate calibration and checking of meters, and because variations in the applied voltage do not detract from the accuracy of the measurements. In this case, even the comparison standard should not require calibration if carefully computed and constructed. Then this transformer balance is independent of the frequency, so that constancy of the oscillator frequency is not essential. This tolerance of variations in oscillator voltage and frequency permits the use of a low-power oscillator, with the result that the equipment is light and portable. Also the equipment can be operated without unnecessary delays, because the tubes need not come to equilibrium after being lighted and because there is no time lag in the galvanometer circuit as contrasted with thermal instruments. The use of a radio frequency is to be preferred over an audio frequency, since for the latter the impedance of such small capacities is very high, and also the difficulties of oscillator design are increased.

In high precision laboratory work, this system offers indefinite opportunities for further refinement by improving the transformer design and construction, and by using a radio-frequency amplifier before the detector. It is especially adaptable to the measurement of the minute coupling capacities encountered in screen-electrode tubes. The variable condenser can be improved by the use of a micrometer screw. The highest accuracy is attainable by taking the mean of two settings equally spaced on opposite sides of balance.

In factory testing, this system has the advantage that an error in capacity either above or below normal gives a rapid increase in galvanometer current, and a relay can be operated to show when tubes should be rejected for such errors. The absence of time lag in the detector is especially important in this class of work.

A DIRECT-CAPACITY BRIDGE FOR VACUUM-TUBE MEASUREMENTS*

By

LINCOLN WALSH

(Consulting Engineer, Elizabeth, N. J.)

Summary—*A direct-capacity bridge is described which permits the measurement at a single setting of a capacity associated with other capacities in a system having more than two terminals, such as the grid-plate capacity of a vacuum tube. Two forms of the bridge are described. By making one connection the standard form of capacity bridge already in use in many laboratories may be converted into a direct-capacity bridge. The recommendation is made that vacuum-tube inter-element capacities be specified as direct capacities. Suggestions are made for other uses of the direct-capacity bridge in the laboratory.*

THE object of this paper is to present a modification of the standard capacity bridge which permits the measurement of direct capacities, and which has been found suitable for measurement of vacuum tubes.

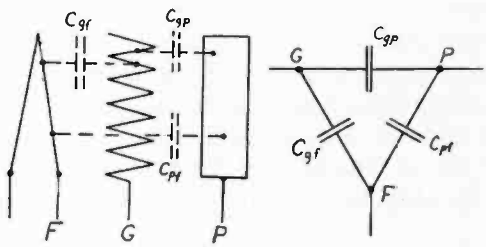


Fig. 1

The direct capacity between two elements of a system such as the vacuum tube may be described as the capacity existing between those two elements, excluding all other capacities of the system.[1]

In the vacuum tube there exist three direct capacities, grid-plate, grid-filament, and plate-filament, the system having three terminals, grid, plate, and filament, as shown in Fig. 1. The standard capacity bridge is adapted to measure the capacity of two-terminal systems only, such as the single capacity between the two terminals of a condenser, and cannot measure directly the individual direct capacities of the vacuum tube.

To meet the need for apparatus capable of measuring the direct capacities of vacuum tubes, the bridge to be described was developed in the Hazeltine Laboratories by the writer.

* Original Manuscript Received by the Institute, December 14, 1927.
* Presented at the Annual Institute Convention, January 11, 1928.

[1] See definition 4031 of the "Report of the Standardization Committee for 1926"

The circuit of the direct capacity bridge is shown in Fig. 2. The capacity to be measured, C_{gp}, is connected between corners A and D of the bridge and the terminal or terminals not associated with the capacity to be measured are connected to the junction of the ratio arms, which is grounded. C_s is the standard of capacity, and r_m the phase-angle resistance. The capacity C_{pf} is thus placed across the bridge from B to D, where it is effectively

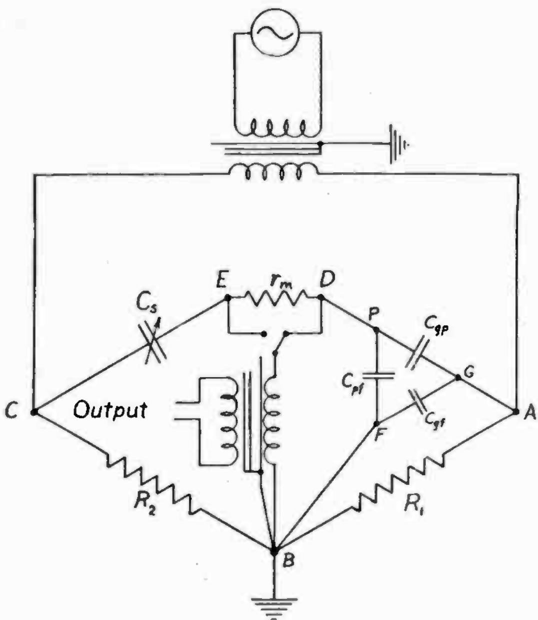


Fig. 2

outside the bridge and does not in any way affect the balance. The capacity C_{gf} is in parallel with the resistance arm R_1. Fig 3 shows the bridge in simplified form.

When the bridge is balanced,

$$\frac{Z_2}{Z_1}=\frac{Z_4}{Z_3} \text{ or } \frac{R_2}{\dfrac{1}{\dfrac{1}{R_1}+j\omega C_1}}=\frac{R_4+\dfrac{1}{j\omega C_4}}{\dfrac{1}{j\omega C_3}}.$$

This reduces directly to

$$\frac{R_2}{R_1}(1+j\omega C_1R_1)=\frac{C_3}{C_4}(1+j\omega C_4R_4),$$

which leads to the two requirements, that

$$C_1R_1 = C_4R_4$$

and that

$$\frac{R_2}{R_1} = \frac{C_3}{C_4}.$$

The result shows that the only effect of the capacity introduced in parallel with R_1 is to require resistance to be inserted in series with the standard capacity to balance it, in addition to the resistance needed to balance the loss in the capacity being measured, and that it does not affect the ratio of the unknown to the standard

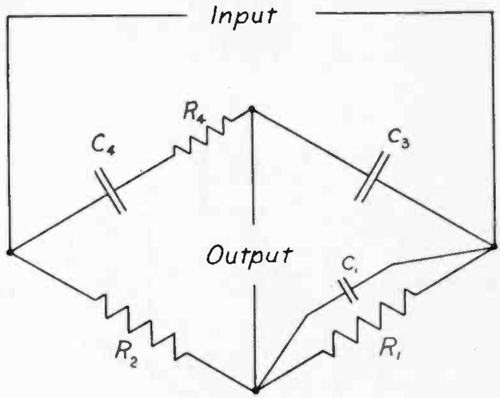


Fig. 3

capacity. Therefore the bridge as described may be used to measure direct capacity.

Only one setting is needed to measure a direct capacity after the "zero" setting of the standard condenser has been found. The procedure is the same as that followed on the standard bridge.

The only difference between the direct capacity bridge and the standard bridge is the connection between the grounded junction of the ratio arms and the terminal or terminals not associated with the capacity being measured. Therefore any standard bridge can be readily converted into a direct capacity bridge by providing a grounded terminal to which the non-associated terminal or terminals of the capacity system may be connected.

The rule to be followed in connecting apparatus for direct capacity measurements is:

Connect to the unknown terminals of the bridge, A and D, the two terminals associated with the direct capacity to be measured.

Connect to ground all other terminals of the capacity system and shields. (It is assumed that the "indicator" terminal B is grounded).

The accuracy of the bridge is limited only by the accuracy of the standard, and may be increased for small capacities by using ratios of 10:1 or 100:1, instead of the usual 1:1. When using these ratios it is generally necessary to use a high-voltage input to the

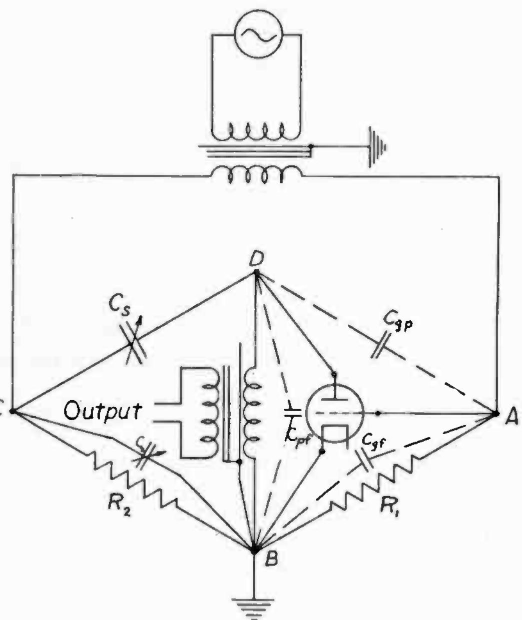


Fig. 4

bridge, and an amplifier on the output, to obtain the sharpest useful balance.

A modification which has appeared in an unpublished report is shown in Fig. 4. The grid-filament capacity in parallel with one of the ratio arms is balanced by a capacity in parallel with the other ratio arm, instead of being balanced by the resistance in series with the standard capacity, as above described. This capacity also serves to balance the bridge for phase angle due to loss in the capacity being measured.

In the wire communication field, the need for accurate measurements of the direct capacities of a multi-capacity system has long been recognized, and apparatus capable of such measurements is in constant use, but this apparatus has not found general application in the radio field. Those who wish to study the subject further will find this apparatus described in a comprehensive paper on "Measurement of Direct Capacities," by Dr. G. A. Campbell, in the Bell System *Technical Journal* of July, 1922.

Error due to extraneous capacities can be very easily eliminated in direct capacity measurements, so that there is no need to specify exact conditions of mounting in order to secure agreement between various laboratories.

In view of the simplicity and accuracy of apparatus now made available for direct capacity measurements, it is recommended that hereafter all capacities of vacuum tubes shall be given as direct capacities. This is to eliminate the inaccuracy and confusion resulting from the use of total capacities, and capacities measured with one element floating in potential.

Among the uses of the direct capacity bridge in a laboratory, other than measuring vacuum tubes, may be mentioned the measurement of stray coupling capacities; simplification of measurements on dielectrics; and the elimination of error in two-terminal capacity measurements due to stray capacities to leads. by permitting the shielding of the leads.

Discussion

Mr. Walsh: The question has been asked whether or not the use of a Wagner ground would be of advantage on the direct-capacity bridge. The object of the Wagner ground is to eliminate the error caused by capacities from the supply lines to ground, which capacities are effectively in parallel with one or the other of the ratio arms. It was shown in the analysis of Fig. 3 that capacity in parallel with one of the ratio arms does not affect the capacity measurement. In general then, the use of a Wagner ground is not advantageous for any capacity bridge measurements, either total or direct-capacity, except for measurements involving the determination of power factor, in which case its use is always desirable.

The question has been asked as to which of the two forms of the bridge, shown in Figs. 2 and 4 respectively, is preferred. The two forms are equally accurate and satisfactory. The General Radio standard capacity bridge may be converted into the bridge shown in Fig. 2 by providing a grounded terminal, as described in the paper, and as this bridge or something equivalent to it seems to be in general use, the form shown in Fig. 2 was described first.

A BRIDGE METHOD FOR THE MEASUREMENT OF INTER-ELECTRODE ADMITTANCE IN VACUUM TUBES*

By

E. T. Hoch

(Bell Telephone Laboratories, New York City)

Summary—*A description is given of the Colpitts-Campbell bridge as applied specifically to the measurement of direct admittances in vacuum tubes. Data are given on several tubes.*

IN 1904 G. A. Campbell described a bridge circuit[1] which has proved very useful for the separation of complex electrical networks into their component direct impedances or admittances. In 1922, Campbell discussed further the definition and measurement of direct capacitances.[2] The object of this paper is to describe in greater detail the application of this method to the measurement of the direct capacitances or admittances in vacuum tubes.

As is well known, in a network of three or more terminals the capacitance measured between any two terminals with the other terminal floating, includes not only the direct capacitance between those terminals but also a capacitance consisting of a series parallel arrangement of the direct capacitances to all of the other terminals of the network. For example, the admittances between elements in a three-element vacuum tube constitute a network of six individual admittances as shown in Fig. 1. In this figure, the admittances are shown as capacitances and resistances in parallel although mathematically they may be considered equally well as capacitances and resistances in series. It is the segregation of the individual capacitances shown in the diagram which constitutes the problem of measuring the direct capacitance as compared with the total capacitance between any two terminals.

In Fig. 1, the outer circle marked S represents in general any conductor in proximity to the tube which is not definitely connected to one of the tube elements. In particular, it may represent the earth or, in certain types of tubes, the metal shell surrounding the base. So far as the operation of the tube in a circuit

* Original Manuscript Received by the Institute, January 6, 1928.

* Presented at the Annual Convention, January 11, 1928.

[1] G. A. Campbell, "The Shielded Balance," *El. W.* 43, 1904, (647–649).

[2] G. A. Campbell, "Direct Capacity Measurements," Bell System *Tech. Journal*, 1, 1922 (18–38).

is concerned, the resultant effective capacitance from plate to grid, plate to filament and grid to filament, including the effect of capacitances from each element to S can be determined without attempting to segregate the capacitance from each element to S, providing only that S is connected (or disconnected) the same way during the measurement as it will be when the tube is in use. For design purposes, however, it is sometimes desirable to determine the capacitance to shell or other metal parts independently as shown in the diagram.

It is understood, of course, that the grid-to-filament admittance referred to above is entirely different from the input admit-

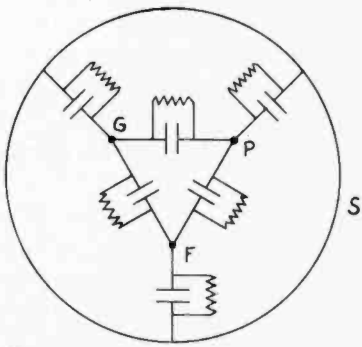


Fig. 1—Network of Admittances in a Vacuum Tube.

tance of the tube under operating conditions since the latter is a function of the plate-circuit impedance and the amplification factor of the tube.[3] The same bridge can, however, be used for the measurement of input admittance under operating conditions.

Description of Bridge

The bridge as originally described by Campbell and as further described by Shackelton and Ferguson,[4] is quite general in its application. For a specific use such as the measurement of small direct capacitances, the details of the bridge may be very much simplified; hence we shall consider only the simplified form shown in Fig. 2.

[3] H. W. Nichols, *Phys. Rev.*, 13, 1919 (404–419). Miller, Bureau of Standards Scientific Paper No. 351.

[4] Shackleton and Ferguson, "High-Frequency Measurement of Communication Apparatus." Presented at Regional Meeting of the A.I.E.E., Pittsfield, Mass., May 25–28, 1927. See Bell System *Tech. Journal*, Jan. 1928.

As shown in this figure, the bridge proper consists of two shielded transformers one of which should be double shielded, two double shielded equal ratio arms, a differential air capacitor of suitable range, one fixed and one variable resistor. The fixed resistor *CD* is usually of 10,000 ohms resistance. For general purpose work, the *AD* resistor usually consists of six decades having a total resistance of 11,000 ohms variable in steps of 0.01 ohm. For vacuum-tube testing this may consist of a fixed resistor in series with a small variable resistor to give a variation of a few ohms on either side of 10,000 in steps of 0.01 ohm.

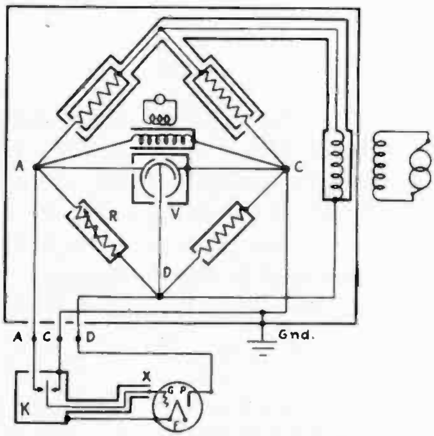


Fig. 2—Bridge Circuit for Measurement of Direct Capacitance and Conductance.

Fig. 2 also shows the connections from the bridge for measuring the direct capacitance from grid to plate of a vacuum tube. The terminals between which the capacitance is to be measured are connected to wires *D* and *X* and the remaining terminal or terminals are connected to *C*. Fig. 2 represents the case of a tube with a metal shell around the base and the shell considered as a separate terminal. If the capacitance with the shell floating is desired, the connection to the shell is omitted. *K* is a shielded key by means of which the capacitance under test may be thrown from the *CD* to the *AD* arm of the bridge or vice versa without disturbing any of the other capacitances in the network.

Procedure

The procedure for making a measurement is as follows: The apparatus is connected as shown in Fig. 2. *K* is set to connect the capacitance from grid to plate in, say, the CD arm. The bridge is then balanced by adjusting R and V, the readings being R_c and V_c. K is then thrown to the A side and the bridge balanced again, the readings being R_a and V_a. If capacitor V is calibrated in terms of the capacitance which it will balance in the CD arm of the bridge, the direct capacitance is

$$C_{gp}=\frac{V_c-V_a}{2}.$$

The corresponding conductance is

$$G_{gp}=\frac{R_a-R_c}{2R_aR_c}.$$

This may be shown as follows. For the first measurement C_{gp} and C_{pf} are both in the CD arm of the bridge. C_{gf} is short-circuited and so does not affect the bridge balance. Since the bridge is assumed to be calibrated so that capacitances in CD give increasing readings on V, the capacitance in this arm may be considered positive and that in AD as negative. Therefore, for the first measurement the capacitances being balanced are

$$C_{gp}+C_{pf}=V_c.$$

For the second measurement C_{gp} is in AD, C_{pf} is in CD and C_{gf} is across AC and constitutes a shunt across the receiver but has no effect on the balance point of the bridge; therefore the capacitances being balanced on the second measurement are

$$-C_{gp}+C_{pf}=V_a.$$

Solving, we get

$$C_{gp}=\frac{V_c-V_a}{2}.$$

The conductance equation is derived in the same way taking account of the fact that the conductance being measured is added in parallel with the conductance arms of the bridge. If R is normally 10,000 ohms and R_a and R_c do not depart from this value by more than say 100 ohms, G reduces to $\dfrac{R_a-R_c}{200}$ micromhos approximately.

It should be noted that measurements made as described above do not include the capacitances from the tube elements to ground. If it is desired to measure the capacitance of any element to ground independently, corner D of the bridge is connected to ground instead of C as above and the terminal is switched from C to A as before. Likewise, the direct capacitance from one terminal to another terminal which is grounded is made by connecting the grounded terminal to D and switching the other terminal from C to A, all other terminals being connected to C. Therefore, if a vacuum tube is operated with the filament circuit grounded, the capacitances operative in the circuit are obtained by measuring C_{gp} with C of the bridge grounded and measuring C_{pf} and C_{gf} with D grounded and the filament connected to D.

Precautions

The principal difficulty which limits the accuracy of these measurements is the proper handling of the lead wires. For this reason it is usually preferable to measure the tube in some kind of a jig or socket. The socket can be rigidly connected to the bridge and switching key as shown, and measured by itself. A tube is then inserted and the increase in capacitance is taken as the capacitance of the tube. While this introduces a slight error due to the added capacitance from the tube elements to the metal parts of the socket, this is believed to be at least as small as for any other possible arrangement of leads and since some capacitance of this nature is always present when the tube is in use, it can logically be considered as part of the tube capacitance. If an ordinary socket is used it is important that both filament terminals be strapped together when the socket is measured alone or else the socket capacitance will change when a tube is inserted.

If it is desired to make the measurement without the use of a socket, the leads should be rigidly placed in the position which they will occupy when connected to the tube and their capacitance measured. This, however, does not eliminate the error referred to above since the tube elements will still have capacitance to the leads when brought close enough to make the connections.

