VOLUME 19 NOVEMBER, 1931 NUMBER 11

Walter J. Malm
W HAM

PROCEEDINGS
of
The Institute of Radio Engineers

Form for Change of Mailing Address or Business Title on Page XLIII

Institute of Radio Engineers
Forthcoming Meetings

ROCHESTER FALL MEETING
November 9-10, 1931
Rochester, New York

CINCINNATI SECTION
November 17, 1931

NEW YORK MEETINGS
November 4, 1931
December 2, 1931

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 19 November, 1931 Number 11

CONTENTS

Part I

Page

Part II

Technical Papers

INSTITUTE SECTIONS

	Chairmen	Secretaries
ATLANTA	H. F. Dobbs	Philip C. Bangs, 23 Kensington Rd., Avondale Estates, Ga.
BOSTON	George W. Pierce	Melville Eastham, 30 State St., Cambridge, Mass.
BUFFALO-NIAGARA	Stanley W. Brown	E. C. Waud, 235 Huntington Ave., Buffalo, N. Y.
CHICAGO	Byron B. Minnium	J. Barton Hoag, Ryerson Laboratory, University of Chicago, Chicago, Ill.
CINCINNATI	D. D. Israel	H. G. Boyle, Crosley Radio Corp., Cincinnati, Ohio.
CLEVELAND	G. B. Hammon	P. A. Marsal, National Carbon Co., Inc., P.O. Box No. 400, Cleveland, Ohio.
CONNECTICUT VALLEY	R. S. Kruse	George Grammer, 334 South Quaker Lane, West Hartford, Conn.
DETROIT	Lewis N. Holland	Samuel Firestone, Room 615, 2000 Second Ave., Detroit, Mich.
LOS ANGELES	T. E. Nikirk	L. Elden Smith, 345 N. Painter Ave., Whittier, Calif.
NEW ORLEANS	Pendleton E. Lehde	Anton A. Schiele, 1812 Masonic Temple, New Orleans, La.
PHILADELPHIA	G. W. Carpenter	G. C. Blackwood, 243 E. Upsal St., Mt. Airy, Philadelphia, Pa.
PITTSBURGH	J. G. Allen	J. G. McKinley, West Penn Electric Co., 14 Wood St., Pittsburgh, Pa.
ROCHESTER	H. A. Brown	M. A. Wood, 175 Winbourne Ave., Rochester, N. Y.
SAN FRANCISCO	Ralph M. Heintz	Frederick E. Terman, Stanford University, Calif.
SEATTLE	Abner R. Willson	L. C. Austin, 540 N. 82nd St., Seattle, Wash.
TORONTO	F. K. Dalton	G. E. Pipe, 335 Beresford Ave. Toronto, Ont., Canada.
WASHINGTON	L. P. Wheeler	Herbert G. Dorsey, U. S. Coast and Geodetic Survey, Washington, D. C.

Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED OCTOBER 7, 1931

Transferred to the Fellow grade

Massachusetts	Cambridge, 7 Craigie Circle, Suite 4	McElroy, P. K.
New York	Brooklyn, 1277 E. 14th St.	Evans, P. H.
Argentina	Buenos Aires, Compania Internacional de Radio, 143 Defensa	Stevens, A. M.
England	Middlesex, St. John's Darkes Lane, Potters Bar	Appleton, E. V.

Transferred to the Member grade

New Jersey	Harrison, RCA Radiotron Co. Inc., Development Laboratory	Ferris, W. R.
New York	New York City, c/o Radiomarine Corp. of America, 75 Varick St.	Shandy, G. P.
	Riverhead, 140 Moriches Rd.	Peterson, H. O.
Canada	Toronto, 88 Hubbard Blvd.	Lowry, C. A.

Elected to the Member grade

New York	New York City, 485 Madison Ave.	Cohan, E. K.
Oklahoma	Oklahoma City, Station KFJF, Security Bldg.	Shaw, D.
Spain	Cartagena, Aire 20	Oliva Llamusi, F.

Elected to the Associate grade

California	Compton, 721 E. Laurel St.	Orr, F.
	San Diego, 4465-50th St.	Ware, A. S.
	San Francisco, c/o Tropical Radio, 1001-4th St.	Daily, H. C.
	Santa Barbara, 820 Carpenteria St.	Hart, D. W.
Dist. of Columbia	Anacostia, Bellevue, Naval Research Lab.	Granger, H.
Idaho	Idaho Falls, Box No. 315	Provis, J.
Illinois	Chicago, 6601 S. Laramie Ave.	Jensen, P. L.
	Chicago, 3305 Michigan Ave.	Schrader, W. A.
Indiana	Valparaiso, Dodge's Wireless Institute	Bringhurst, E. S.
	Valparaiso, Dodge's Wireless Institute	Wood, L. C.
	Valparaiso, 606 Union St.	Woodard, T. R.
	West Lafayette, Varsity Apartments	Barragan, M. B.
Kansas	Mankato, Correll Hotel	Pope, F. J.
Maryland	Salisbury, 104 W. Landon Ave.	Powell, L. D.
Massachusetts	Boston, Radio Dept., c/o United Fruit Co., S.S. San Bruno	Tuddenham, W. A.
	Brookline, 89 Mason Terrace	Pippy, G. A.
	Cambridge, 1663 Cambridge St.	Hok, G.
	Hudson, 55 Lincoln St.	Groves, E. F.
Michigan	Bay City, 1612 Second St.	Thompson, R. W.
	Flint, 1024 Mason St.	Burbank, L. A.
	Rogers City, S. S. John G. Munson, c/o Dock Office	Moutoux, E. G.
Minnesota	Minneapolis, 612 University Ave., S.E.	Emery, B. C.
	Minneapolis, 2221-3rd St., N.E.	Lefebore, U. A.
Missouri	Columbia, 211 Thilly Ave.	Selvidge, H.
	St. Louis, 3909 Russel Blvd.	Nye, E. C.
Nebraska	Grand Island, U. S. Radio Monitoring Station	Holey, W. J.
New Jersey	Bloomfield, 46 Hinrichs Pl.	Cox, A.
	Camden, 3013 Constitution Rd.	Knapp, G. P., Jr.
	East Orange, 14 Summit St.	Olsen, E. U.
	New Brunswick, Engineering Bldg., Rutgers University	Kahn, L.
	Passaic, 45 River Dr.	Bishop, W. T.
	Passaic, 15½ Howe Ave.	Ekstrom, E. J.
New York	Binghamton, 92 Seneca St.	Gilbert, L. H.
	Brooklyn, 863 Carroll St.	Greibach, E. H.
	New York City, 89-91 Fairview Ave.	Horscroft, R. G.
	New York City, 264-5th Ave.	Peterson, K. C.
Oregon	Freewater	Parr, C.
Pennsylvania	Perkasie, 3rd St.	Reichley, C. A.
	Warren, 212 Liberty St.	Olson, P. C.
Texas	Fort Worth, 3711 Meadowbrook Dr.	Currie, W. O.
Virginia	Richmond, 2614 Seminary Ave.	Whitehorne, G. L.
Washington	Seattle, U.S.S. Northland, c/o Postmaster	Crennan, E. M.
Wisconsin	Wausau, 1002-5th Ave., S.	Best, B.
Brazil	Rio de Janeiro, 180 Praia do Russell	Pareto, J. V.
Canada	Verdun, P.Q., 3462 Verdun Ave.	Ridd, W. T.
China	Shanghai, 25 Tien Don Loon, West Gate	Loo, T. C.
England	Essex, "Poldhu," 2a, Salisbury Rd., Seven Kings	Summerfield, J. L.
	Hayes, Middlesex, 8-9 Station Rd.	Spratley, C.
	Hoghton, Lancashire, "The Firs," The Straits	Jones, H.

INSTITUTE SECTIONS

Chairmen		*Secretaries*
H. F. Dobbs	ATLANTA	Philip C. Bangs, 23 Kensington Rd., Avondale Estates, Ga.
George W. Pierce	BOSTON	Melville Eastham, 30 State St., Cambridge, Mass.
Stanley W. Brown	BUFFALO-NIAGARA	E. C. Waud, 235 Huntington Ave., Buffalo, N. Y.
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G. B. Hammon	CLEVELAND	P. A. Marsal, National Carbon Co., Inc., P.O. Box No. 400, Cleveland, Ohio.
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T. E. Nikirk	LOS ANGELES	L. Elden Smith, 345 N. Painter Ave., Whittier, Calif.
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G. W. Carpenter	PHILADELPHIA	G. C. Blackwood, 243 E. Upsal St., Mt. Airy, Philadelphia, Pa.
J. G. Allen	PITTSBURGH	J. G. McKinley, West Penn Electric Co., 14 Wood St., Pittsburgh, Pa.
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Ralph M. Heintz	SAN FRANCISCO	Frederick E. Terman, Stanford University, Calif.
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L. P. Wheeler	WASHINGTON	Herbert G. Dorsey, U. S. Coast and Geodetic Survey, Washington, D. C.