Results of Measurements

Tables I and II give measurements on several tubes picked at random illustrating the use of the above method. In Table I the capacitance to ground is included in the plate-to-filament

TABLE I

DIRECT CAPACITANCE AND CONDUCTANCE BETWEEN ELEMENTS OF VACUUM TUBES

	Plate to Grid		Plate to Fil. and Ground		Grid to Fil. and Ground	
	*C**	*G**	*C*	*G*	*C*	*G*
Measurements on Sockets and Leads						
Socket for 101-D and 101-F Tubes	0.2	0.0000	7.7	0.0042	7.8	0.0042
Socket for 231-D Tubes	0.6	0.0001	2.1	0.0005	2.1	0.0006
Socket for 215-A Tubes	0.8	0.0002	2.7	0.0006	2.9	0.0005
Measurements on Above with Tubes Inserted						
Tube 101-D No. 1	4.9	0.0003	11.3	0.0046	13.0	0.0047
Tube 101-D No. 2	5.2	0.0004	11.3	0.0045	13.0	0.0047
Tube 101-F No. 1	6.2	0.0002	11.5	0.0044	12.3	0.0045
Tube 101-F No. 2	6.3	0.0003	11.6	0.0047	12.2	0.0050
Tube 231-D No. 1	4.3	0.0008	4.4	0.0012	4.5	0.0013
Tube 231-D No. 2	4.2	0.0009	5.1	0.0011	4.8	0.0012
Tube 215-A No. 1	3.7	0.0005	4.6	0.0012	4.7	0.0009
Tube 215-A No. 2	3.5	0.0003	4.1	0.0006	4.4	0.0006
Increase Due to Tubes						
Tube 101-D No. 1	4.7	0.0003	3.6	0.0004	5.2	0.0005
Tube 101-D No. 2	5.0	0.0004	3.6	0.0003	5.2	0.0005
Tube 101-F No. 1	6.0	0.0002	3.8	0.0002	4.5	0.0003
Tube 101-F No. 2	6.1	0.0003	3.9	0.0005	4.4	0.0008
Tube 231-D No. 1	3.7	0.0007	2.3	0.0007	2.4	0.0007
Tube 231-D No. 2	3.6	0.0008	3.0	0.0006	2.7	0.0006
Tube 215-A No. 1	2.9	0.0003	1.9	0.0006	1.8	0.0004
Tube 215-A No. 2	2.7	0.0001	1.4	0.0000	1.5	0.0001

* Capacitance in micromicrofarads and conductance in micromhos.

TABLE II

DIRECT CAPACITANCE AND CONDUCTANCE BETWEEN ELEMENTS OF VACUUM TUBES

	Plate to Filament		Grid to Filament	
	C	*G*	*C*	*G*
Measurements on Sockets and Leads				
Socket for 101-D and 101-F Tubes	1.5	0.0009	1.5	0.0008
Measurements on Above with Tubes Inserted				
Tube 101-D No. 1	3.2	0.0010	5.3	0.0012
Tube 101-D No. 2	3.2	0.0010	5.2	0.0012
Tube 101-F No. 1	3.2	0.0009	5.2	0.0010
Tube 101-F No. 2	3.2	0.0010	5.1	0.0015
Increase Due to Tubes				
Tube 101-D No. 1	1.6	0.0001	3.8	0.0004
Tube 101-D No. 2	1.6	0.0001	3.7	0.0004
Tube 101-F No. 1	1.6	0.0000	3.7	0.0002
Tube 101-F No. 2	1.6	0.0001	3.6	0.0007

and grid-to-filament measurements as would be the case when the tube is used with the filament circuit grounded. Table II gives the corresponding measurements with the ground capacitance eliminated. Comparison shows that 1-½ to 2 micromicrofarads of these capacitances as given in Table I are capacitance to ground. This is due partly to the fact that the socket used has a metal shell which was grounded and which increases the capacitance to ground in the base of the tube. The grid-to-plate capacitance of course is always measured with the ground capacitance eliminated.

The above measurements were made at a frequency of 1000 cycles. It was originally in connection with the development of telephone repeaters and audio-frequency amplifiers that measurements of this type were required. However, since a considerable part of the capacitance is through the vacuum and does not change with frequency, the change of capacitance with frequency which is due to the solid dielectric cannot be a very large proportion of the total. Therefore, audio-frequency capacitance measurements can usually be applied to radio-frequency computations without excessive error. However, when it is desired to take the conductance into account in radio-frequency computations it is desirable to have radio-frequency measurements.

With proper bridge design the same method can of course be applied to radio-frequency measurements, the principal difference being in the transformers and detector. A bridge of this general type but having only one transformer and therefore suitable only for measurements with the *D* corner grounded has been used experimentally at frequencies up to 1500 kc. Measurements of plate-to-filament and ground, and grid-to-filament and ground capacitance were made on this bridge at a frequency of 1000 kc. on some of the tubes of Table I and were found to check the audio-frequency measurements within one- or two-tenths of a micromicrofarad. The corresponding conductance measurements were too uncertain to give any significance to the results. However, the tests indicate that the method is applicable at radio frequencies although, on account of the very small quantities to be measured, great refinement is necessary in the physical construction of the bridge and accessory apparatus.

Discussions on
THE DISTORTIONLESS RECEPTION OF A MODULATED WAVE AND ITS RELATION TO SELECTIVITY
(F. K. Vreeland)*

Henry Shore:† There is one very important factor that Dr. Vreeland has overlooked in his excellent paper. This factor is that the transmitter has the same inherent fault as the ordinary receiver. That is, the higher audio-frequencies are discriminated against much the same as in receiver as shown in Fig. 3 of Dr. Vreeland's paper.

Thus, the same means used to square up the frequency characteristic of the receiver might be used to make the transmitter's characteristic linear. If this were done, considerable power would be sacrificed in the additional circuit. Consequently, it would appear better to exaggerate the peaks of the frequency characteristics shown in Figs. 10, 16, and 17 in order to compensate fully for the non-linear characteristic of the transmitter.

J. R. Nelson:‡ Dr. Vreeland's explanation of the behavior of his "band selector" is very ingenious and interesting. He gives as one frequency where the reactance will be zero the value determined by the constants of one side of his balanced circuit.

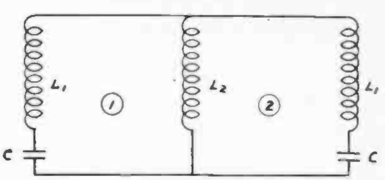


Fig. 1

There are, however, several points regarding the operation that are not clearly brought out in the paper. These are:

The other frequency at which the circuit will have zero reactance; or

The width of the resonance curve, and

The variation of width with frequency.

It was suggested during the discussion after the meeting that this circuit was a tuned coupled circuit. Leaving this question

* Presented at the Annual Convention of the Institute of Radio Engineers, January 9, 1928. Proc. I.R.E., 16, 3; March, 1928.

† Research Engineer, Radio Corporation of America, New York City.

‡ Radio Engineer, E. T. Cunningham Co., Inc., New York City.

aside, however, the circuit may be analyzed mathematically as shown below.

Fig. 1 shows the circuit. This is an electrical network with two meshes, so the network will have two degrees of freedom. Imagine one of the condensers charged and then allowed to discharge through the circuit. Oscillation would occur as the resistances are neglected. Using Kirshoff's first law the equations for meshes (1) and (2) are:

$$I_1\left[P(L_1+L_2)+\frac{1}{PC}\right]+PL_2I_2=0 \tag{1}$$

$$I_2\left[P(L_1+L_2)+\frac{1}{PC}\right]+PL_2I_1=0 \tag{2}$$

where $P=\dfrac{d}{dt}$ and $\dfrac{1}{P}=\int dt$

Both sides have the same constants so L will be written for L_1+L_2

$$I_1\left(PL+\frac{1}{PC}\right)+PL_2I_2=0 \tag{3}$$

$$I_2\left(PL+\frac{1}{PC}\right)+PL_2I_1=0 \tag{4}$$

from (4) $$I_2=-\frac{PL_2I_1}{PL+\dfrac{1}{PC}} \tag{5}$$

Substituting (5) in (3) and clearing of fractions

$$P^4(L^2C^2-L_2{}^2C)+2P^2LC+1=0 \tag{6}$$

Solving (6) for P^2

$$P^2=-\frac{LC\pm L_2C}{L^2C^2-L_2{}^2C^2} \tag{7}$$

We are only interested in the steady conditions,

therefore $$P=jw \tag{8}$$

$$w^2=\frac{LC\mp L_2C}{L^2C^2-L_2{}^2C^2} \tag{9}$$

The meshes have a common impedance so that

$$K=\frac{L_2}{\sqrt{L^2}}=\frac{L_2}{L} \tag{10}$$

therefore $L_2=KL$ (11)

$$\omega^2=\frac{LC(1\mp K)}{L^2C^2(1-K^2)}=\frac{1}{LC(1+K)} \text{ or } \frac{1}{LC(1-K)} \tag{12}$$

Let

$$\omega_1=\sqrt{\frac{1}{LC}} \tag{13}$$

Then

$$\omega'=\frac{\omega_1}{\sqrt{1+K}} \tag{14}$$

$$\omega''=\frac{\omega_1}{\sqrt{1-K}} \tag{15}$$

Substituting for k

$$\omega'=\frac{1}{\sqrt{(L_1+L_2)C}\sqrt{\frac{2L_2+L_1}{L_1+L_2}}}=\frac{1}{\sqrt{(2L_2+L_1)C}} \tag{16}$$

$$\omega''=\frac{1}{\sqrt{(L_1+L_2)C}\sqrt{\frac{L_1}{L_1+L_2}}}=\frac{1}{\sqrt{L_1C}} \tag{17}$$

From this anaylsis we find that one of the frequencies at which this circuit has zero reactance is determined by the constants of one side of the "band selector." The other is determined by $\sqrt{(2L_2+L_1)C}$. Thus it is easily seen that this circuit can be adjusted to any desired band width by changing L_2. Referring to equations (14) and (15) it is seen that as $\sqrt{I+K}$ and $\sqrt{I-K}$ are constant, and L_2 is constant, the width of the resonance curve varies with frequency. It would be approximately three times as wide at 1500 kc. as at the 500 kc.

There are several possible methods of using a common reactance which would tend to keep the width of the resonance curve constant independent of frequency. One way would be to use a variable inductance for L_2, which would necessitate, however, another control making three controls for one circuit.

F. K. Vreeland: The point raised by Mr. Shore as to the trimming of side bands in the transmitter is an interesting one.

Mr. Shore in his written discussion has correctly quoted the author's statement at the meeting that the principle of the band selector may be applied to a transmitting system, giving it a band transmission characteristic. It is not clear, however, that this involves a material sacrifice of power. The result can be obtained with substantially the same efficiency that is secured in a transmitter using an ordinary tank circuit associated with the antenna.

In Mr. Nelson's discussion, his derivation of the limiting frequencies is perhaps more elegant than that given in the paper, but the result is the same. Thus the last equation on page 12 gives the condition for the limiting frequency F_1. Substituting the values of the circuit constants this becomes

$$x_1 = x_2 = 0 = L_1\omega_1 - \frac{1}{\omega_1 C_1}$$

whence we get the familiar expression

$$\omega_1 = \frac{1}{\sqrt{L_1 C_1}}$$

Similarly, the preceding equation states the condition for the limiting frequency F_2. Substituting the specific values of the reactances x_1, x_2, and x_3 this becomes

$$L_1\omega_2 - \frac{1}{\omega_2 C_1} = -2L_3\omega_2$$

whence we obtain

$$\omega_2 = \frac{1}{\sqrt{(L_1 + 2L_3)C_1}}$$

These results are the same as those given by Mr. Nelson though he has used the symbol L_2 for the inductance L_3.

BROADCAST CONTROL OPERATION*

By

Carl Dreher

(Staff Engineer, National Broadcasting Company, New York City)

Summary—*This paper is limited to a consideration of the audio-frequency elements of a broadcast control system. A two-studio electrically interlocked plant suitable for network operation is described. The methods of specifying and measuring telephonic energy levels, arranging low impedance (as 500-ohm) and bridging apparatus, equalizing lines, and maintaining the audio energy within permissible limits by means of amplifying and attenuating units are described in connection with the specifications of the plant. The co-ordinative and regulative functions of the technical staff of a broadcasting system, the relations of engineering and studio personnel and typical precautions against breaks in program continuity are then discussed.*

FUNDAMENTALLY broadcast operation is radio telephone transmitter operation with a complicated input system, which takes in sound energy from one group of persons, the performers, is operated by a separate group of technical men, and, in addition, is usually tied up with wire telephone lines. This diversity of function introduces many problems of organization and coordination, both electrical and human. Furthermore, the necessity for uninterrupted program service makes it essential to time everything to the second, to leave nothing to chance, and to maintain many delicate adjustments of apparatus and procedure. Thus there is considerable difference between the operation of a radio-telephone transmitter by more or less skilled personnel, for communication purposes only, and the functioning of a broadcasting system.

The technical problems of a broadcasting system may be divided into audio-frequency operation, which includes pick-up of sound energy, the control of telephonic power levels, switching, and line operation; and radio-transmitter operation. This paper will be confined to the audio-frequency elements, including the operation of broadcast studios, the associated control rooms, field pick-up, and some features of network operation. The writer does not wish to claim originality for the material presented. The aim has been to get together a compendium of operational practice as it has developed in various broadcast

* Original Manuscript Received by the Institute, February 1, 1928.

* Presented before the Philadelphia Section, January 27, 1928; presented before the Buffalo Section, February 15, 1928.

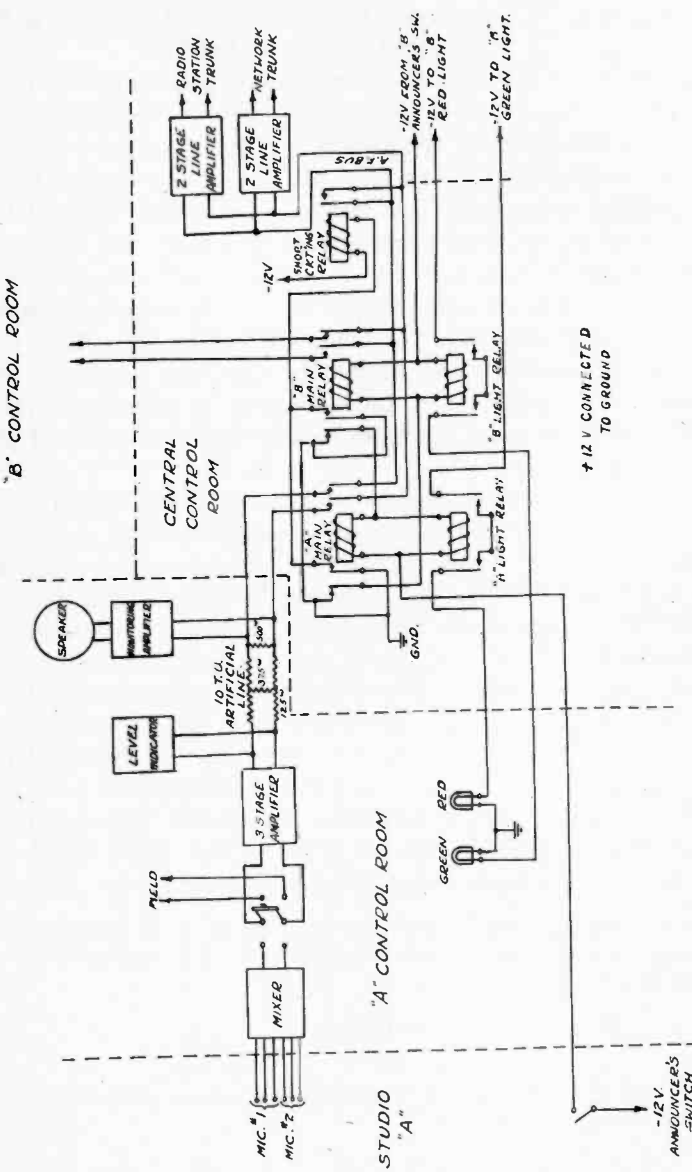

"B" CONTROL ROOM
CENTRAL CONTROL ROOM
"A" CONTROL ROOM
STUDIO "A"
MIC. #1
MIC. #2
MIXER
FIELD
3 STAGE AMPLIFIER
LEVEL INDICATOR
10 T.U. ARTIFICIAL LINE
SPEAKER
MONITORING AMPLIFIER
2 STAGE LINE AMPLIFIER
2 STAGE LINE AMPLIFIER
RADIO STATION TRUNK
NETWORK TRUNK
-12V
SHORT CKT'ING RELAY
A. & B BUS
"B" MAIN RELAY
"A" MAIN RELAY
"B" LIGHT RELAY
"A" LIGHT RELAY
GND.
-12V FROM "B" ANNOUNCER'S SW.
-12V TO "B" RED LIGHT
-12V TO "A" GREEN LIGHT
+12 V CONNECTED TO GROUND
RED
GREEN
-12V ANNOUNCER'S SWITCH

Fig. 1

stations, and the instruction books of manufacturers of broadcast equipment, the experience of the writer, and the work of his colleagues, have been drawn on with equal freedom.

In general, it will be remembered that considerations of quality or naturalness of reproduction, and efficiency in transmission, require (1) the design of the system to respond more or less impartially to the frequencies within the practical audio band; (2) the matching of impedances of connected elements; and (3) the confining of energy levels between such limits that (a) noise will not become noticeable, (b) cross-talk, either into or from broadcast circuits, may be avoided, and (c) overloading of tubes or other circuit elements will not occur. The theoretical and practical reasons for these precautions are well known in the literature and do not differ fundamentally in broadcast transmission from the same considerations in other branches of the communication arts.

Fig. 1 is a schematic outline of a more or less typical two-studio and control lay-out suitable for simple network operation. The design of the component parts, such as the mixer and amplifiers, will be discussed later. Following the circuit from the left, we see that the input of the first amplifier may be connected either to an outside (field) pick-up point, or to the studio microphones, of which two are shown combined in a mixer. The actual switching would not be accomplished with a knife switch, as shown in the diagram for the sake of simplicity, but by means of a telephone key or plug-jack arrangement in which the transition from one circuit to another is made without a long break. The output of the amplifier is connected to an artificial line which drops the level 10 *TU* (telephonic transmission units).[1] This line presents

[1] The telephonic transmission unit is merely a convenient means of expressing energy or current ratios logarithmically. The number of *TU* is given by the formula

$$TU = 10 \log_{10} \frac{P_1}{P_2} \tag{1}$$

where P_1 and P_2 are two powers or quantities of energy. If the impedance remains the same it follows that

$$TU = 20 \log_{10} \frac{E_1}{E_2} = 20 \log_{10} \frac{I_1}{I_2} \tag{2}$$

E_1 and E_2 being voltages, I_1 and I_2 currents.

an impedance of 500 ohms in both directions. The amplifier has the same output impedance, while the input impedance is 200 ohms, which is correct for a standard double-button carbon transmitter, or a number of such microphones combined in a mixer. The matching requirements are not highly critical and a feeding impedance of, say, 130 ohms, which is the value for one type of mixer, is allowable. Continuing with the main circuit, we note that a level indicating device is bridged across the input of the artificial line. This indicator is designed to give correct readings when connected across a 500-ohm circuit of the type shown. The output of the artificial line feeds a monitoring amplifier, but the main circuit passes through a switching system to the input of two line amplifiers containing two stages of amplification each. One of these amplifiers feeds the local radio station, while the other transmits telephone currents to a network. The purpose of splitting the circuit by means of one-way repeaters at this point is to permit local announcements to be made by short-circuiting the network amplifier, thus confining whatever is said in the studio to the radio station which remains connected. The function of the artificial line, which may seem an unnecessary loss device between the preliminary and line amplifiers, is to provide an intermediate low-impedance circuit with constant level, suitable for measurement purposes, and unaffected by the addition of ordinary bridging impedances.