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	San Francisco, c/o Tropical Radio, 1001-4th St.	Daily, H. C.
	Santa Barbara, 820 Carpenteria St.	Hart, D. W.
Dist. of Columbia	Anacostia, Bellevue, Naval Research Lab.	Granger, H.
Idaho	Idaho Falls, Box No. 315	Provis, J.
Illinois	Chicago, 6601 S. Laramie Ave.	Jensen, P. L.
	Chicago, 3305 Michigan Ave.	Schrader, W. A.
Indiana	Valparaiso, Dodge's Wireless Institute	Bringhurst, E. S.
	Valparaiso, Dodge's Wireless Institute	Wood, L. C.
	Valparaiso, 606 Union St.	Woodard, T. R.
	West Lafayette, Varsity Apartments	Barragan, M. B.
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Maryland	Salisbury, 104 W. Landon Ave.	Powell, L. D.
Massachusetts	Boston, Radio Dept., c/o United Fruit Co., S.S. San Bruno	Tuddenham, W. A.
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	Cambridge, 1663 Cambridge St.	Hok, G.
	Hudson, 55 Lincoln St.	Groves, E. F.
Michigan	Bay City, 1612 Second St.	Thompson, R. W.
	Flint, 1024 Mason St.	Burbank, L. A.
	Rogers City, S. S. John G. Munson, c/o Dock Office	Moutoux, E. G.
Minnesota	Minneapolis, 612 University Ave., S.E.	Emery, B. C.
	Minneapolis, 2221-3rd St., N.E.	Lefebore, U. A.
Missouri	Columbia, 211 Thilly Ave.	Selvidge, H.
	St. Louis, 3909 Russel Blvd.	Nye, E. C.
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New Jersey	Bloomfield, 46 Hinrichs Pl.	Cox, A.
	Camden, 3013 Constitution Rd.	Knapp, G. P., Jr.
	East Orange, 14 Summit St.	Olsen, E. U.
	New Brunswick, Engineering Bldg., Rutgers University	Kahn, L.
	Passaic, 45 River Dr.	Bishop, W. T.
	Passaic, 15½ Howe Ave.	Ekstrom, E. J.
New York	Binghamton, 92 Seneca St.	Gilbert, L. H.
	Brooklyn, 863 Carroll St.	Greibach, E. H.
	New York City, 89-91 Fairview Ave.	Horscroft, R. G.
	New York City, 264-5th Ave.	Peterson, K. C.
Oregon	Freewater	Parr, C.
Pennsylvania	Perkasie, 3rd St.	Reichley, C. A.
	Warren, 212 Liberty St.	Olson, P. C.
Texas	Fort Worth, 3711 Meadowbrook Dr.	Currie, W. O.
Virginia	Richmond, 2614 Seminary Ave.	Whitehorne, G. L.
Washington	Seattle, U.S.S. Northland, c/o Postmaster	Crennan, E. M.
Wisconsin	Wausau, 1002-5th Ave., S.	Best, B.
Brazil	Rio de Janeiro, 180 Praia do Russell	Pareto, J. V.
Canada	Verdun, P.Q., 3462 Verdun Ave.	Ridd, W. T.
China	Shanghai, 25 Tien Don Loon, West Gate	Loo, T. C.
England	Essex, "Poldhu," 2a, Salisbury Rd., Seven Kings	Summerfield, J. L.
	Hayes, Middlesex, 8-9 Station Rd.	Spratley, C.
	Hoghton, Lancashire, "The Firs," The Straits	Jones, H.

Geographical Location of Members Elected October 7, 1931

England (cont.)	Hull, E. Yorkshire, 80a Newland Ave	Pearson, A.
	Keighley, 9 Church St., Oxenhope	Mainwaring, W.
	London, East Ham E. 6, 65 Leigh Rd	Coppings, W. H.
	Widnes, Lancashire, 106 Norlands Lane	Lewis, B.
Japan	Arimatsucho Aichiken, Okehazama Hosojo	Momotsuka, K.
	Osaki-Mati, Nr. Tokyo, Electrotechnical Laboratory, Ministry of Communications	Kimura, S.
	Sendai, 28 Nakasugiyamadori	Arisaka, I.
	Shimizu-hosojo, Nr. Kumamoto	Nagasaki, K.
	Tokyo, c/o The Japanese Wireless Telegraph Co., Ltd., Jiji Bldg. Marunouchi	Ogawa, R.
	Tokyo, c/o The Japanese Wireless Telegraph Co., Ltd., Jiji Bldg., Marunouchi	Satoh, H.
	Tokyo, c/o The Japanese Wireless Telegraph Co., Ltd., Jiji Bldg., Marunouchi	Tobiyama, K.
Malaya	Kuala Lumpur, Posts and Telegraphs Dept	Higgins, P. V.
Newfoundland	St. John's, 256 New Gower St	Galgay, W. F.
Peru	Lima, P.O. Box No. 40	Harry, H. B.