The electrical operation of the interlocked studios may be understood from an inspection of the relay circuits. In Fig. 1 the details are shown only for Studio A, the circuits of Studio B

While it is necessary to calculate the TU loss or gain in each section of a circuit from (1) or (2), which in turn requires full engineering data secured in the usual way and in the usual fundamental units, once the TU figures have been obtained they may be added for the over-all attenuation or "gain." This is not only more convenient than multiplication and division when such computations are a matter of daily employment, but as both the attenuation of lines and the subjective sensation of loudness in the ear are logarithmic functions, the TU calculation is a direct quantitative reflection of a practical physical condition in these and other cases.

Plus and minus in the TU system are reckoned from an arbitrary "zero level" of 10 milliwatts, which is assumed as the output of a standard commercial telephone transmitter on peaks of normal speech. This corresponds to a current of 4.47 milliamperes in a 500-ohm circuit. Thus a power of 100 milliwatts would be expressed as a telephonic level of plus 10 TU while 1 milliwatt corresponds to a level of minus 10 TU. One TU also corresponds approximately to the loss along one mile of standard No. 19 A.W.G. telephone cable.

being precisely similar. The output of the 10 *TU* artificial line goes to two fixed contact points of a telephone relay. The winding of this relay is supplied with 12 volts when the announcer's switch in the studio is closed. If the *B* main relay is open, the other terminal of the *A* relay winding is connected to the positive side of the 12-volt battery, which is grounded. The same action supplies current to a red light in the *A* studio or control room, visible to both operator and announcer, warning both of them that their studio is connected through to the line amplifiers. If the *B* studio is in use, then it is impossible to connect the *A* studio to the audio-frequency bus which leads to the line amplifiers, since the *B* relay keeps the *A* relay coil from being energized. Thus there is no possibility of putting two studios on the air simultaneously. The studio which is not in use receives a green light from the studio which is in operation. If neither studio is in use both lights are dark. In this condition, also, the audio-frequency bus supplying the line amplifiers is short-circuited by an auxiliary relay, as shown in Fig. 1. Were this not done the input of the line amplifiers would be open when neither studio was "on the air," with the result that if these amplifiers had their filaments lit cross-talk pick-up would be likely to go out on the lines.

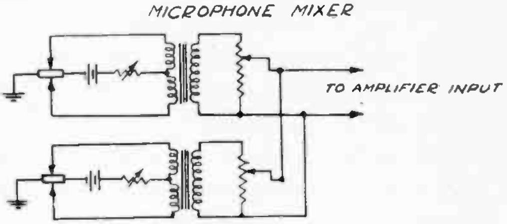


Fig. 2

Fig. 2 shows the circuits of a microphone mixer which allows the outputs of two microphones to be combined in any desired proportion. In the case of standard carbon transmitters, the a-c. impedance being 200 ohms, one-to-one repeating coils with windings of the same impedance are used to match the transmitters, and to provide a mixing circuit free from any d-c. flow which would give rise to noise when variations were made. The potentiometers are of 400 ohms total resistance. The combination of several such elements works into the 200-ohm input of the first amplifier.

As for level considerations, a typical instance would start with the output of the mixer some 50 *TU* below zero level, which may be raised by the first amplifier to slightly above zero level, say plus 2 *TU*. (Peaks of modulation are always understood in such expressions.) In other words, the "gain" of the first amplifier is commonly 50 *TU* in average broadcasting. This corresponds to an energy amplification of 100,000 times, or a voltage amplification of 316. This first amplifier, which may be termed the microphone amplifier, generally uses three tubes, impedance- or resistance-coupled, to produce this amplification. The available gain may actually be 80 *TU*, which, by means of a potentiometer gain control on the input of the second stage, combined with a tap arrangement on the secondary of the input transformer, is variable in steps of about 3 *TU* from 20 *TU* to the maximum. The first tube may have an amplification constant of 30, while the two following triodes have an amplification constant of 6 or 7. The safe undistorted output is plus 10–12 *TU*, corresponding in the case of the lower figure to 100 milliwatts of audio energy. Such a tube will have an oscillator rating in the neighborhood of 5 watts.

The plus 2 *TU* level in the output of the first amplifier is dropped to about minus 8 *TU* by the attenuation network. Such a network has the property of presenting any desired impedance, within practical limits, in either direction, while introducing a loss of the desired magnitude. If an attempt were made to drop a certain number of transmission units by means of a simple shunt resistance, the impedance requirements looking forward and backward could not be met. The design of such a network as the H-form shown is, within limits, simply a problem of calculating currents by Kirchhoff's Laws and expressing the results in telephonic units. However, the network design cannot be relied upon unless definite terminal conditions are met; for example, the transformers must be flat within given frequency limits, and reasonably close to ideal design in such matters as magnetic leakage and open-circuit impedance. The relations are of course reciprocal, so that unless the artificial network design is correct the terminating transformers will also lose quality. It will be noted, in the case of the 10 *TU* line shown in Fig. 1, that a 500-ohm resistance must be connected across the output in order to carry out the design.

The line output level of minus 8 *TU* is suitable for feeding the monitoring amplifier, which is a bridging amplifier, that is, one with a high-impedance input, in this case about 12,000 ohms, suitable for connection across a 500-ohm circuit without affecting the quality or telephonic energy level of the latter. In this case, by means of two stages of amplification the level is raised about 20 *TU* to plus 12 *TU*, which is sufficient to drive a cone speaker with a good monitoring signal.

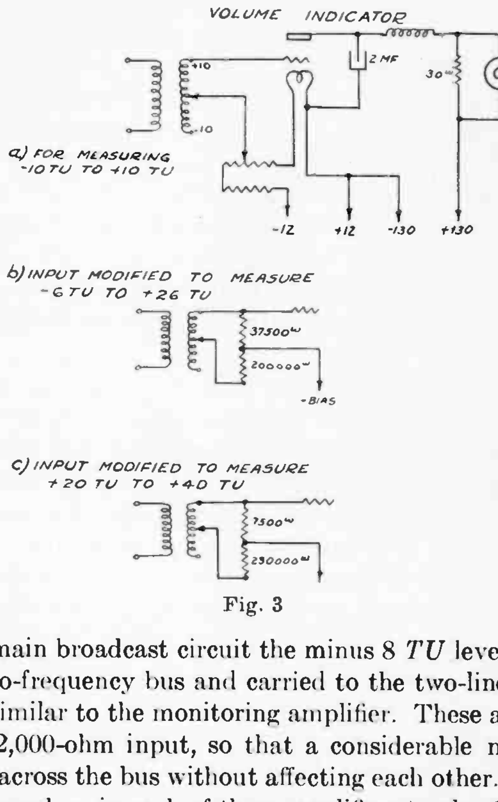


Fig. 3

In the main broadcast circuit the minus 8 *TU* level is supplied to the audio-frequency bus and carried to the two-line amplifiers, which are similar to the monitoring amplifier. These are also used with the 12,000-ohm input, so that a considerable number may be bridged across the bus without affecting each other. The minus 8 *TU* is stepped up in each of these amplifiers to plus 2 *TU*, which is the standard for input to the lines when conditions are normal. The output of the line amplifiers is 500 ohms, to match the cable impedance. In addition to the reason which has already been given for the use of separate line amplifiers, in that they afford independent control of the outgoing circuits, it is also found a convenient arrangement when a large number of studios, each with an associated control room, are handled through a central control office where most of the functions of measurement and outside communication are concentrated.

A description of a level indicator known as the Western Electric 518-B type may be of interest. The circuits of this instrument, which is substantially a thermionic voltmeter used to measure audio-frequency alternating voltages, are shown in Fig. 3. The instrument is of the bridging type, with an input impedance of about 10,000 ohms. The grid of the high-μ tube is biased negatively so far that the plate current is reduced to a reading of 5 out of 60 scale divisions on a certain type of d-c. galvanometer, the terminals of which are shunted by 30 ohms. This corresponds to a plate current of about 0.2 milliampere. Under these conditions the tube rectifies. When the rectified current, smoothed out to syllable frequency by the combination of inductance and capacity in the plate circuit, causes peaks of 30 scale divisions, corresponding to about 1.12 milliamperes plate current, the tap on the secondary of the input transformer and the value of the potentiometer shunt across it may be read to express the telephonic level of the 500-ohm circuit across which the instrument is bridged. A key controls steps of 0, 16, and 30 *TU*, while an auxiliary tap switch may be set to a value between minus 10 and plus 10 *TU*. The latter is the coil tap arrangement shown in Fig. 3, while the large steps are determined by the setting of the grid voltage divider. The instrument measures from minus 10 to plus 40 *TU*, is itself flat to within 1 *TU* between 100 and 5,000 cycles, introduces a slight and correctable loss at various frequencies, and may be used to measure voltages or currents as well as *TU* levels. While its indications are variable with the wave form of the voice or musical currents under measurement, so that some percussion instruments, for example, do not cause the galvanometer needle to swing as high as rounder peaks of the same amplitude, thus introducing the possibility of misleading indications, it is a valuable visual check in broadcast stations. Control methods based on hearing alone would be extremely primitive; the ear has no bright possibilities as a precision instrument. Of course a visual indicator based on the use of a photo-electric or other relatively inertialess response instrument would dispose of the ballistic and form factor complexities of a tube-filter-d-c. galvanometer arrangement, but no such equipment has yet been devised in a shape suitable for application outside of the laboratory.

Fig. 4 is a sketch of the arrangement employed for field broadcasting. The field amplifier is often easily portable, with dry-cell tubes of limited output capacity, say plus 2 *TU*. The amplifier is then operated at a peak level of minus 4 *TU*, affording 6 *TU* overload margin. This is convenient for volume indicator measurement (the field-amplifier also contains a volume indicator) but higher than necessary for a quiet line, so that a 10 *TU* artificial line is inserted, reducing the level at the line terminals to about minus 14 *TU*. If the line has a 1000-cycle equivalent of 6 *TU*, meaning that it introduces a loss of 6 *TU* at the mean speech frequency, the telephone currents will reach the broadcast station at minus 20 *TU*. As the volume at the receivers must not change

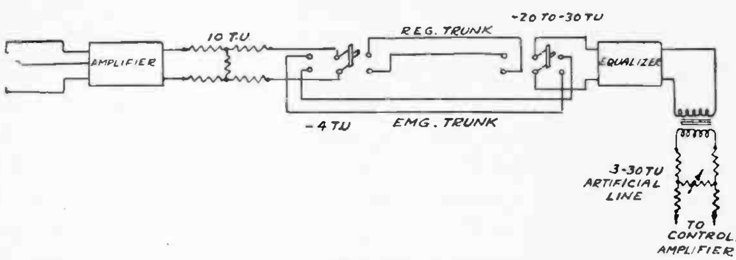


Fig. 4

appreciably during field-studio change-over operations, this is still too high for input to the station amplifier, which, it will be recalled, takes energy from the studio at about minus 50 *TU*. An artificial line with attenuation variable between 3 and 30 *TU* makes up the difference. By this means the change from studio to field pick-up, or vice versa, may be made without an abrupt change in level.

So far we have not discussed in any detail frequency characteristics of broadcast circuits. The presence of the equalizer in Fig. 4 brings up this consideration. In general, broadcast circuits are now designed to be "flat" between 100 and 5000 cycles per second, within 1 *TU*. That is, the over-all transmissi n characteristic from microphone to antenna should be horizontal for all audio frequencies within this band. A line, because of its distributed capacity (0.054 μfd between wires per mile for standard No. 19 A.W.G. cable) will manifest a progressively higher attenuation for the higher frequencies. Fig. 5-A shows this characteristic. By means of an equalizer, which is a network possessing a compensating characteristic (Fig. 5-B), flat where the line is flat and with losses decreasing where the line losses increase with frequency, a resultant may be secured which brings up the relative strength of the high notes and smooths out the over-all characteristic for the essential band of frequencies (Fig. 5-C).

The equalizer, shown schematically in Fig. 6, has a variable impedance for different frequencies. It consists of a parallel circuit resonant to approximately the upper limit of frequency to which it is desired to extend the line characteristic, in series with a variable resistance. The function of the resistance is to control the extent to which the parallel circuit will affect the

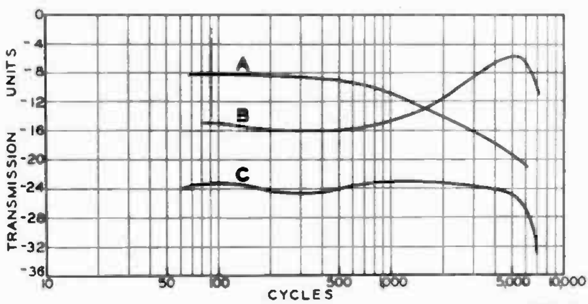


Fig. 5—*A*, Attenuation Characteristic of Cable with 11 *TU* Equivalent at 1000 cycles. *B*, Characteristic of Shunt Equalizer, $R = 10\ \Omega$. *C*, Characteristic of Cable and Equalizer.

transmission characteristic of the whole circuit. For low frequencies the inductive reactance of the coil is negligible (3.14 ohms at 100 cycles for a 5-millihenry coil) so that the value of the shunt is practically determined by the resistance in series. As the frequency rises the inductive reactance of the network increases proportionately, thus increasing the shunt impedance for the higher notes. In the meantime the capacitive reactance of the condenser has been decreasing inversely as the frequency, and at resonance the shunt impedance is a maximum. It drops off again at higher frequencey, causing a cut-off. The loss introduced by such a network is about 10 *TU* at the mean speech frequency (1,000 cycles). With this type of equalizer it is not feasible to correct the characteristic of a line having an equivalent by itself above 12 *TU* at 1,000 cycles.

Now that an outline of the technical basis of broadcast operation has been given, we may consider in some detail the actual procedure whereby programs are put on the air.

The function of the control operators, whether in the field or at the studio, is partly coordinative, as in connection with inter-studio contact and switching, and partly regulative, in that it is found necessary to compress the natural volume variation of speech and music, which may be as high in some cases as 60 TU, into a compass of about 40 TU, if overloading is to be avoided on the one hand and noise interference on the other. The operator makes up this 20 TU difference, in exteme cases, by bringing up his gain control carefully on low passages. Some vocal artists who have adapted their renditions to the requirements of broadcast transmission take care of this themselves by avoiding extreme pianissimos or by swaying back and forth as they sing, approach-

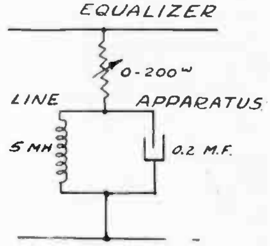


Fig. 6

ing the microphone during pianissimo portions and withdrawing during fortissimos. The former procedure may also be followed by orchestras. The rule is for the operator to handle the gain control as little as possible, but to regulate it when necessary to avoid overloading or the loss of low passages. The volume indicator galvanometer should flicker slightly during the peaks of low passages and rise to the maximum of 30–40 scale divisions during the loudest intervals. Gain regulation must be confined to one place, which is logically at the point of control nearest the origin of the program. The field operator therefore assumes the function of changing the level when necessary, in the case of field programs, the studio operator in the case of studio programs, and the transmitter operator only in the event of serious line irregularities or careless operation which may endanger the radiation of the program at his end.

With regard to the placing of performers in the studio for the best musical balance there is some difference of opinion as to the proper arrangements. In general the non-technical studio staff wishes to place the musicians conveniently (for them) and to move microphones freely. The engineers, on the contrary, prefer a fixed position for the microphones, neccessitating the grouping of the musicians to secure the best musical balance. On this basis the microphone position is fixed according to the acoustic characteristics of the room. In studios which have not been highly damped it is frequently found that standing waves set up at certain frequencies between reflecting surfaces manifest themselves in their various interferences as rattling sounds following an initial impulse. It is possible, by placing a small rug on the floor near a wall drape, to form a space relatively free from such acoustic disturbances, in which the microphone will pick up a program with greater freedom from disturbing transients and distortions in reproduction. This amounts to stating that optimum microphone placing is a function of the studio characteristics and should be left to the judgment of the electro-acoustic experts, not to that of musicians, who, as a class are lacking in scientific qualifications. Musical balance then becomes a problem in placing instruments with reference to the fixed microphones and standardizing on the best positions. This responsibility may devolve on a musician especially delegated to the task, or on the announcer if he has musical training, or on a committee of musicians and musically-experienced technical men capable of listening critically and objectively to loud-speaker reproduction. It is often helpful to allow the conductor of an orchestra to listen, during rehearsals, to the monitoring reproduction, either while his men play without him or under the baton of an assistant. The questions of orchestral balance involve many factors of musical taste, imagination, individual auditory characteristics, and imponderables, which make agreement difficult at best. The problems involved are complex and their full discussion would require a separate paper on the acoustic and musical principles underlying them.

In a broadcast station all program matters are laid out beforehand and printed schedules detailing the artists, announcers and announcements, selections, timing, and studio arrangements are distributed to all personnel concerned. The chances of a slip-up are further reduced by the fact that all program "features" are carefully rehearsed and timed beforehand. While this system does not contribute to spontaneity it has been found the only means of running off a complicated program with dispatch and reliability, especially in chain broadcasting. The function of the operating personnel, under such arrangements, is reduced, save in emergencies, to following routine previously established.

Communication between studios is maintained by means of telephone systems. The operator in the control room associated with each studio, and seated within sight through a double glass window, is in touch with the other studio by means of a breast transmitter and single head-band receiver. He is thus in a position to converse with the other operator while continuing to monitor the program going out through his own studio. It is his duty to keep the other operator informed of the progress of the program and to warn him some minutes before a change from one studio to the other is due. Generally head-receiver facilities for listening to the program in another studio are also provided for the announcers, and in the more intricate set-ups of chain broadcasting it is necessary to devise complicated systems of mechanical switching whereby the announcer picks up his station on visual signal from the control room, by pressing buttons which actuate telephone relays and make the necessary circuit changes, which are, however, supervised by the operators, who sit before similar control boxes and are in a position to correct switching errors made by the announcers.

The preliminary procedure of field broadcasting gives a good idea of the precautions taken to prevent breaks in program continuity. Generally two broadcast pairs are provided, in addition to an order pair for speech communication only. The routine is as follows:

(1) The field operator, having set up his microphones and amplifier, calls in on the order pair one hour before program time and talks to the control operator at the station.

(2) The field operator tests all microphones by talking into them with the central operator listening.

(3) The field operator sends test talk or preliminary program material over both regular and emergency broadcast circuits.

(4) The station operator raises the gain of his amplifier 20 *TU* and listens closely for cross-talk from the order wire in his monitoring speaker, if this is available, while the field operator talks on the order wire, the input to the field amplifier having been cut off.

(5) The field operator synchronizes his watch with the station operator, who takes time from a master clock system.

(6) Ten minutes before program time the field operator sends room noise or preliminary program to the station for check of continuity of the broadcast circuit. This is kept on to within two minutes of program time.

(7) At program time the field operator is told over the order wire, "Take it away," ("It" referring to the program) immediately after the broadcast trunk has been connected to the station amplifier input. He gives the signal to his announcer, who is generally within reach of a hand signal, and the remote program starts. Communication is then maintained throughout the program by the two operators for the purpose of criticism of quality and the effecting of any necessary changes.

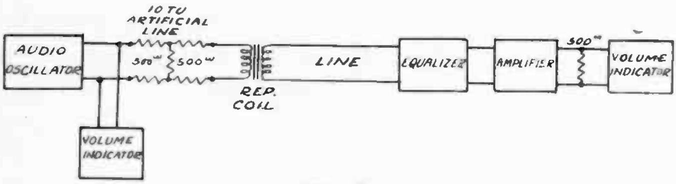


Fig. 7

All such circuits have been previously equalized by means of an audio oscillator sending out tones at a known frequency and level, with an amplifier and volume indicator showing the levels received at the station end. Thus the proper equalizer settings for each line are known and the compensating network is set at this value before or during the above tests. The circuit for the equalization of a wire line shown in Fig. 7, will hardly require comment after the previous description of the functions of the various parts. In general, after the initial run, it is only necessary to check the characteristic daily at three points, say 100, 1,000, and 5,000 cycles. These tests are, of course, in addition to the usual wire chief's d-c. tests for lack of continuity, crosses, grounds, or other defects.

In chain broadcasting similar procedures are followed, the principal difference being that contact between the originating station and the chain is maintained by telegraph. The originating station controls procedure entirely, since obviously with a multiplicity of stations receiving a program unity can be secured only by such a system. The method of making local announcements has been described previously. The fifteen-second intervals in the program left for the announcements are indicated to the chain stations by telegraph a sufficient time before each pre-arranged gap. The individual stations then cut the line input to their amplifiers and turn over to their local microphones, scurrying back to the chain before the fifteen seconds are up. Test tones are sent out by the head station to the network and the volume indicator readings at the points of reception, telegraphed back to the key station, give a necessary check on wire conditions, possible need for re-routing circuits, etc. All the problems of high-quality telephony, as well as specialized broadcasting procedures, are involved. After each program the syndicate stations wire in reports as to technical quality, entertainment value, and the like. A full consideration of such matters does not fall within the scope of a paper of this type.

I wish to acknowledge the valuable assistance of Mr. R. M. Morris of the National Broadcasting Company in supplying much of the technical detail included in this paper.

Review of Current Literature*

Prepared by

STUART BALLANTINE

Boonton - - - - - New Jersey

THE LORENTZ RECIPROCITY THEOREM FOR ELECTRIC WAVES†

AMONG the tools of thought and artifices by which man forces his mind to give him better service, perhaps the most intensely useful are the simple mathematical rules of inversion known as *reciprocity theorems.* A number of these have been invented and have become of classical importance in almost every field of physics in which the phenomena can be described by means of linear equations. In the field of optics we have the celebrated theorem of Helmholtz (restated by Schuster) concerning the reversibility of light rays, in dynamics the theorem of Rayleigh (recently restated by G. W. Pierce and generalized by J. R. Carson for electric networks), in sound that of Helmholtz, in pure mathematics the theorems concerning the reversal of the modulus and argument of elliptic-integrals, in electro-statics the extremely clear and useful reciprocity theorem due to Green; and now concerning the radiation and reception of electric waves by wireless antennas, we have a reciprocity theorem due to H. A. Lorentz. The following résumé of the theorem is based upon a recent article by A. Sommerfeld and will be of interest to radio engineers. The theorem itself has recently been applied to the calculation of the distribution of radiation about a transmitting antenna erected over an imperfect earth by T. L. Eckersley, and to the equivalent problem of the reception of waves arriving from various altitudinal angles, by L. Bouthillon. As to its history Sommerfeld remarks that the theorem was proved in a dissertation (Munich, 1925) by H. Pfang, but it was subsequently pointed out by M. von Laue that it was really of much greater antiquity, having been clearly stated and proved by H. A. Lorentz[1] thirty years before.

* Original Manuscript Received by the Institute, February 3, 1928.

† A. Sommerfeld: *Zeit. für Hochfrequenztechnik*, **26**, 93, 1925; T. L. Eckersley: *Proc. Wireless Sect.*, I. E. E., **2**, 85, June, 1927; L. Bouthillon: *L'Onde Electrique*, **6**, 533, 1927.

[1] H. A. Lorentz: *Amst. Akad. van Wetenshappen*, **4**, 176, 1895.

1. **Statement of the Lorentz Reciprocity Theorem:** *If A_1 and A_2 are two antennas situated at O_1 and O_2 respectively and having arbitrary orientations, and signals are first sent from A_1 and received by A_2, and then sent with the same average power from A_2 and received by A_1, then the intensity and phase of the electric field at the receiver A_1 will be equal to that previously produced at A_2, regardless of the electrical properties and geometry of the intervening media (water, land, or combinations of these, stratified or otherwise inhomogeneous atmosphere, of any degree of ionization, etc.) and the forms of the antennas.*

Sommerfeld gives a detailed proof of this theorem for both electrical and magnetic antennas which the reader may wish to consult for further details.

2. **Conditions under which the Theorem is Valid:** Sommerfeld gives a critical summary of the conditions under which Lorentz's original proof is valid, considering particularly questions (e.g., the state of the upper atmosphere) which have become important in recent years. In the first place no difficulty is presented by its extension to anisotropic media of which the constitutive properties (conductivity σ, and dielectric constant, ϵ) may be different in different directions, provided only that the determinant of these quantities is symmetrical, e.g., $\epsilon_{ik}=\epsilon_{ki}$, and so forth. The proof fails completely, however, when the constitutive relations $D=\epsilon E$, $B=\mu H$, $I=\sigma E$, are non-linear, or when dielectric and magnetic hysteresis are present. Considerable interest attaches to the question of propagation through an ionized medium, but here again it is rather apparent that the validity is unchanged so long as the total convection current remains proportional to the electric force; this would be expected to be the case at all important altitudes. (The motion of ions in the direction of the wave-normal due to "radiation pressure" is not considered).

The theorem fails in a very important case, viz. when the waves are propagated in an ionized medium in the presence of the earth's magnetic field. In these circumstances "gyroscopic" terms are introduced in the motion. As in the Faraday effect in optics a rotation of the plane of polarization occurs and the forward and backward progress of the ray is non-reciprocal. Mathematically the σ's and ϵ's are now partly of an anisotropic character, for example $I_k=\sum_i \sigma_{ik}E_i$, where the σ_{ik}'s are now proportional to the magnetic field. The structure of ϵ may be represented by[2]

$$(\epsilon)=\begin{vmatrix} \epsilon_1 & -j\alpha & 0 \\ j\alpha & \epsilon_1 & 0 \\ 0 & 0 & \epsilon_2 \end{vmatrix}$$

which is no longer symmetric ($\epsilon_{ik}=\epsilon_{ki}$) as required above, but skew ($\epsilon_{ik}=-\epsilon_{ki}$).

3. **Example of Application of the Theorem. Energy Distribution about a Transmitting Antenna over Imperfect Earth:** An instructive example of the application of this theorem has been given by T. L. Eckersley, who has considered the distribution of energy about a transmitting antenna when the earth conductivity is finite. The idealized case of an antenna over *perfect* earth has been discussed by van der Pol, Jr. and others [3] and presents a relatively elementary problem. When, however, the earth is taken to be a dielectric-conductor the ordinary theory of images is no longer available for the simplification of the mental work. This more complicated case was rigorously investigated by A. Sommerfeld[4] in a much neglected paper; an extension of this analysis to the case of the horizontal dipol was made by his pupil, H. von Hoerschelmann. Broadly speaking Sommerfeld considers the field produced on the horizon by a vertical dipol at a negligible distance above the surface of a flat dielectric-conducting earth. The results of the somewhat complicated mathematical analysis are quite amenable to calculation when expressed in simple series and in terms of the so-called "numerical distance". An excellent summary of them, with specimen calculations, has been given by Smith-Rose and Barfield[5] which the non-mathematical reader will find especially entertaining and useful.

Sommerfeld's formulas may be applied to the problem of finding the polar distribution of energy about an antenna of finite length; it simply suffices to consider the antenna as a series of

[2] See René Mésny; "Les Ondes Electriques Courtes," p. 44, Paris, 1926.

[3] Balth, van der Pol, Jr., *Proc.* Roy. Soc., 29, 269, 1917. H. Chireix, *Radio-Electricite*, 5, 65, July 1924. Stuart Ballantine, Proc. I. R. E., 12, 833, December 1924.

[4] A. Sommerfeld; *Jahr. der draht Tel. und Tel.*, 4, 157, 1910. H. von Hoerschelmann; *Jahr. der draht Tel. und Tel.*, 5, 188, 1911. T. L. Echersley; previous citation, p. 119, App. I.

[5] R. L. Smith-Rose and R. H. Barfield; *Proc.* Wireless Sect., I. E. E., 1, 182, September 1926.

electric dipols of moments graduated in accordance with the assumed current distribution, and to integrate over the string of dipols. In the case of a perfect earth we represent the effect of reflection by integrating also over a *positive* image A' (current in the same phase as that of the antenna) of the antenna A below the earth's surface. Eckersley first shows by means of Sommerfeld's analysis that over the actual earth the field horizon at large distances is that due to the antenna plus a *negative* image, i.e., one in which the current is 180 deg. out of phase with that of A. This result and the actual calculation of the polar diagram for the antenna's radiation may be checked and obtained more simply by means of the reciprocity theorem as follows:

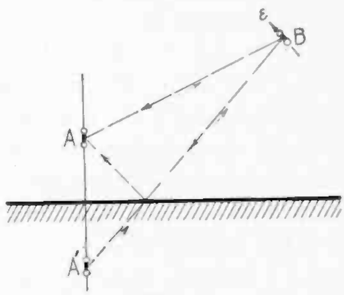


Fig. 1

With reference to Fig. 1, A represents a radiating dipol whose field at a distant point B it is desired to calculate. The wave from A strikes the earth and is reflected, but since A is so close to the earth the wave is certainly spherical when it strikes the earth and it is not at all obvious how the reflection is to be calculated. However, according to the reciprocity theorem the field at B due to A is precisely equal to that at A due to B. The wave from B is, on the other hand, very nearly plane by the time it reaches the reflection point on the earth, and its reflection can be readily calculated by means of the classical Drude equations for a *plane* wave. The total field at A is of course the sum of the direct and reflected waves. The accuracy of the application depends upon the separation of A and B; Eckersley suggests that the results will be accurate provided the distance is large compared with the "numerical distance".

Without going into the details of this calculation the results may be sketched as in Fig. 2. The solid curve represents the variation with the zenith angle ϑ, of the electric force about a vertical dipol at the earth's surface, assuming infinite conductivity. The effect of decreasing the conductivity is to decrease E at small earth angles as shown by the dotted curve.

Eckersley does not actually carry through the computation of the polar diagrams, but in considering a number of antenna types, suggests that in general the actual curve will follow the curve for perfect earth for polar angles up to about 80 deg. and thereafter approach more closely the curve calculated for a *negative* image. Bouthillon (loc. cit.), on the other hand, carefully calculates diagrams for the cases of sea-water, wet earth and dry earth, rocks, etc., for a receiving antenna upon which are incident rays making various angles with the earth's surface.

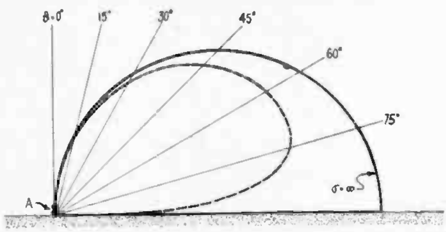


Fig. 2—Variation of Electric Field About Vertical Dipol near Earth's Surface for Cases of Perfectly Conducting Earth ($\varepsilon = 10$; $\sigma = 5 \times 10^7$) at about 70 meters wavelength.

According to the reciprocity theorem these diagrams are of course equally appropriate for the radiation from a transmitting antenna of the same form. Unfortunately Bouthillon's diagrams are not suitable for reproduction.

Figs. 2 and 3 are included to illustrate the actual form of the distribution curves for two representative cases, and were selected from some cases which had been computed for me by Lieut. Raymond Asserson.[6] Fig. 2 represents the case of a vertical dipol at the earth's surface; in Fig. 3 the dipol is elevated above the surface by a distance equal to $\lambda/2$. The assumed earth constants were as follows: $\epsilon - j4\pi\sigma/\omega = 10 - j10$. These values appeared to be the best compromise between the somewhat divergent data of Zenneck, Hack, Loewry, and Smith-Rose and Barfield for ordinary earth at wavelengths between 15 and 150 meters.

The effect of increasing the conductivity is to restore the radiation (and reception) at low angles with the earth, until for

[6] These computations are considerably facilitated by means of Pierce's tables of f and g functions; *Proc.* Amer. Acad., 57, 175, April 1922.

perfect conductivity the curve becomes discontinuous; then the ray along the surface may be mathematically zero, but finite for the slightest physical elevation. The idea is somewhat strange but not hopeless; in the case of sea-water at short wavelengths, for example, a hyper-critic would probably drown himself trying to observe experimentally the low intensities predicted for almost glancing incidence.[7]

It would appear that at distances so great that the ground wave has become very much attenuated a notable increase in signal strength should be observed with increasing elevation aside from any magneto-ionic effects of the upper atmosphere. It would be interesting to check this experimentally by means of a receiver located in an airship, using waves of such short length that the

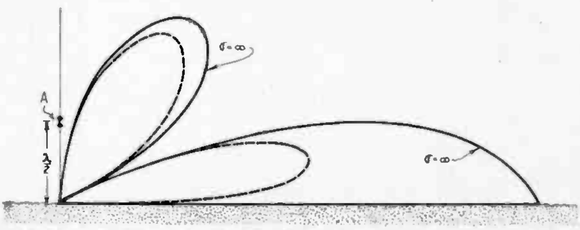


Fig. 3—Variation of Electric Field about Vertical Dipol at a Height of $\lambda/2$ for Cases of Perfect Earth (solid curve) and Actual Earth (dotted curve).

distances could be small and the effect of the bulge of the earth thereby avoided. The results would also suggest that communication at short wavelengths between airplanes might be feasible at medium distances when communication between ground stations over the same distances might be impossible due to the absorption of the ground wave. In other words the extent of the so-called skip-distance zone should be considerably diminished in the case of inter-aircraft signalling due to the enlargement of the ground wave range. This idea appears to me to account for the experimental results recently reported by H. Fassbender[8], who states that in aircraft communication a clearly defined skip-distance is not observed.

Another practical consequence of these calculations, which was pointed out by Eckersley, is the advantage for ground communication of increasing the height of short wave antennas.

[7] The corresponding acoustic case is interesting. Prof. G. W. Pierce recently related to me that on a lake in New Hampshire he was able, by placing his ear close to the water surface, to hear with considerable intensity the voice of a man speaking in a boat three miles away. While destructive reflection is also predicted in this case, the phenomena is not simple and Rayleigh surface waves in the water may also play an important part on the propagation.

[8] H. Fassbender: *Zeit. für Hoch.*, 30, 176, 1927.

BOOK REVIEWS

The Cable and Wireless Communications of the World, BY F. J. BROWN. Published by Isaac Pitman and Sons, London and New York. Price $2.25.

The author of this book was formerly Assistant Secretary to the British Post Office in charge of cables and wireless. He is now Director of the International Cable Companies' Association. The first third of the book contains a brief historical and geographical résumé of the existing cable systems of the world together with a description of the general aspects of manufacture and laying of cables and the technique of cable communication.

Following this is a discussion of the relations between the cables and radio in the communication business of the world from which the conclusion is drawn that up until about the present time cable and radio costs were such that there has been no great inherent difference between the two on that basis. It is pointed out, however, that only the future can determine what will be the change in relationship, if any, brought about by the development of the new high-speed cables, (for example, the permalloy cable), and the increasing use of short waves in radio.

One chapter is devoted to a discussion of the relationships between governments and private agencies in the operation of communication services. Reference is here made to the International Telegraph and Radiotelegraph Conventions.

Several chapters touch on financial questions, such as capital investment, depreciation and rate of return on both cable and radio systems and the rates charged for various classes of telegraphic service.

The book closes with a chapter devoted to international broadcasting. Moreover, the book is written in a style which makes it very easy to read.

The Theory and Practice of Radio Frequency Measurements. BY E. B. MOULLIN. Published by J. B. Lippincott Company, 277 South 6th St., Philadelphia, Penna. First edition, 278 pages and 134 illustrations.

This publication is offered as a handbook for the laboratory and a textbook for advanced students. It consists for the most part of a collection of the best-known methods of measuring the fundamental characteristics of radio-frequency apparatus and systems. Beginning with a fairly complete description of the vacuum-tube oscillator as a source of testing power, the author discusses in separate chapters the measurement of potential difference and current, frequency, resistance, capacity, inductance, antenna characteristics, and finally, radiated fields. The closing chapter contains notes on miscellaneous items such as measurement of the harmonics of a generator, transformer equations, rectification with a heterodyne, etc.

Alternative methods are generally given, with those preferred by the author receiving the more complete treatment. Sufficient explanatory matter is presented, however, to permit the reader to make an independent choice. The chapters on potential and current and on frequency measurements are particularly good; the only important exceptions to this that have been noted are that in the former there is a highly unsatisfactory discussion of the design of a current transformer and in the latter the important use of the phonic wheel in absolute measurements is omitted.

Resonance methods of measuring capacity and inductance by means of indicating instruments are quite satisfactorily treated. No adequate discussion of null or bridge methods is given, these being briefly dismissed by the author without due consideration of their merits. Similarly, practically nothing is said regarding the use of electrostatic shielding. The latter being almost essential to accurate bridge measurements, one suspects that lack of experience with such shielding may account for the stand taken on the former. Resistance measurements, whether of resistors, inductors, or capacitors are less satisfactorily covered, particularly with reference to suitable standards. Much space is devoted to calculations of skin effect and eddy currents in conductors of a type that would seldom be used in standards of either resistance or inductance and little useful information given as to the resistance or phase angle of convenient laboratory forms.

Taking the book as a whole, it is noted that the various methods are grouped in accordance with the characteristics to be determined rather than according to the principles employed. While this arrangement, of course, makes it very easy to select a method for making a particular test, it does not lend itself so well to the logical development of the subject. Perhaps it is on this account that there is almost no attention given to the interrelations of the methods studied. However, in spite of the adverse comments here made, this contribution to the field of radio engineering fills a definite need.

W. J. Shackelton

BIBLIOGRAPHY ON PIEZO-ELECTRICITY*

By

W. G. Cady

(Department of Physics, Wesleyan University, Middletown, Conn.)

IN response to various requests, there is presented herewith a general bibliography on piezo-electricity and its applications. While the writer hopes that it is fairly complete to the beginning of 1928, still he realizes that some of the literature on the subject has doubtless been overlooked. He would be grateful to any who would call his attention to errors or omissions, since he hopes to publish a supplementary list at some future time.

Part I

Books and Periodical Literature

The following list is arranged alphabetically according to authors. In the cases of a few anonymous publications, however, articles are listed by title or by name of publication. Many references to papers in which piezo-electricity is quite subordinate have been included, where the portion in question seemed of sufficient interest. The English equivalents of foreign titles have been made as literal as possible. For the early literature, which is very voluminous, citation is made only of those publications which are of historical value or otherwise of outstanding importance. More complete references to the early literature on the subject may be found in Nos. 49, 85, 87, 109, 158, 214, and 222 below.

For the convenience of those who make use of the bibliography, the subject-matter has been arbitrarily classified into seven categories, as follows:

A. Fundamentals, theory, and early numerical data.

B. General articles on the piezo-electric resonator and oscillator.

C. Optical and other tests; preparation and mounting of crystals.

D. Luminous effects of vibrating crystals.

E. Standards of frequency and wavemeter calibration.

F. Transmitting apparatus and circuits.

G. Miscellaneous applications.

Appended to each reference are one or more of the above seven key-letters, indicating the general nature of the contents.

*Original Manuscript Received by the Institute February 28, 1928.

Abbreviations

Ann. d. Phys. *Annalen der Physik* (Leipzig).

Arch. sc. phys. et nat. *Archives des sciences physiques et naturelles* (Geneva).

Elektr. Nachr.-Techn. *Elektrische Nachrichtentechnik* (Berlin).

Elektrot. ZS. *Elektrotechnische Zeitschrift* (Berlin).

Elektrot. u. Maschinenb. *Elektrotechnik und Maschinenbau* (Vienna).

Exp. W. & W. Eng. *Experimental Wireless & Wireless Engineer* (London).