Elected to the Junior grade

Georgia	Cedartown, 310 College St	Burke, J.M., Jr.
Indiana	South Bend, 236 E. Broadway	Uleman, T.
Hawaii	Honolulu, Box No. 1391	Pickle, C. B.

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before November 30, 1931. These applicants will be considered by the Board of Direction at its December 2nd meeting.

For Transfer to the Fellow grade

New Jersey	Upper Montclair, 9 Bradford Way	DuMont, A. B.
New York	Flushing, 4360-170th St.	Farrington, J. F.

For Transfer to the Member grade

New Jersey	Haddonfield, 504 Avondale Ave.	Whelan, D. O.

For Election to the Member grade

Massachusetts	Watertown, 59 Bailey Rd.	Bareiss, M.

For Election to the Associate grade

Alabama	Birmingham, 8300 Division Ave.	Godwin, C. E.
Arizona	Phoenix, 914 N. 3rd St.	Grigg, J. W.
	Whiteriver	Mentor, E. L.
California	Fullerton, 230 W. Chapman St.	Mathewson, E. L.
	Hollywood, 1415 N. Fairfax Ave.	Kelch, M.
	Hollywood, 1337 N. Gardner St.	Ruggles, J. E.
	Los Angeles, 2419 S. Highland Ave.	Davis, H.
	Los Angeles, 1621-4th Ave.	Simonds, W. E.
	Oakland, 243 30th St.	Black, L. J.
	San Francisco, c/o KFRC, 1000 Van Ness Ave.	Baldwin, R. S.
	San Gabriel, 243 N. Bradbury Dr.	Henry, R. E.
	Tracy, P.O. Box 12	Kurth, W. O.
	Van Nuys, 6952 Vesper Ave.	Chesney, A. P.
Connecticut	Hartford, 64 Webster St.	Roach, J. C.
Dist. of Columbia	Washington, Saul Rd., Chevy Chase	Hodge, A. H.
	Washington, c/o Graybar Elec. Co., 714-12th St., N.W.	Whitten, L. H.
Florida	Palatka, Box 456	Peterson, T. R.
Georgia	Atlanta, 1533 Melrose Dr., S.W.	King, S. O., Jr.
Illinois	Chicago, 6548 Woodlawn Ave.	Oliver, M. J.
	Evanston, 2630 Prairie Ave.	Butow, A. J.
	Urbana, 208 N. Harvey St.	Abel, A. E., Jr.
Indiana	Goshen, 302 N. Main St.	Rieth, H.
Kansas	Fort Scott, 407 S. Holbrook St.	Hess, H. H.
Kentucky	Paducah, 210 N. 13th St.	Sims, C. G.
Louisiana	New Orleans, 202½ Bourbon St.	Hymel, L. F.
Maine	Rockland, 397 Main St.	Fickett, L. W.
Michigan	Detroit, 7626 Duncon Ave.	Lettich, M. M.
	Detroit, 12897 Woodward Ave.	Schall, R. C.
	Hastings, 213 W. State St.	Branch, R.
Minnesota	Rochester, 1225-1st St., S.W.	Biltz, F. J.
	St. Paul, 562 Holly Ave.	Skifter, H. R.
Missouri	Kansas City, 118 W. 47th St.	Sears, E. W.
	Kansas City, Radio Station WOQ, 917 Tracy Ave.	Winchel, H. T.
New Jersey	Atlantic City, 420 N. Massachusetts Ave.	Helmuth, C. F.
	Atlantic Highlands, R.F.D. 116	Eastmond, H. V.
	Jersey City, 220 Duncan Ave., Apt. 303	Hammerich, H. A.
	Keansburg, P.O. Box 111	Barrett, E.
	Rochelle Park, 91 Franklin Ave.	Gibson, R.
	Union City, 433 Bergenline Ave.	Krohn, R.
	West New York, 325-29th St.	Campbell, A. G.
New Mexico	Roswell, Box 421	Falconi, L.
New York	Brooklyn, 1670-58th St.	Babkes, E. A.
	Brooklyn, 594 Bedford Ave.	Culley, P.
	Brooklyn, 2130-59th St.	Jahrl, E.
	Buffalo, 111 Virgil Ave.	Blinzler, R. F.
	Buffalo, 767 Bird Ave.	Tompkins, R. S.
	Kingston, 56 Crane St.	Kent, G. C.
	Long Island City, 451 Grand Ave.	Phoenix, Z.
	Maine	Lainhart, V.
	New York City, 18 Morningside Ave.	Alvarado, M. A.
	New York City, c/o Radiomarine Corp., 75 Varick St.	Caum, H. J.
	New York City, 430 E. 89th St.	Seichter, M.

New York (cont.)	New York City, 867 Hornaday Pl.	Sklar, H. L.
	New York City, 925 Westchester Ave.	Stutz, M.
	New York City, 2061 Davidson Ave.	Weinhoeppel, K. L.
	Oakfield, R.R. 1	Howard, E. V.
	Rochester, 193 Shelter St.	Schifino, A. G.
	Rocky Point, P.O. Box 171	Goodfellow, D.
	Schenectady, 859 Hazelwood Ave.	Schwenker, A. H.
	Slaterville Springs	Bull, E. M.
Ohio	Akron, 662 Schiller Ave.	Kappus, P. B.
	Cincinnati, 4051 Clifton Ave	Kemper, W. E.
	Cincinnati, 104 E. Auburn Ave.	Stocker, H. C.
	Dayton, c/o Walker & Dybvig, Reibold Bldg.	Dybvig, H. G.
	Uhrichsville	Dempster, A. R.
	Youngstown, 213 Holmes St.	Shaw, C. E.
Pennsylvania	East Lansdowne, 155 Penn Blvd.	Michaelis, H. P., Jr.
	Harrisburg, 1616 N. 5th St.	Drumheiser, A. W.
	Keiser, 401 North St.	Coroniti, S. C.
	Philadelphia, 5752 N. Lawrence St.	Bell, G. D.
	Philadelphia, 459 E. Wyoming Ave.	Miller, S. H.
	Pittsburgh, 3341 Latonia Ave., Dormont	Goodboy, G. O.
	Verona, 5th St.	Sheaffer, C. T.
Texas	Beaumont, 2535 Grand Ave.	Green, J. J.
	Galveston, 3719 Ave. Q½	Warren, A. J.
	Houston, 739 Yale St.	Archer, F. G.
	Tyler, c/o "Stephens"	Sawyer, T. M.
Virginia	Norfolk, 604 Banker's Trust Bldg.	McFarland, D. C.
Washington	Seattle, USCGC Northland, c/o Postmaster	Bryan, E. O.
	Seattle, 218-10th Ave., N.	Martin, P. L.
	Seattle, 221 Belmont N.	Menard, A.
	Seattle, 202 Burke Bldg.	Vincent, A. M.
West Virginia	Buckhannon, 158 Pocahontas St.	Schrecengost, J. C.
	Hinton, 110 Main St.	Criser, R. J.
Wisconsin	Ripon, 521 Liberty St.	Hoffman, O.
Australia	Mosman, Sydney, "Illalandia," Coronation Ave.	Persson, A. R.
Bermuda	Hamilton, P.O. Box 404	Gady, J. W.
Brazil	Rio de Janeiro, Cia Radio Internacional do Brazil, 50 Rua da Alfandega	Andrade, M.D.
Canada	Wetaskiwin, Alberta, Box 535	Maggs, P. J.
	Moosejaw, Sask., 361 Coteau St., W.	Price, E. E.
	Prescott, Ont., King St., E.	Knight, L. F.
	Rouyn, P. Q., P.O. Box 822	Ouzounian, H.
	Sudbury, Ont., 135 S. Regent St.	Sweezey, F.
Channel Islands	Guernsey, Bridge House, St. Sampson's	Wright, H.
Cuba	Caimanera, Oriente	Blanco, J.
England	Burnley, Lancs., 10 Ightenhill Cross St.	Whitaker, H.
	Hornchurch, Essex, "Lynton," Hanes Park	Harvey, J. R.
	Liverpool, 31 Booker Ave., Mossley Hill	Cowan, P. R.
	Lydd, Kent, North View	Craufurd, Q.
	Osterley, Middlesex, 51 Burlington Rd.	Dancker, J. A.