Göttinger Nachr. *Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen, Math.-Phys. Klasse.*

J. Opt. Soc. Am. *Journal* of the Optical Society of America and *Review of Scientific Instruments.*

J. de phys. *Journal de physique* (Paris).

Phil. Mag. London, Edinburgh and Dublin *Philosophical Magazine* and *Journal of Science.*

Phys. Rev. *Physical Review* (Corning, N. Y.).

Phys. Ber. *Physikalische Berichte* (Braunschweig).

Phys. ZS. *Physikalische Zeitschrift* (Leipzig).

Proc. Amer. Acad. *Proceedings* of the American Academy of Arts and Sciences.

Wiener Ber. *Berichte der Kaiserlichen Akademie der Wissenschaften zu Wien, Math.-Nat. Kl.*

W. World. *Wireless World* (London).

ZS. f. Hochfrequenztechn. *Zeitschrift für Hochfrequenztechnik* (*Jahrbuch der drahtlosen Telegraphie u. Telephonie*) (Berlin).

ZS. f. Instrkde. *Zeitschrift für Instrumentenkunde* (Berlin).

ZS. f. Phys. *Zeitschrift für Physik* (Berlin).

ZS. f. techn. Phys. *Zeitschrift für technische Physik* (Leipzig).

AUTHORS' INDEX

1. Abello, T. P. Absorption of ultrasonic waves by some gases (abst.). *Phys. Rev.* **31**, p.157, 1928. (G)

2. Adams, E. P. *On electrets.* J. Frankl. Inst. **204**, p.469, 1927. (A)

3. Bayard, T. L. A new crystal pilot. *Popular Radio* (New York) **9**, p.342, April 1926. (E, F)

4. Bazzoni, C. B. The piezo-electric oscillograph. *Radio News* (New York) **7**, p.142, August 1925. (G)

5. Beckman, Anna. The piezo-electric excitation of quartz at low temperatures. *Onnes-Festschrift* (Leyden) 1922, p. 454; *Phys. Ber.* **4**, p.1574, 1923. (A)

6. Bedeau, F. Network equivalent of a piezo-electric quartz. *QST Francais* **8**, p.22, April 1927. (B)

7. Bedeau, F., and J. deMare. Sustained note produced by a quartz plate oscillating simultaneously at two different high frequencies. *C. R.* **185**, p.1591, 1927. (B)

8. Bloxham, R. W. H. Crystal-controlled transmitter. *W. World* **20**, p.449, 1927; see also **21**, p.190, 1927. (F)

9. Born, M. Thermodynamics of crystal lattices. *ZS. f. Phys.* **7**, p.217, 1921. (A)

10. Born, M. Atomtheorie des festen Zustandes (Atomic theory of the solid state), Leipzig 1923. (A)

11. Born, M., and Eliz. Bormann. Grating theory of zinc blende. *Ann. d. Phys.* **62**, p.218, 1920. (A)

12. Bown, R., D. K. Martin, and R. K. Potter. Some studies in radio broadcast transmission. Bell Syst. *Tech. J.* **5**, p.143, January 1926. (F)

13. Boyle, R. W., and G. B. Taylor. Reflecting powers of various materials for ultrasonic waves. *Trans.* Roy. Soc. Canada **20**, Sec 3, p.245, 1926. (G)

14. Boyle, R. W., S. C. Morgan, and J. F. Lehmann. Audible sonic beats from inaudible sources. *Trans.* Roy. Soc. Canada **17**, Sec. 3, p.141, 1923. (G)

15. Bragg, W., and R. E. Gibbs. The structure of alpha and beta quartz. *Proc.* Roy. Soc. London, (A), **109**, p.405, 1925. (A)

16. Braillard, R., and E. Divoire. The exact and precise measurement of wavelength in radio transmitting stations. *Exp. W. & W. Eng.* **4**, p.322, June 1927, and p.394, July 1927. (E)

17. Brain, K. R. Investigations of piezo-electric effects with dielectrics. *Proc.* Phys. Soc. London **36**, p.81, 1924. (A)

18. Browne, C. O. Demonstration of high-frequency fluctuations in the intensity of a beam of light. *Proc.* Phys. Soc. London **40**, p.36, 1927. (C, G)

19. Buchanan, F. Muscular piezo-electricity. *Nature* (London) **108**, p.340, 1921. (A)

20. Buisson, H. Method of observing the optical purity of quartz crystals. *J. de phys.* **8**, p.25, 1919. (C)

21. Bureau of Standards Letter Circular 183. Directions for use of the piezo-oscillator and auxiliary generator for calibration of a radio-frequency meter. October 12, 1925. (E)

22. Bureau of Standards Letter Circular 186. Specifications for portable piezo-oscillator, Bureau of Standards Type N. November 20, 1925. (E)

23. Bureau of Standards Letter Circular 223. Use of the piezo-oscillator in radio broadcasting stations. January 12, 1927. (E, F)

24. Byrnes, I. F. Quartz crystals control wavelengths of broadcast stations. *Radio News* (New York) **7**, p.953, January 1926. (F)

25. Cady, W. G. The piezo-electric resonator. PROC. I. R. E. **10**, p.83, 1922. (A, B, C, E, G)

26. Cady, W. G. A method of testing plates from piezo-electric crystals. *J.* Opt. Soc. Am. **6**, p.183, 1922. (C)

27. Cady, W. G. Piezo-electrically driven tuning-forks and rods (abst.). *Phys. Rev.* **21**, p.371, 1923. (G)

28. Cady, W. G. A resonance tube excited by crystals (abst.) *Phys. Rev.* **23**, p.558, 1924. (G)

29. Cady, W. G. An international comparison of radio wavelength standards by means of piezo-electric resonators. PROC. I. R. E. **12**, p.805, 1924. (E)

30. Cady, W. G. The quartz crystal as a new wavelength standard. *Popular Radio* (New York) **7**, p.357, 1925. (A, B, E)

31. Cady, W. G. Piezo-electric standards of high frequency. *J.* Opt. Soc. Am. **10**, p.475, 1925. (A, B, E)

32. Cady, W. G. A shear mode of crystal vibration. (abst.). *Phys. Rev.* **29**, p.617, 1927. (B)

33. Clapp, J. K. "Universal" frequency standardization from a single frequency standard. *J.* Opt. Soc. Am. **15**, p.25, 1927. (E)

34. Clayton, J. M. Crystal control for amateur stations. *QST* **9**, November 1925, p.8. (C, F)

35. Clayton, J. M. Navy developments in crystal-controlled transmitters. *QST* 9, November 1925, p.41. (F)

36. Clayton, J. M. An A. C. crystal control set. *QST* **10**, January 1926, p.23. (F)

37. Clayton, J. M. Calibrating your wavemeter from a quartz crystal. *QST* **10**, February 1926, p.39. (E)

38. Clayton, J. M. Neutralizing the crystal amplifier. *QST* **10**, March 1926, p.36. (F)

39. Clayton, J. M. Quartz crystal mountings. *QST* **10**, July 1926, p.15. (C)

40. Clayton, J. M. Luminous frequency standards. *QST* **10**, September 1926, p.17. (D)

41. Clayton, J. M. A shielded crystal-controlled unit. *QST* **10**, November 1926, p.22. (F)

42. Clayton, J. M. Low-power crystal-controlled transmitter. *QST* **11**, January 1927, p.14. (F)

43. Clayton, J. M. A D. C.-A. C. crystal-controlled transmitter. *QST* **11**, February 1927, p.31. (F)

44. Colabich, P. Utilization of piezo-electric phenomena. *L'Elettricista* **32**, p.60, April 15, 1923. (B, G)

45. Collins, J. H. The voice in a lump of salt. *Popular Radio* (New York) **2**, September 1922, p.42. (G)

46. Crandall, I. B. Theory of vibrating systems and sound. Van Nostrand, New York, 1926. (P.142, quartz supersonic oscillator, and echo receiving). (G)

47. Crossley, A. Piezo-electric crystal-controlled transmitter. PROC. I. R. E. **15**, p.9, 1927. (F)

48. Crossley, A., Quartz crystal calibrators. *QST* **11**, March 1927, p.23. (E)

49. Curie, P. Oeuvres de Pierre Curie. Gauthier-Villars, Paris 1908. (A, G)

50. Curie, J. and P. Development by pressure of polar electricity in hemihedral crystals with inclined faces. *C. R.* **91**, p.294, 1880; *J. de phys.* (2), Vol. 1, p.245, 1882; *Bull.* Soc. Miner. France **3**, p.90, 1880. (Discovery of piezo-electricity). (A)

51. Curie, J. and P. Contractions and dilatations produced by electric fields in hemihedral crystals with inclined faces. *C. R.* **93**, p.1137, 1881. (First observation of converse effect). (A)

52. Curie, J. and P. Electric deformations of quartz. *C. R.* **95**, p.914, 1882. (A)

53. Curie, J. and P. Electric dilatation of quartz. *J. de phys.* **8**, p.149, 1889. (First determination of piezo-electric constant; quartz electrometer). (A, G)

54. Czermak, P. On the electric behavior of quartz. *Wiener Ber.* **96**, p.1217, 1887; **97**, p.301, 1888. (A)

55. Davies, R. M. The temperature variation of the elasticity of Rochelle salt. *Nature* (London) **120**, p.332, 1927. (A, B)

56. Dawson, L. H. Examining quartz for oscillator use. *QST* **10**, p.23 September 1926. (C)

57. Dawson, L. H. Piezo-electricity of crystal quartz. *Phys. Rev.* **29**, p.532, 1927. (C)

58. Dow, J. B. The operation and construction of quartz crystals. *Radio* (San Francisco) **8**, p.27, November 1926. (B)

59. Dow, M. T. Piezo-electric crystals. *Radio Broadcast* (New York) **10**, p.263, January 1927. (E)

60. Dow, M. T. Piezo-electric crystals. *Radio Broadcast* (New York) **11**, p.271, September 1927. (E)

61. Dye, D. W. Piezo-electric quartz resonator and equivalent electrical circuit. *Proc.* Phys. Soc. London **38**, pp.399 and 457, 1926. (B, E)

62. Dye, D. W. Piezo-electric quartz resonator (abstract of No. 61). *Elec. Review* (London) **99**, p.733, 1926. (B,E)

63, Eguchi, M. Permanently polarized dielectrics. *Proc.* Phys. Math. Soc. Japan **2**, p.169, 1920; *Phil. Mag.* **49**, p.178, 1925. (A)

64. Eshelby, A. W. Looking at quartz. *QST* **10**, p.52, November 1926. (C)

65. Fitch, C. J. Visible Radio waves. *Radio News* (New York) **8**, p.791, January 1927. (G)

66. Frayne, J. G. Reversible inductivity of Rochelle salt under high-frequency fields. *Phys. Rev.* **20**, p.97, 1922. (A)

67. Frayne, J. G. Reversible inductivity of Rochelle salt crystals. *Phys. Rev.* **21**, p.348, 1923. (A)

68. Fujimoto, T. On the determination of the piezo-electric constant of a quartz resonator at high frequencies (abst.). *Phys. Rev.* **31**, p.312, 1928. (A, B)

69. Gabel, V. A practical mounting for piezo-quartz plates. *ZS. f. Hochfrequenztechn.* **29**, p.194, 1927. (C)

70. Galitzin, B. Apparatus for direct determination of accelerations. *Proc.* Roy. Soc. London, (A), **95**, p.492, 1919. (G)

71. Gieger, H., and K. Scheel. Handbuch der Physik. Springer, Berlin. Vol. 8, 1927, pp.332, 567 (acoustics) (G); Vol. 13, 1928, Chap. 8. (A,B)

72. General Radio Co. A rock-bottom standard. General Radio *Experimenter* **1**, No. 6, p.4, December 1926. (E)

73. Gibbs, R. E. The variation with temperature of the intensity of reflection of X-rays from quartz and its bearing on the crystal structure. *Proc.* Roy. Soc. London, (A), **107**, p.561, 1925. (A)

74. Gibbs, R. E. Structure of alpha quartz. *Proc.* Roy. Soc. London, (A), **110**, p. 443, 1926. (A)

75. Giebe, E. Luminous piezo-electric resonators as high-frequency standards. *ZS. f. techn. Phys.* **7**, p.235, 1926. (D)

76. Giebe, E., and A. Scheibe. Luminous effects of high-frequency longitudinal vibrations in piezo-electric crystals. *ZS. f. Phys.* **33**, p.335, 1925. (D)

77. Giebe, E., and A. Scheibe. A simple method for qualitative indication of piezo-electricity of crystals. *ZS. f. Phys.* **33**, p.760, 1925. (A)

78. Giebe, E., and A. Scheibe. Luminous piezo-electric resonators as high-frequency standards. *Elektrot. ZS.* **47**, p.380, 1926. (D)

79. Giebe, E., and A. Scheibe. Activity of the Phys.-tech. Reichsanstalt in the year 1926. *ZS. f. Instrkde,* **47**, p.269, 1927. (D)

80. Giebe, E., and A. Scheibe. Piezo-electric excitation of elastic vibrations. *ZS. f. Hochfrequenztechn.* **30**, p.32, 1927. (Abbreviation of No. 79) (D)

81. Glaser, E. M. A flexible crystal transmitter. *QST* **11**, p.18, June 1927. (F)

82. Goyder, C. W. The piezo-electric effect and its application to wireless. *Exp. W. & W. Eng.* **3**, p.94, February, and p.165, March, 1926. (A, C, E, F)

83. Goyder, C. W. Complete control for the medium power station. *T. and R. Bull.* **2**, p.4, December 1926. (C, F)

84. Goyder, C. W. Frequency stabilization by means of the quartz oscillator. *Exp. W. & W. Eng.* **3**, p.717, December 1926; supplementary note in Vol. 4, p.188, March 1927. (F)

85. Graetz, L. *Handbuch der Elektrizität und des Magnetismus.* Leipzig 1918. Vol. I, chapter on piezo-electricity. (A)

86. Griffiths, E. A gas analysis instrument based on sound velocity measurement, *Proc.* Phys. Soc. London **39**, p.300, 1927. (G)

87. Groth, P. Physikalische Krystallographie. Leipzig 1905. (A)

88. Hallborg, H. E. Some practical aspects of short wave operation at high power. Proc. I. R. E. **15**, p.501, 1927. (F)

89. Hallborg, H. E., L. A. Briggs, and C. W. Hansell. Short wave commercial long distance operation. Proc. I. R. E. **15**, p.467, 1927. (F)

90. Harris, R. G. Oscillating crystals for wavemeter calibration. *Radio News* (New York) **5**, p.1418, April 1924. (E)

91. Harrison, J. R. Piezo-electric resonance and oscillatory phenomena with flexural vibrations in quartz plates. Proc. I. R. E. **15**, p.1040, 1927. (B, C, D, E, F)

92. Hartley, J. J., and R. H. Rinaldi. Demonstration of the application of piezo-electric properties of a Rochelle salt crystal and the three-electrode valve to the determination of impact stresses in granular material. *Proc.* Phys. Soc. London **38**, p.273, 1926. (G)

93. Heckmann, G. Note on the lattice theory of piezo-electricity. *ZS. f. Phys.* **33**, p.646, 1925. (A)

94. Heegner, K. On measurements with piezo-electric crystals. *ZS. f. Hochfrequenztechn,* **29**, p.177, 1927. (B, G)

95. Hettich, A., and A. Schleede. Polarity and piezo-electric excitation. *ZS. f. Phys.* **46**, p.147, 1927. (A)

96. Hinderlich, A. Calibrating a quartz wavelength standard. *W. World* **19**, p.95, 1926. (E)

97. Hinderlich, A. Quartz crystals and their practical applications. *Exp. W. & W. Eng.* **4**, p. 29 (also discussion on p. 36), January 1927. (C, F)

98. Hinderlich, A. Quartz. Pamphlet published by Quartz Oscillators, Ltd., London 1927. (B, C, E, F)

99. Hirschhorn, S. J. On a translatory motion of a piezo-quartz crystal in an electric field. *ZS. f. Phys.* **44**, p.223, 1927. (B)

100. Hitchcock, R. C. Radio frequency standards. *Electric Journal* (Pittsburgh) **24**, p.430, 1927. (E, F)

101. Hitchcock, R. C. Mounting quartz oscillator crystals. PROC. I. R. E. **15**, p.902, 1927. (C, E, F)

102. Hubbard, J. C., and A. L. Loomis. Compressibilities of liquids by the sonic interferometer (abst.). *Phys. Rev.* **31**, p. 158, 1928; see also *Nature* (London) **120**, p.189, 1927. (G)

103. Huggins, M. L. The crystal structure of quartz. *Phys. Rev.* **19**, p.363, 1922. (A)

104. Hulburt, E. O. Piezo-electric quartz oscillators coated with metallic films (abst.). *Phys. Rev.* **27**, p.814, 1926. (C)

105. Hull, G. F. Some applications of physics to ordnance problems. *J. Frankl. Inst.* **192**, p.344, 1921. (G)

106. Hund, A. Uses and possibilities of piezo-electric oscillators. PROC. I. R. E. **14**, p.447, 1926. (C, E, F)

107. Hund, A. Note on piezo-electric generators with small back action. PROC. I. R. E. **15**, p.725, 1927. (B)

108. Hydrographic Review 2, No. 1, November 1924, p.51. A number of articles on applications of piezo-electricity to under-water acoustics. (G)

109. International Critical Tables. McGraw-Hill Book Co., New York. Volume containing piezo-electric data will soon be published. (A)

110. Iseley, F. C. The relation between the mechanical and piezo-electrical properties of a Rochelle salt crystal. *Phys. Rev.* **24**, p.569, 1924. (A)

111. Jolliffe, C. B., and Miss Hazen. Establishment of radio standards of frequency by the use of a harmonic amplifier. Bur. of Standards, Sci. Paper No. 530, Vol. 21, p.179, 1926. (E)

112. Jouaust, R. Piezo-electric quartz as a frequency standard. *L'Onde Electrique* 6, November 1927. (E)

113. Karcher, J. C. A piezo-electric method for the instantaneous measurement of high pressures. Bur. of Standards, Sci. Paper No. 445, Vol. 18, p.257, 1922; *J. Frankl. Inst.* **194**, p.815, 1922. (A, G)

114. KDKA 309.1 metre transmitter. *W. World* **19**, p.413, 1926. (F)

115. Kelvin, Lord. On the piezo-electric property of quartz. *Phil. Mag.* **36**, p.331, 1893 (also pp.342, 384, 453). (A)

116. Kelvin, Lord. Baltimore Lectures. London 1904, pp.559, 637. (A)

117. Keys, D. A. Piezo-electric method of measuring explosion pressures. *Phil. Mag.* **42**, p.473, 1921. (G)

118. Keys, D. A. Adiabatic and isothermal piezo-electric constants of tourmaline. *Phil. Mag.* **46**, p.999, 1923. (A)

119. Kröncke, H. Piezo-electric vibrations in quartz crystals. *W. World* **17**, p.896, 1925. (D)

120. Langevin, P. Sounding by means of sound waves. Publ. Spec. No. 3, Bur. Hydrogr. Internat., Monaco 1924. (G)

121. Langevin, P., and C. Chilowsky. Echo Sounding. *Nature* (London) **115**, p.689, 1925; also Publ. Spec. No. 14, Bur. Hydrogr. Internat., Monaco, August 1926. (G)

122. Larmor, J. Electro-crystalline properties as conditioned by atomic lattices. *Proc.* Roy. Soc. London, (A), **99**, p.1, 1921. (A)

123. Laue, M. v. Piezo-electrically excited vibrations of quartz rods. *ZS. f. Phys.* **34**, p.347, 1925. (B)

124. Lee, W. J. Practical crystal-controlled transmitters. *QST* **10**, January 1926, p.21. (C, F)

125. Lichte, H. Theory of the electrostatic telephone. *Elektr. Nachr.-Techn.* **3**, p.390, 1926. (B, G)

126. Lippmann, G. Principle of the conservation of electricity. *J. de phys.* (1) **10**, p.381, 1881; *Ann. de chim. et de phys.* (5) **24**, p.145, 1881. (Prediction of converse effect.) (A)

127. Little, D. G., and R. L. Davis. KDKA. PROC. I. R.E. 14, p.479, 1926 (F)

128. Lucas, R. Piezo-electric and molecular asymmetry. *C. R.* 178, p.1890, 1924. (A)

129. Mallett, E. and V. J. Terry. The quartz oscillator. *W. World* 16, p.630, 1925. (B, E)

130. Marchand, H. Piezo-electricity and its applications. *La Nature* 49, p.20, 1921. (A, G)

131. Marti, P. Depth-sounding by sound waves. *La Nature* 49, p.125, 1921. (G)

132. Mason, H. F. Crystal cutting. *QST* 10, p.59, February 1926. (C)

133. McGown, D. B. The quartz crystal oscillator. *Radio* (San Francisco) 7, p.29, July 1925; p.33, October 1925. (B, E)

134. McKeehan, L. W. The crystal structure of quartz. *Phys. Rev.* 21, p.503, 1923. (A)

135. McMinn, S. P. Adjusting the crystal-controlled transmitter. *QST* 10, p.43, May 1926. (F)

136. Meissner, A. Piezo-electric crystals at high frequency. *ZS. f. techn. Phys.* 7, p.585, 1926, and 8, p.74, 1927; *Elektr. Nachr.-Techn.* 3, p. 401, 1926; *Elektrot. u. Maschinenb.* (*Radiotechnik*) 45, p.1, 1927; *ZS. f. Hochfrequenztechn.* 29, p.20, 1927; abstract in *W. World* 20, p.202, 1927, (A, B, F)

137. Meissner, A. Piezo-electric crystals at radio frequencies. PROC. I. R. E. 15, p.281, 1927. (A, B, F) (English transl. of No. 136)

138. Meissner, A. Investigations with quartz. *Phys. ZS.* 28, p.621, 1927. (A, B)

139. Miller, H. S. Piezo-electric crystal patents. *J.* Patent Office Society 9, p.416, May 1927, (B, C, E, F, G)

140. Moens, R., and J. E. Verschaffelt. Optical phenomena exhibited by quartz when vibrating piezo-electrically. *C. R.* 185, p.1034, 1927. (C)

141. Moore, R. W. Growing Rochelle salt crystals. *J.* Am. Chem. Soc. 41, p.1060, 1919. (C)

142. Morecroft, J. M. How crystal frequency control works. *Radio Broadcast* (New York) 9, p.116, 1926. (B, F)

143. Mueller, P. A method of grinding quartz plates. *QST* 11, p.24, May 1927. (C)

144. Nachtikal, F. Proportionality between piezo-electric moment and pressure. Göttinger Nachr. 1899, p.109. (A)

145. Nancarrow, F. E. Quartz crystal resonators. P. O. Elec. Engineers *J.* (London) 18, p.168, 1925. (B, C, E)

146. Nicolson, A. M. The piezo-electric effect in the composite Rochelle salt crystal. *Trans.* Am. Inst. Elec. Eng. 38, p.1467, 1919; *Proc.* Am. Inst. Elec. Eng. 38, p.1315, 1919; *Electrician* (London) 83, p.32, 1919. (A, B, G)

147. Nicolson, A. M. Crystals for sound amplification demonstrated. *Elec. Review* (Chicago) 74, p.954, 1919. (G)

148. Nicolson, A. M. Quantitative investigation of piezo-electromotive forces. *Electrical World* (New York) 75, p.1358, 1920. (A, G)

149. Olinet, P. Absolute calibration of a wavemeter. *QST* Français 8, p.6, September 1927. (E)

150. Onnes, H. K., and A. Beckman. Piezo-electric and pyro-electric properties of quartz at low temperatures. Konink. Akad. Wetensch. Amsterdam, *Proc.*, 15, p.1380, 1913; Communication No. 132f from Phys. Lab. Leyden. (A)

151. Perrier, A. Hypotheses concerning spontaneous dielectric polarization, and some experimental results. *Arch. sc. phys. et. nat.* (4) 41, p.492, 1916. (A)

152. Perrier, A., and B. de Mandrot. Elasticity and symmetry of quartz at high temperatures. *C. R.* 175, pp.622 and 1006, 1922. (A)

153. Pierce, G. W. Piezo-electric crystal resonators and crystal oscillators applied to the precision calibration of wavemeters. *Proc.* Amer. Acad. 59, p.81, 1923. (E)

154. Pierce, G. W. Piezo-electric crystal oscillators applied to the precision measurement of the velocity of sound in air and carbon dioxide at high frequencies. *Proc.* Amer. Acad. **60**, p.271, 1925. (G)

155. Pierce, R. An oscillating amplifier for the crystal transmitter. *QST* **11**, p.15, October 1927. (F)

156. Piezo-electric wavemeters. *W. World* **19**, p.65, 1926. (D)

157. Piezo-electricity and its Technical Applications. *Technik für Alle* (Stuttgart) **15**, p.176, 1924. (G)

158. Pockels, F. Encyklopädie der Math. Wissenschaften. Vol. 5, Part 2. Leipzig, 1907. (A)

159. Powers, W. F. Temperature coefficient of frequency of quartz resonators (abst.). *Phys. Rev.* **23**, p.783, 1924. (B)

160. Poynting and Thomson. Textbook of Physics. Vol. 4, Electricity and Magnetism. London, 1920. (A)

161. Quimby, S. L. On the experimental determination of the viscosity of vibrating solids. *Phys. Rev.* **25**, p.558, 1925. (G)

162. Radio Amateur's Handbook. Amer. Radio Relay League, Hartford 1927. (B, C, E, F)

163. Rich, D. L., and W. H. Pielemeier. Absorption of high-frequency sound (abst.). *Phys. Rev.* **25**, p.117, 1925. (G)

164. Ridley, J. H. D. A crystal-controlled 45-metre transmitter. *Modern Wireless* (London) **6**, p.674, December 1926. (F)

165. Riecke, E. Molecular theory of the piezo-electricity of tourmaline. *Phys. ZS.* **13**, p.409, 1912; *Göttinger Nachr.* 1912, p.253; *Arch. sc. phys. et nat.* **34**, p.260, 1912. (A)

166. Riecke, E. On pyro-electricity and piezo-electricity. *Arch. sc. phys. et nat.* **36**, pp.101, 216, 305, 405, 1913. (A)

167. Riecke, E., and W. Voigt. Piezo-electric constants of quartz and tourmaline. Göttinger Nachr. 1891, p.247; *Widemann's Annalen* **45**, p. 523, 1892; Groth's *Zeitschrift* **22**, p.185, and **23**, p.635. (A)

168. Riley, J. New 50 K. W. transmitter of station WEAF. *Radio News* (New York) **9**, p.462, 1927. (C, F)

169. Röntgen, W. C., and A. Joffé. On the electric conductivity of certain crystals and the effect of radiation thereupon. *Ann. d. Phys.* **41**, p.449, 1913. (A)

170. Röntgen, W. C. Pyro- and piezo-electric investigations. *Ann. d. Phys.* **45**, p.737, 1914. (A)

171. Root, L. B. A 20-40-80-meter crystal-controlled transmitter. *QST* **10**, p.33, August 1926. (F)

172. Russell, E. W. Muscular piezo-electricity. *Nature* (London) **108**, p.275, 1921. (A)

173. Russell, E. W. C., and A. F. R. Cotton. Commercial piezo-electricity. *Elec. Review* (London) **92**, p.284, 1923. (G)

174. Samuel, M. F. J. An interesting quartz note. T. and R. Bull. **2**, p.6, June 1927. (B, F)

175. Scheibe, A. Piezo-electric resonance phenomena. *ZS. f. Hochfrequenztechn.* **28**, p.15, 1926. (A, B, C, D, E, G)

176. Scheibe, A. Frequency standards and absolute frequency measurements. *ZS. f. Hochfrequentztechn.* **29**, pp.120 and 158, 1927. (E, G)

177. Schnell, F. H. Full-wave self-rectification and crystal control. *QST* **11**, p.33, November 1927. (C, F)

178. Schrödinger, E. Kinetics of dielectrics, melting point, pyro- and piezo-electricity. *Wiener Ber.* **121**, 2a, p. 1937, 1912. (A)

179. Scott, E. K. Piezo-electricity of Rochelle salt crystals. *Trans.* Faraday Soc. **17**, p.748, 1921/22. (G)

180. Shafer, A. G. Keying the amplifier. *QST* **11**, p.33, July 1927. (F)

181. Shaw, H. S. Oscillating crystals. *QST* **7**, p.30, July 1924. (B, E, F)

182. Shropshire, R. F. Piezo-electric loudspeaker. *Radio News* (New York) **7**, p.1296, March 1926. (G)

183. Simmonds, E. J. The application of quartz crystal control to transmitters. *T. and R. Bull.* **2**, p.9, December 1926. (F)

184. Simmonds, E. J. Quartz control. *Modern Wireless* (London) **8**, p.25, July 1927. (F)

185. Smith, M. R. Quartz crystals as wavelength standards. *Radio Journal* (Los Angeles) **6**, p.16, July 1925. (E)

186. Sosman, R. B. The Properties of Silica. Chemical Catalog Co., New York, 1927. (A)

187. South Schenectady and the April tests. *QST* **10**, p.33, June 1926. (F)

188. Strock, M. S. The salt on the tail of the broadcast frequency. *Popular Radio* (New York) **10**, p.773, 1926. (E, F)

189. Strock, M. S. Standard frequency dissemination. PROC. I. R. E. **15**, p.727, 1927 (E)

190. Strout, H. S. The temperature coefficient of oscillating quartz plates (abst.). *Phys. Rev.* **31**, p.156, 1928. (B)

191. Tawil, E. P. On the variations of the optical properties of piezo-electric quartz under the action of high-frequency electric fields. *C. R.* **183**, p.1099, 1926. (B, C)

192. Tawil, E. P. Observations on piezo-electric quartz at resonance. *C. R.* **185**, p.114, 1927. (B, C)

193. Taylor, A. H. Crystal Control. *QST* **9**, p.62, December 1925. (F)

194. Terry, E. M. Factors affecting the constancy of quartz piezo-electric oscillators (abst.). *Phys. Rev.* **29**, p.366, 1927. (B, E)

195. Thomas, J. S. G. Piezo-electricity and its technical applications. *J.* Soc. Chem. Industry **38**, p.159R, 1919. (G)

196. Thomson, J. J. Piezo-electricity and its applications. *Engineering* (London) **107**, p.543, 1919. (G)

197. Troller, A. Submarine listening devices. *La Nature* **49**, p.4, 1921. (G)

198. Tschappat, W. H. New instruments for physical measurements *Mech. Engineering* (New York) **45**, p.673, 1923. (G)

199. Tschappat, W. H. Experiments in interior ballistics. *Mech. Engineering* (New York) **48**, p.821, 1926. (G)

200. Turner, A. H. 5-meter work at 2XM with crystal control. *QST* **11**, p.24, June 1927. (F)

201. Tykocinski-Tykociner, J. Precise determination of frequency by means of piezo-electric oscillators (abst.). *Phys. Rev.* **29**, p.366, 1927. (E)

202. Valasek, J. Piezo-electricity and allied phenomena in Rochelle salt. *Phys. Rev.* **17**, p.475, 1921. (A)

203. Valasek, J. Piezo-electric activity of Rochelle salt under various conditions. *Phys. Rev.* **19**, p.478, 1922. (A)

204. Valasek, J. Properties of Rochelle salt related to the piezo-electric effect. *Phys. Rev.* **20**, p.639, 1922. (A)

205. Valasek, J. Dielectric anomalies in Rochelle salt crystals (abst.) *Phys. Rev.* **24**, p.560, 1924. (A)

206. Valasek, J. Piezo-electric effect in sodium bromate (abst.). *Phys. Rev.* **27**, p.254, 1926. (A)

207. Valasek, J. Note on the piezo-electric effect in Rochelle salt crystals. *Science* **65**, p.235, 1927. (A)

208. Vallauri, G. Frequency comparisons by means of piezo-resonators. *L'Elettrotecnica* **14**, July 15 and September 25, 1927; Publ. No. 42, Istituto Elet. e Rad. della R. Marina, Livorno, 1927. (E)

209. Van der Pol, B. The use of piezo-electric quartz crystals in wireless telegraphy and telephony. Gedenkboek Ned. Vereen. voor Radiotel., 1926, p.293. (B)

210. Van Dyke, K. S. The electric network of a piezo-electric resonator (abst.). *Phys. Rev.* **25**, p.895, 1925. (B)

211. Van Dyke, K. S. The use of the cathode ray oscillograph in the study of resonance phenomena in piezo-electric crystals (abst.) *Phys. Rev.* **31**, p.303, 1928. (C)

212. Verbeek, D. C. Quartz control for short wave transmitters. *Radio Nieuws* (Hague) **10**, p.194, 1927. (F)

1,562,578. A. M. Nicolson (Western Electric Co.). November 24, 1925. Piezo-electric device and method of producing the same. (Rochelle salt crystal with interior electrode, and lever for attachment to loudspeaker).

213. Voigt, W. Piezo- and pyro-electricity, dielectric influence and electrostriction. *Ann. d. Phys.* 55, p. 701, 1895. (A)

214. Voigt, W. Lehrbuch der Kristallphysik. Leipzig, 1910, Chap. 8 (A)

215. Voigt, W. Theory and experiments on piezo-electric excitation of

1,565,566. R. V. L. Hartley (Western Electric Co.). December 15, 1925. Translating device. (To record voice on motion-picture film, polarized light passes through piezo-electric plate).

1,572,773. A. Crossley. February 9, 1926. Piezo-electric crystal apparatus. (Mounting and hermetical sealing of crystal).

1,574,302. A. M. Nicolson (Western Electric Co.). February 23, 1926. Piezo-electric loud speaker. (Rochelle salt crystal, with mounting for attachment to loudspeaker cone).

1,578,296. A. H. Taylor (Wired Radio). March 30, 1926. Multifrequency crystal-controlled oscillator. (Two or more crystal plates stacked one upon another). Same as British Pat. No. 259,174.

1,581,701. A. H. Taylor (Wired Radio). April 20, 1926. Piezo-electric crystal control system. (Two or more crystals, with synchronizing coils, in parallel).

1,583,417. A. M. Nicolson (Western Electric Co.). May 4, 1926. Piezo-electric device and method of producing it. (Rochelle salt crystal attached to loudspeaker).

1,584,490. A. H. Taylor (Wired Radio). May 11, 1926. Three-phase oscillator. (Piezo-electric control of three tubes).

1,587,098. H. Whittle (Western Electric Co.). June 1, 1926. Transformer circuits. (Tube coupled to piezo-electric loudspeaker).

1,588,176. A. L. R. Ellis (General Electric Co.). June 8, 1926. Piezo-electric device. (Methods of avoiding damping due to air in contact with vibrating crystal). Same as German Pat. No. 441,583, and a portion of British Pat. No. 255,463.

1,590,311. A. M. Nicolson (Western Electric Co.). June 29, 1926. Piezo-electric device and method of producing the same. (A division of No. 1,438,-965).

1,599,922. T. C. Rathbone (Westinghouse Co.). September 14, 1926. Balancing machine. (Use of piezo-electric plate as aid in determining the condition of balance of a rotating body).

1,606,791. J. W. Horton (Western Electric Co.). November 16, 1926. Oscillation generator. (Piezo crystal, or other selective system, connected to tube circuits designed for constancy of frequency).

1,608,048. A. H. Taylor (Wired Radio). November 23, 1926. Piezo-electric crystal control system. (Relay and protective device to prevent overloading of crystal).

1,608,311. A. L. R. Ellis (General Electric Co.). November 23, 1926. Oscillator. (Device to make quartz plate start oscillating easily).

1,609,744. A. M. Trogner. December 7, 1926. Multiple piezo-electric crystal holder. (Several crystals on circumference of a drum).

1,617,995. A. L. R. Ellis (General Electric Co.) February 15, 1927. Piezo-electric device. (Compensation for changes in frequency caused by varying temperature).

1,619,125. C. W. Hough (Wired Radio). March 1, 1927. Piezo-electric-crystal apparatus. (One electrode held in contact with quartz plate by pressure of a column of mercury).

1,619,854. A. Crossley (Wired Radio). March 8, 1927. Piezo-electric crystal apparatus. (Crystal plate held in place by guard-ring of insulating material).

1,628,009. A. H. Taylor (Wired Radio). May 10, 1927. Signal transmission system. (Potential supply for crystal-controlled generator system, facilitating production of harmonics; also keying system).

1,632,369. A. Crossley (Wired Radio). June 14, 1927. Radio signaling system. (Arrangement for control of negative voltage on grid of crystal-controlled transmitter).

1,636,921. A. M. Nicolson (Wired Radio). July 26, 1927. Piezo audion. (Crystal plate mounted in evacuated bulb, serving as receiver or emitter of sound).

1,639,817. A. H. Taylor (Wired Radio). August 23, 1927. Pizo-electric crystal system. (Calibration of a receiving set by quart resonators, using telephone as indicator).

1,654,184. R. B. Meyer (Wired Radio). December 27, 1927. Frequency-control circuits. (Emergency device to replace piezo-electric crystal in case of failure of latter).

1,654,189. E. L. Powell (Wired Radio). December 27, 1927. Piezo-electric crystal apparatus. (Drum on which are mounted a number of piezo-electric resonators, which can be successively connected to a receiving set for purpose of calibration).

1,654,195. A. H. Taylor and L. C. Young (Wired Radio). December 27, 1927. Modulation system for frequency multiplier circuits. (Crystal-controlled oscillator, frequency-multiplying amplifier, modulation introduced at frequency-multiplying tube).

1,654,196. A. H. Taylor (Wired Wireless). December 22, 1927. Three-phase oscillator. (Piezo-electric control of three tubes, using 1 or 3 crystals).

1,655,974. E. W. Russell and A. F. R. Cotton (Cleveland Trust Co.) January 10, 1928. Piezo-electric device. (Rochelle salt crystal, adapted for use as microphone, receiver, or pickup for phonograph).

British

139,496 M. I. Pupin. May 25, 1921. Improvements in or connected with receivers of high-frequency sound waves. (Two piezo-electric sound receivers so related as to exclude low-frequency disturbances).

145,691. P. Langevin. July 28, 1921. Improvements relating to the emission and reception of submarine waves. (Quartz-metal sender and receiver).

222,150. M. C. Batsel (Metrop.-Vickers Elec. Co. Ltd.). April 9, 1925. Improvements relating to receiving systems for electric signals. (Crystal used as coupling between two tubes).

226,795. P. Langevin and C. L. Florisson. October 22, 1925. Improvements in methods and apparatus for sounding and for locating submarine obstacles by means of ultra-audible waves. (Piezo-electric sender-receiver and recording apparatus).

227,801. P. Langevin. February 4, 1926. Improvements in method and apparatus for the continuous indication or for the recording of depths and distances at sea by means of the ultra-audible echo. (Method involving piezo-electric sender-receiver, for measurement of depth by means of echo).

239,175. W. A. Marrison (Western Electric Co.). September 30, 1926. Improvements in piezo-electric frequency control devices. (Methods of shaping and exciting quartz plates for vibrations of relatively low frequency).

245,810. Western Electric Co., Inc. January 14, 1926. Improvements in telephone transmitters and receivers and the like. (Same as German Pat. No. 430,169, and nearly the same as U. S. Pat. No. 1,574,302).

252,170. E. Giebe and A. Scheibe. Convention date May 15, 1925. Electric tests and measurements. (Luminous effect from quartz bar in evacuated bulb).

252,387. W. H. Whitten (Metropolitan-Vickers Elec. Co., Ltd.). December 2, 1926. Improvements in or relating to scanning devices for television systems. (Mirror vibrated by deformations of piezo-electric crystals).

255,463. A. L. R. Ellis (British Thomson-Houston Co., Ltd.). November 11, 1926. Improvements in piezo-electric devices. (Same as U. S. Pats. Nos. 1,617,995 and 1,588,176; in addition, a device same as German Pat. No. 441,628).

256,611. E. P. Tawil. Published October 6, 1926. Television apparatus; optical systems. (Control of beam of light by piezo-crystal, for television etc.).

258,707. Bell Telephone Laboratories. September 30, 1926. Improvements in radio receiving systems. (Crystal-controlled locally generated oscillations beat with signal waves of a carrier system).

259,174. A. H. Taylor (Wired Radio). May 5, 1927. (Same as U. S. Pat. No. 1,578,296).

260,609. W. G. Cady (Marconi's Wireless Tel. Co., Ltd.). August 11, 1927. Improvements in or relating to means for mounting piezo-electric crystals. (Methods for centering crystal between electrodes, and for avoiding friction).

261,013. S. Loewe. Convention date Nov. 4, 1925. Thermionic valves. (Crystal-resonator mounted in amplifier or detector tube).

261,040. E. Giebe and A. Scheibe (Radiofrequenz Ges.). Convention date November 7, 1925. Electric measurements. (Low-frequency oscillations and musical note from crystal vibrating in partial vacuum).

261,041. E. Giebe and A. Scheibe (Radiofrequenz Ges.). Convention date November 7, 1925. Wireless signaling. (In receiving system, luminous and acoustic effects from resonator in partial vacuum).

261,042. E. Giebe and A. Scheibe (Radiofrequenz Ges.). Convention date November 7, 1925. Non-contact making relays. (Glow discharge around crystal resonator in partial vacuum utilized as tuned relay).

263,841. Radiofrequenz Ges. and H. Eberhard. Convention date December 29, 1925. Electric measurements. (In parallel with piezo-resonator mounted for luminous effect is a glow-discharge lamp serving as coarse indicator of resonance and to protect the resonator).

264,103. C. W. Rice (British Thomson-Houston Co., Ltd.). January 13, 1927. Improvements in or relating to sound reproducing devices. (Piezo-electric crystal as pickup for phonograph).

264,878. A. W. Hull (British Thomson-Houston Co., Ltd.). June 9, 1927. Method of preparing piezo-electric elements. (Metallic deposit on crystal, subsequently reduced to right thickness.) Same as German Pat. No. 445,046.

266,690. A. W. Hull (British Thomson-Houston Co., Ltd.). March 31, 1927. Improvements in or relating to electric oscillation generators. (Piezo-crystal between filament and screened grid of four-element tube).

268,048. Western Electric Co., Inc. March 28, 1927. Improvements in space discharge tube systems for electric wave signaling. (Crystal in master oscillator circuit, between grid and a point in the anode circuit).

268,367. Telefunken Gesellschaft. October 20, 1927. Improvements in or relating to high-frequency circuits and indicating arrangements therefor. (Air-blast from vibrating crystal closes a contact or moves a lever or mirror).

269,192. Telefunken Gesellschaft. October 20, 1927. Improvements in or relating to piezo-electric devices. (In order to damp vibrations in a crystal or in a body connected thereto, the electrodes of the crystal are connected to a circuit designed to absorb energy).

269,643. W. H. Eccles and W. A. Leyshon. April 19, 1927. Improvements in methods of generating electrical and mechanical oscillations. (Maintaining a body, piezo-electric or other, in vibration, by means of a negative resistance, for example a neon tube).

269,935. E. Giebe and A. Scheibe. Convention date April 24, 1926. Ring-shaped piezo-crystal. (Same as German Pat. No. 450,398).

272,954. Telefunken Gesellschaft. Convention date June 18, 1926. Piezo-electric wave control. (Device to indicate when a crystal resonator is in resonance).

274,660. C. W. Goyder. July 28, 1927. Improvements in or relating to the stabilization of high-frequency oscillations. (Device to keep circuit oscillating if crystal fails).

275,581. J. B. Coleman (Westinghouse Co.). September 8, 1927. Improvements in or relating to high-frequency electric transmitting apparatus. (To send key signals by varying frequency, the airgap of the crystal oscillator is made variable).

276,037. Telefunken Gesellschaft. December 1, 1927. Improvements in or relating to piezo-electric relay and the like devices. (Crystal used as relay or motor employing air-blast effect.)

277,002. H. Eberhard (Radiofrequenz Ges.). Applied for August 31, 1927. (To make vibrations of crystal visible, the latter is mounted close to the wall of a vacuum tube).

277,008. Thomson-Houston Co. October 13, 1927. Thermionic oscillation generator. (Crystal oscillator connected between the grids of two tubes).

Canadian

250,631. A. M. Nicolson (International Western Electric Co.). June 9, 1925. Piezo-electrical transmitter. (Same as U. S. Pat. No. 1,525,823).

French

183,851. J. and P. Curie. May 27, 1887. Electrometer system. (Two piezo-electric bars cemented together so as to give flexure in an electric field).

602,280. Le Materiel Téléphonique. March 16, 1926. Piezo-electric devices. (Method of cutting quartz plate for low-frequency vibrations).

German

430,169. International Western Electric Co. June 12, 1926. (Rochelle salt device for operating loudspeaker. Same as British Pat. No. 245,810).

435,998. International General Electric Co. October 22, 1926. Piezo-electric oscillation generator. (Same as U. S. Pat. No 1,617,995).

441,583. International General Electric Co. March 7, 1927. (Same as U. S. Pat. No. 1,588,176).

441,628. International General Electric Co. March 11, 1927. (Same as part of British Pat. No. 255,463. Composite piezo-oscillator, formed of a mosaic of several quartz plates).

445,046. International General Electric Co. Patent granted June 12, 1926. (Same as British Pat. No. 264,878).

445,052. Telefunken Ges. Patent granted December 13, 1925. Wavemeter and frequency control by means of crystals. (Quartz resonators of progressively increasing lengths, each connected to a small lamp).

450,398. E. Giebe and A. Scheibe. October 7, 1927. Quartz resonator. (Same as British Pat. No. 269,935. Quartz resonator in form of a flat ring with inner and outer electrodes).

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED

March 7, 1928

Transferred to the Fellow grade

New York	New York City, 463 West Street	Oswald, A. A.
	New York City, 463 West Street	Schelleng, J. C.
	New York City, 463 West Street	Wilson, William

Transferred to the Member grade

Illinois	Chicago, 2020 Farragut Avenue	Marco, F. J.
Maryland	Baltimore, Room 13, Custom House	Herndon, Landon C.
New York	Hollis, 9027 199th Street	MaDan, Edwin C.
Germany	Berlin-Charlottenburg 4, 21 Schlueter Street	Hofman, A. C.
India	Calcutta, c/o Indian Broadcasting Co., Ltd.	Cobb, F. Arthur

Elected to the Member grade

New Jersey	Montclair, 73 Orange Road	Krahl, Walter L.
New York	New York City, 233 Broadway	Adams, Quinton
	New York City, Engineers' Club, 32 W. 40th.	Johnston, J. P.
England	London, Golders Green, 37 Montpelier Rise.	McQuillan, Cecil
	Surrey, Wallington, 115 Onslow Gardens	Amis, F. H.
Federated Malay States	Lumpur, Kuala, G. P. O.	Cadman, Claude G.

Elected to the Associate grade

California	Monterey Park, 607 E. Newark Avenue	Alker, Charles
	Los Angeles, 1540 W. Sherman Way	Black, Robert
Connecticut	Hartford, Radio Station W. T. I. C.	Wood, Herbert H.
	Middletown, Electric House	Langreth, George L.
Dist. of Columbia	Washington, Federal Radio Commission	Butman, Carl H.
	Washington, 1519 Connecticut Ave., N. W.	Jenkins, C. Francis
	Washington, 1753 N. St., N. W.	Lamb, James J.
	Washington, 1706 Pennsylvania Ave., N. W.	Mates, T. Joaquin
	Washington, Box 3213	Thomsen, Paul H.
Florida	Key West, D Naval Radio Station	Pope, James C.
	St. Petersburg, 440–20th Ave., North	Silcox, Albert S., Jr.
Illinois	Chicago, 3034 Leland Avenue	Burns, Robert P.
	Chicago, 1826 Diversey Parkway	Gurrie, Morris
	Chicago Heights, 1213 Emerald Avenue	Tartak, Paul Herbert
	Quincy, 1621 Ohio Street	Wilson, A. J.
Iowa	Forest City, 851 N. 7th Street	Jurgensen, Louis
	Mt. Vernon, 712–6th Avenue, N	Kafer, Merle D.
Kansas	Atchison, 313 N. 6th Street	Welsh, George E.
	El Dorado, 1137 W. Central Avenue	Graham, I. H.
	Emporium, 301 East Third Street	Schweikart, William F.
Kentucky	Lexington, 145 North Mill Street	Hill, Orville H.
	Newport, 1045 Washington Avenue	Pepper, R. K.
Louisiana	New Orleans, 719 Masonic Temple Bldg	Westphal, Richard D.
Massachusetts	Cambridge, 31 Holden Green	Sherman, Warren K.
	Cambridge, Y. M. C. A.	Tsia, Hock Lan
	Clifton, 325 Atlantic Avenue	Leahy, John E.
	Springfield, 50 Cherry Street	Moauro, Joseph S.
Michigan	Detroit, 6225 Stanton Avenue	Almas, Stan L.
	Detroit, 6221 Crane Street	Blumenthal, Raymond W.
	Detroit, 423 Eastlawn Avenue	Seielstad, Harold
	Farmington, 139 Whadham Avenue	Kreuzer, A. R.
Minnesota	Hallock, General Delivery	Jensen, Karl K.
Missouri	St. Louis, 4808 Washington Blvd	Harl, G. P.
	St. Louis, 4311 South Compton Avenue	Hock, Kurt J.
Nebraska	Norfolk, 1216 Norfolk Avenue	Tyler, Kenneth G.
New Jersey	East Orange, 66 Prospect Street	Brigham, Cecil E.
	Newark, c/o Boris Law, 773 So. 17th St.	Betwinek, Jack L.
	Newark, 418 South Orange Avenue	Fink, William D.
	Newark, 856 South 16th Street	Jacobs, Louis
New Mexico	Raton, 845 S. 5th Street	Abshere, Lilburn O.
New York	Brooklyn, 1698 East 21st Street	Dummett, H. W.
	Brooklyn, 5324 Avenue L	Ellingham, Irving
	Brooklyn, Room 506, 1121–1125 Bedford Ave.	Greene, C. Francis
	Brooklyn, 281 Carlton Avenue	Johnson, William J.
	Brooklyn, 146 Monroe Street	Knowles, Jerome H., Jr.
	Brooklyn, 1931 King's Highway	Lewis, Robert V.
	Brooklyn, Bedford Y. M. C. A.	Stewart, Donald P.
	Brooklyn, 713 Avenue O.	Vogel, Erwin W.
	Brooklyn, 716 Ocean Avenue	Zimmerman, Charles W.
	Buffalo, 70 Minnesota Ave.	Hemedinger, Willard
	Buffalo, 18 Carmel Road	Hukle, Roy Miller

New York (con't)	Buffalo, 381 Ellicott Street	Nauth, Raymond
	Buffalo, 113 High Street	Reinhard, Melvin C.
	Buffalo, 3172 Main Street	Smith, Hugo C.
	Flushing, L. I., 3519—147th Street	Van Siclen, Andrew H.
	New York City, 865 East 180th Street	Gutoff, Boris
	New York City, c/o R. C. A., 233 Broadway	Kinsella, John A.
	New York City, 52 William Street	Muirhead, John E.
	New York City, 64 W. 22nd Street	Pasayiotis, George N.
	New York City, 8 West 40th Street	Payne, Charles C.
	New York City, United Press, 61 Park Row	Pineau, Norman T.
	Poland	Prentiss, Howard H.
	Stapleton, U. S. Marine Hospital No. 21	Eklund, Gus
Ohio	Niles, 103 East Madison Avenue	Parlas, Joseph L.
	Toledo, 443 Third Street	Browne, Merton S.
	Toledo, 1121 Moore Street	Pilzecker, Arthur
	Toledo, 2323 Charleston Avenue	Pilzecker, Harold
Oklahoma	Bartlesville, D. Phillips Petroleum Co.	Adams, Paul Roy
	Tulsa, 210 West 8th Street	Drake, Norman B.
Pennsylvania	Fullerton, 1964 Catasaqua Street	Bachman, Edwin J.
	Northumberland, 353 Front Street	Smith, Harry Evans
	Philadelphia, 529 Glenwood Avenue	Bauman, Michael
	Philadelphia, c/o Graybar Elec. Co., 910 Cherry St.	Ponsford, W. W.
	Pittsburgh, 1133 Creedmoor Avenue	Miller, Paul J.
	Wilkinsburg, 513 Holmes Street	Cunningham, David H.
Tennessee	Cleveland, West 26th Street	Slaughter, Jack D.
	Memphis, 474 Edith Place	Viser, John H., Jr.
Texas	Amarillo, 503 Lincoln Street	Berg, Arthur A. E.
	Dallas, 312 North Edgefield Avenue	Thiele, L. E.
	Houston, 231½ W. 19th Street	Kelly, Claude H.
Virginia	Petersburg, Box 21	Cooper, David L.
	Rosslyn, Franklin Park	Billups, Robert W.
Washington	Seattle, 6809—17th, N. E.	Avery, Alfred L.
	Seattle, 1115—36th Avenue	Carver, Orin H.
	Seattle, 558 1st So.	Hill, Herbert H.
	Seattle, 3714 W. Austin Street	Sylvester, W. V.
Wisconsin	Eau Claire, R. R. No. 4, Box 82	Langdell, Henry R.
	Madison, 2317 Winnebago Street	Iveen, Erwing A.
	Milwaukee, 3111 Park Hill Avenue	Cummings, George B.
Argentina	Monte Grande, F. C. S., Transradio Internacional	Zuev, Vitaly V.
Australia	Sydney, Kensington, The Nest, College Road	Shaw, Raymond H.
England	Abingdon Berks, Bath Street, Electricity Offices	Tozer, Wm. C.
	Bournemouth, 43, Queens Park South Drive	Boyd, W. Forbes
	Channel Islands, Guernsey, Rue du Pre	Bennett, F. T.
	Cheshire, Rock Ferry, 38, Inglemere Road	Wilde, Richard C.
	London E. 8, Dalston, 93 Albert Road	Hows, Leonard J.
	London, N. W. 2, Dollis Hill Lane, P. O. Research Station	Barker, P. L.
	Middlesex, Wembley Park, 27, Grendon Gardens	Mumford, Albert H.
	Newcastle-on-Tyne, 23 Claremont Road	Moore, John T.
	Northumberland, Forest Hall Hawthorne Cottage	Rowell, George R.
	North Sheffield, Dronfield, 29 Lea Road	Dixon, Ronald
	Sheffield, 905 Ecclesall Road	Turvey, Henry C.
Federated Malay States	Naiping, 47 Barrack Road	Suares, Jose B.
New Zealand	Christchurch, Beckenham, 41 Malcolm Avenue	Perkins, Eric R.
South India	Madras Presidency, Sankaranainarkoil S. I. Ry.	Pichumani, K. K.
Straits Settlements	Singapore, Hongkong Bank Chambers, c/o G. I. C.	Parry, Albert H.

Elected to the Junior grade

California	Los Angeles, 959½ Crensaw Blvd., Apt. 205	Houdyshell, L. B.
Illinois	Chicago, 4824 Woodlawn Avenue	Michelis, Rudolph
Iowa	Ames, 317 Stanton Avenue	Osborne, Ralph H.
Kansas	Lawrence, 1008 Tennessee Street	Monfort, Ray A.
Massachusetts	Cambridge, 49 Wendell Street	Hsu, C. L.
	Cambridge, 57 Gorham Street	Tung, Kai
	Uxbridge, 66 Hazel Street	Kozaczko, Walter H.
New Jersey	Englewood, 163 Waldo Place	Ashton, John E.
	Hackensack, 288 Stanley Place	Frank, James A.
New York	New York City, 522 W. 158th Street	Chu, Quong Y.
	Schenectady, General Electric Co.	Darjany, S. H. W.
	Port Chester, 465 Westchester Avenue	Holbrook, Robert A.
Tennessee	Memphis, 1292 Linden Avenue	Cowles, John W., Jr.
Texas	Houston, 1902 Ridgewood Street	Biar, L. E.
Wyoming	Casper, 1428 Mitchell Street	Mackenzie, Jack

"Stand by"—for WESTON Announcement

A New A. C. and D. C.

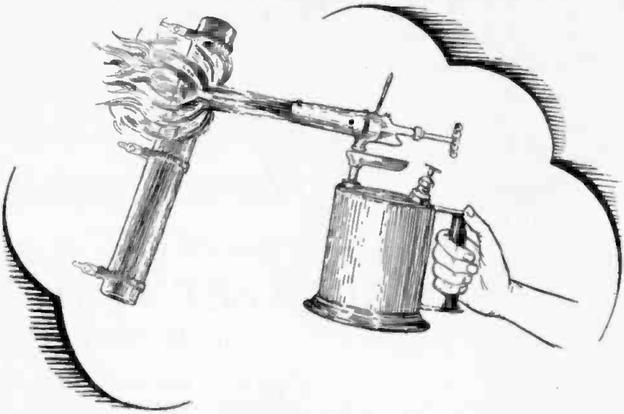
RADIO SET TESTER

for the Service Man

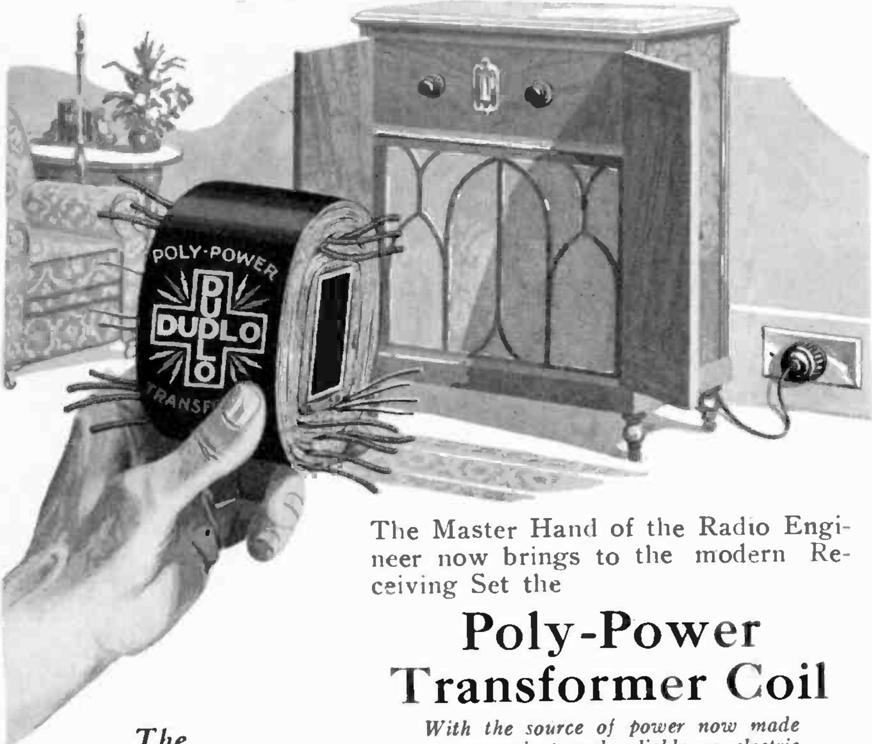
ONE of the most important radio instruments, and the most convenient and profitable for the dealer, service man, and custom set builder, ever developed. It solves all the problems of radio set servicing—for both A. C. and D. C. receivers—without any other testing equipment being required. It is provided with two special 3¼" diameter instruments for both A. C. and D. C. readings. Connections are automatically made by an ingenious system of switches and binding posts. Complete with the necessary socket adaptors and instruction book.

WESTON
ELECTRICAL
INSTRUMENT
CORPORATION
589
Frelinghuysen
Ave.
Newark, N. J.

WESTON
RADIO
INSTRUMENTS




Get the Latest
From Formica!
This is the time when layouts for the new season are being made in the engineering departments.
Before you complete the details of the insulating parts consult Formica. Some new grades and qualities of material have been developed since last year.
They show better insulating qualities and decidedly better working qualities than we believe, have ever been available before.
Ask for samples.
The Formica Insulation Company
4646 Spring Grove Avenue
Cincinnati, Ohio
FORMICA
Made from Anhydrous Bakelite Resins
PANELS FOR SIGNS



The Master Hand of the Radio Engineer now brings to the modern Receiving Set the

Poly-Power Transformer Coil

With the source of power now made as convenient and reliable as electric lights, a great new market is opened up.

Thousands of folks who never before thought they could operate a Radio can now enjoy the wonderful programs without worry about the A, B, or C current supplies.

So again Dudlo meets the needs of the Radio manufacturer by preparing far in advance for volume production of these, the most intricate of all Radio coils. Special machinery has been designed and installed in anticipation of the greatest season the industry has ever known.

The

Coil's the thing!

that makes the "Light Socket" set possible.

Dudlo Poly-Power Transformer Coils can be wound and tapped to furnish A, B, and C currents at any specified voltages required by Radio receivers or power units.

Dudlo engineers are at the service of Radio Manufacturers to assist in designing a Poly-Power coil to meet their special needs.

DUDLO

DUDLO MANUFACTURING CORP., FORT WAYNE, INDIANA

Division of the General Cable Corporation

56 Earl Street NEWARK, N. J.	160 North La Salle St. CHICAGO, ILL.	4153 Bingham Ave. ST. LOUIS, MO.	274 Brannan St. SAN FRANCISCO, CALIF.

The Radio Engineer *Knows*

Paper condensers, long considered satisfactory in Radio, are no longer competent to give the service required in the new Electrical Sets.

Mershon Condensers are particularly well suited to power supply devices employing the 210 tube. They COST LESS than a paper condenser block designed for 210 operation and are MUCH MORE EFFICIENT.

Ask any Radio Engineer. He will know the history and accomplishments of the Mershon Condenser. And he probably knows that several of the leading manufacturers of high class electrical radio receivers have adopted the Mershon Condenser as standard equipment. To all of its other qualities it adds the decidedly favorable one of tremendous economy. And is self-healing, in case of puncture.

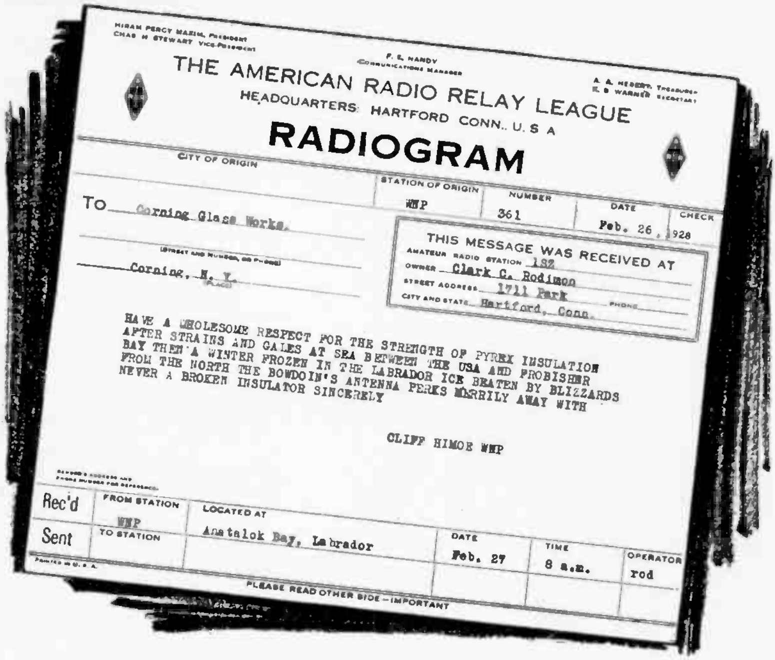
Let us send you our new Engineering Bulletin, with illustrations of typical uses of the Mershon. There is no obligation. Address Dept. 48.

THE AMRAD CORPORATION
Medford Hillside, Mass.

J. E. HAHN, *President* — POWEL CROSLEY, JR., *Chr. of the Board*

Mershons are fitted for many radio uses in addition to employment in electrical sets. And out of 100,000 shipped by us in the last season, just ONE was electrically defective.

MERSHON
AMRAD
CONDENSER



HIRAM PERCY MAXIM, PRESIDENT
CHAS. H. STEWART, VICE-PRESIDENT

F. E. HANDY
COMMUNICATIONS MANAGER

A. A. HEBERT, TREASURER
K. B. WARNER, SECRETARY

THE AMERICAN RADIO RELAY LEAGUE
HEADQUARTERS: HARTFORD CONN., U. S. A.

RADIOGRAM

CITY OF ORIGIN

STATION OF ORIGIN	NUMBER	DATE	CHECK
WNP	361	Feb. 26, 1928	

TO Corning Glass Works.
(STREET AND NUMBER, OR PHONE)
Corning, N. Y.
(PLACE)

THIS MESSAGE WAS RECEIVED AT
AMATEUR RADIO STATION 1SZ
OWNER Clark C. Rodimon
STREET ADDRESS 1711 Park
CITY AND STATE Hartford, Conn. PHONE

HAVE A WHOLESOME RESPECT FOR THE STRENGTH OF PYREX INSULATION AFTER STRAINS AND GALES AT SEA BETWEEN THE USA AND FROBISHER BAY THEN A WINTER FROZEN IN THE LABRADOR ICE BEATEN BY BLIZZARDS FROM THE NORTH THE BOWDOIN'S ANTENNA PERKS MERRILY AWAY WITH NEVER A BROKEN INSULATOR SINCERELY

CLIFF HIMOE WNP

SENDER'S ADDRESS AND PHONE NUMBER FOR REFERENCE

	FROM STATION	LOCATED AT	DATE	TIME	OPERATOR
Rec'd	WNP	Anatalok Bay, Labrador	Feb. 27	8 a.m.	rod
Sent	TO STATION				

PRINTED IN U. S. A.

PLEASE READ OTHER SIDE—IMPORTANT

*PYREX

RADIO INSULATORS

CORNING GLASS WORKS
Industrial and Equipment Division
DEPT. R-1
CORNING, NEW YORK

* Trade-mark Reg. U. S. Pat. Off.

A Smooth, Positive Volume Control For Circuits Using "AC" Tubes

THE delicate balance of "AC" circuits require a different method of volume control than that commonly used with battery sets.

Centralab Radiohms RX-100 or RX-025 have been developed especially for smooth volume control with "AC" tubes. They have the same appearance as standard Radiohms, but the taper of resistance is entirely special.

The RX-100 Radiohm in the secondary of an R. F. stage will control oscillation as well as volume. The RX-025 across an R. F. primary provides volume control and does not detune. The same unit has the proper resistance for antenna circuit control, but no antenna circuit resistance will prove as uniformly satisfactory as when used across one of the R. F. stages.

A Centralab PR-050 Power Rheostat in series with the "AC" transformer will provide accurate voltage control and lengthen the life of the tubes. Centralab wire wound Potentiometers and Fixed Resistors will prove trouble free in the power circuits.

Write for full information about these high quality controls. The new "AC" information sheet is now ready for you.

CENTRAL RADIO LABORATORIES

Keefe Avenue, Milwaukee, Wisconsin

Centralab

Mail for Institute members listed below has been returned to the Institute. Members knowing the present address of any of these members will render a service to the Institute by advising the Secretary.

Adams, R. G., 630 Roscoe Street, Chicago, Ill.
Albert, Wm. V., c/o General Delivery, Reading, Pa.
Andrae, R. T., Northern Ont. Light & Power Co., Cobalt, Ont., Can.
Andrew, V. J. 4749 Indian Ave. Chicago, Ill.
Andrews, E. E., Andrew Radio Corp., 1414 South Wabash Ave., Chicago, Ill.
Blum, F. O., 425 East 53rd Street, Los Angeles, Calif.
Bolstead, A. L., 1832 4th Ave., Seattle, Wash.
Conrad, V. A., 66 Norton Street, New Haven, Conn.
Cox, Maj. G. C., 177 Washington Ave., Kenmore, L.I., N.Y.
Csernick, S. F., 524 East 6th Street, New York City.
Darrow, L. H., American Tel. & Tel. Co., 195 Broadway, New York City.
Dickman, C. T., 2113 East 16th St., Brooklyn, N.Y.
Dickson, W. A., Southern Calif. Music Co., Los Angeles, Calif.
Duncan, J. E., P.O. Box 1817, Houston, Tex.
Edes, N. H., c/o Messrs. Cox & Co., 16 Charing Cross, London, S.W.1, Eng.
Estey, C. F., 107 Remington Place, New Rochelle, N.Y.
Field, J., 275 East 21st Street, New York City.
Gray, H. E., c/o Radio Station WJAZ, Mt. Prospect, Ill.
Harrington, F. H., 921 N. Spaulding St., Hollywood, Calif.
Hastings, Herbert, 1116 W. Marquette Rd., Chicago, Ill.
Hitch, E. H., 515 South 42nd Street, Philadelphia, Pa.
Hohner, J., Box 81, R.F.D. 2, Elizabeth, N.J.
Houge, C. A., Griffith Mfg. Co., North College Ave., Fort Collins, Colo.
Himoe, C. E., 139 Mass. Ave., Cambridge, Mass.
Jackson, C. C., 915 Worthington St., Springfield, Mass.
Jeffery, J. H., Neerdune Tenement Lane, Bramhall, Cheshire, Eng.
Jorgensen, W. J., Ansley Hotel, Atlanta, Ga.
Kalin, A., 5054–6th Ave., N.E., Seattle, Wash.
Kimball, G. E., Radio Dept., Chicago *Daily News*, Chicago, Ill.
Kleist, A. H., 3100 Broadway, Apartment 65, Detroit, Mich.
Lathrop, F. A., 1401 Calvert Ave., Detroit, Mich.
Leach, H. B., 600 West 144th Street, New York City.
Leighton, L., 4996 Broadway, New York City.
Leonard, P. A., c/o Canadian Marconi Co., Yamachiche, P.Q., Can.
Leoser, T. S., 150 East 93rd Street, New York City.
Lerch, H. W., 245 West Ave., Lockport, L.I., N.Y.
Main, A. J. C., 14268 Greenleaf St., Box 1081, Hollywood, Calif.
Mather, G., Bosley, Macclesfield, Cheshire, Eng.
McDermott, T. A., 846 North Lockwood Ave., Chicago, Ill.
McGalin, A. G., 4251 Bryan Street, Dallas, Tex.
Michael, C., 1677 Milwaukee Ave., Chicago, Ill.
Moxon, A., 132 Willoughby Ave., Brooklyn, N.Y.
Muncey, A. R., 659 N. Markoe Street, W. Philadelphia, Pa.
Nash, F. S., 3806 Fisher Ave., Detroit, Mich.
Nelson, A., c/o Schmelzer Co., 1012 Grand Ave., Kansas City, Mo.
O'Day, A. C., 138 Templeton Street, Dorchester, Mass.
Peterson, C. W., 3518 Ormond Terrace, Cincinnati, Ohio.
Phillips, J. H., 701 W. Eubanks, Oklahoma City, Okla.
Pohlman, J. V., 6729 Artesian Ave., Chicago, Ill.
Powers, A. J., 957 Woodycrest Ave., New York City.
Ritchie, W. G., 2407 Niagara Street, Buffalo, N.Y.
Rosin, J. S., 424 E. Roosevelt Blvd., Philadelphia, Pa.
Rubin, H. E., 17 Prospect St., East Orange, N.J.
Scanlon, D. L., 111-14 146th Street, Jamaica, L.I., N.Y.
Schaffstall, R. F., *S.S. George Washington*, Clyde Line, Pier 45, New York City.
Simon, E. J., 415 Lexington Avenue, New York City.
Simpson, A. K., c/o Stromberg-Carlson Co., 1060 University Place, Rochester, N.Y.
Skapick, S. J., 300 E. Bethune Ave., Detroit, Mich.
Smith, Dr. H. F., R.F.D. 3, Locust St., Hempstead, L.I., N.Y.
Sowell, G. O., Woodmere Hotel, 4631 Woodlawn Ave., Sta. M., Chicago, Ill.
Spaeth, Dr. C., Q R S Music Co., 4829 S. Kedzie Ave., Chicago, Ill.
St. Clair, A. V., 874 Walker Ave., Oakland, Calif.
Stephens, F. H., Box 356, Ketchikan, Alaska.
Stone, C. D., Range, Texas.
Swanson, E. H., c/o General Delivery, Indianapolis, Ind.
Sweet, R. C., 124 East Symmes St., Norman, Okla.
Tatreault, L. E., Box 37, A.R. 1, Redlands, Calif.
Terry, L. M., 48 Charles St., New York City.
Vauchelet, B. F., 331 So. Mariposa Ave., Los Angeles, Calif.
Walker, G. De Forrest, Radio Sta. KFBU, Laramie, Wyo.
Witchern, L., 53 Griffith St., Jersey City, N.J.

RADIO PARTS

IMPROVEMENTS and changes in radio occur in rapid succession. Manufacturers need a dependable source of supply which can assume production responsibilities for small parts at short notice. Scovill, with its tremendous resources, experience and up-to-date methods, offers consistent quality in large volume. From a sample, blueprint, or even an idea, Scovill will make to order any quantity of radio parts: condensers, condenser parts, metal stampings, screw machine parts, switches, etc. A wide variety of butts and hinges, continuous hinges and machine screws are kept on hand.

Scovill means SERVICE to all who require parts or finished products of metal. Great factories equipped with the last word in laboratories, and modern machinery manned by skilled workmen, are at your disposal. Phone the nearest Scovill office.

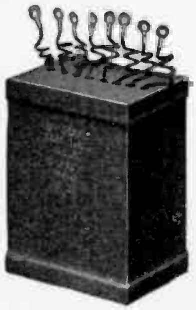
SCOVILL

MANUFACTURING COMPANY Waterbury, Connecticut

NEW YORK - CHICAGO - BOSTON - SAN FRANCISCO
DETROIT - PHILADELPHIA - LOS ANGELES - ATLANTA
PROVIDENCE - CLEVELAND - CINCINNATI

Member, Copper and Brass Research Association

Condensers that Last Longer and Serve Better



CONDENSERS made by Automatic Electric Inc. continue to serve faithfully long after other makes break down or "go dead". To those familiar with the history of this company and its contributions to telephone engineering and development, this fact will not be surprising.

Condensers made to meet the requirments of large telephone companies must "stand up" under years of constant service. There can be no guess work as to design or construction and no compromise with quality.

For nearly forty years, Automatic Electric Inc. has been meeting these rigid specifications. Now, through the enlargement of its condenser manufacturing facilities, filter and by-pass condensers of the same high quality are available to the radio trade and to the radio manufacturers and jobbers. They may be had in a variety of capacities and styles or made to meet particular specifications.

Address all communications to

A. G. BURT, JR.
1033 WEST VAN BUREN ST.
CHICAGO, U. S. A.

REPRESENTING

STROWGER AUTOMATIC CONDENSERS
MADE BY
Automatic Electric Inc.
CHICAGO, U.S.A.

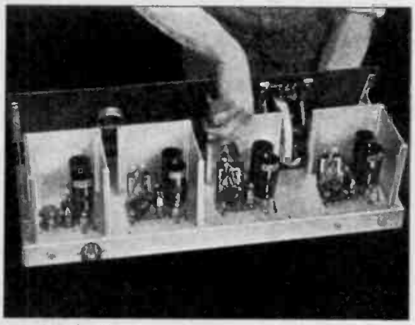
When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

Alphabetical Index to Advertisements

"I have used ACME PARVOLT Condensers for many years and have never had one break down."

S. W. [illegible]



Whether You Buy or Build

a Power Supply Unit for Your Radio

PLAY SAFE WITH PARVOLTS!

WHEN you buy an electrified radio or power supply unit for your receiver, look for ACME PARVOLT Condensers; they are your guide to quality in all other parts. They cost the manufacturer a trifle more, but they are both his and your guarantee against costly condenser break-down.

Should you build your own power supply, be sure to use ACME PARVOLT Condensers and be safeguarded against the possibility of break down. Remember that poor filter condensers have caused untold thousands of dollars worth of loss in the past year or two, for blown out condensers mean blown tubes, burned out transformers and frequently the ruination of speaker units.

Just as PARVOLT By-Pass Condensers have been used for years in high grade receivers, so are PARVOLT Filter Condensers rapidly replacing ordinary condensers in electrified radio. These condensers are wound with the very finest insulating papers combined with highest grade foils. Every detail produced in one of America's most modern plants and under the supervision of experts in condenser design and manufacture.

Uniformity of capacity and uniformity of sizes are two big features. Accuracy of all ratings, based upon the R.M.A. standards, is another guarantee of uninterrupted-service. Play safe with PARVOLTS!

Made by THE ACME WIRE CO., New Haven, Conn., manufacturers of magnet and enameled wire, varnished insulations, coil windings, insulated tubing and radio cables.

ACME PARVOLT CONDENSERS

Made by the Manufacturers of

ACME CELATSITE WIRE

INDOOR AERIAL and LOOP WIRE	CELATSITE FLEXIBLE and SOLID	ACME SPAGHETTI

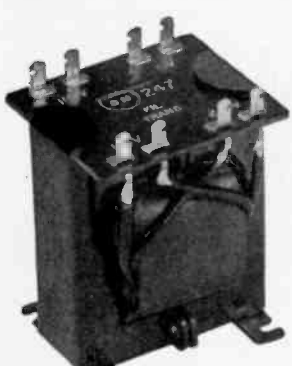
SM

Power for the A. C. Set Manufacturer

Silver-Marshall has solved the power supply problem for A.C. sets with an ABC power unit so small and compact that it will fit right into the smallest of table type set cabinets. This S-M "670 A B C" power unit supplies ample ABC power for six or seven tube sets equipped with power tube, for it delivers 1.5, 2.25 and 5 volts A power, and any desired value of B and C voltage up to 220 volts at 50 M.A. The wholly self-contained unit, requiring one UX-280 rectifier tube, weighs but 14 lbs., is 13″ long, $5\frac{1}{4}$″ high and only $3\frac{5}{16}$″ wide over-all!

Set manufacturers can buy these units adapted to their requirements at a surprisingly low figure—from 25% to 30% below their accustomed costs.

For the manufacturer who appreciates that real tone quality is a definite selling factor in 1928, S-M offers flat characteristic audio transformer equipment at surprisingly low prices. The standard S-M 240 audio transformer in 3:1 ratio with a primary inductance of well over 200 henries inductance at 100 cycles is an example. It gives uniform amplification from below 100 to above 5000 cycles and can be had fully mounted at the price of an ordinary light cheap substitute as a result of quantity production.



To the Interested Manufacturer

If interested S-M engineers can show how to equip any set with UX-210 or UX-250 super power tubes simply, cheaply and efficiently—actually furnish all 450 volt ABC power unit parts at less than usual low voltage power unit costs!

Silver-Marshall, *Inc.*

846 West Jackson Blvd.
Chicago, U.S.A.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN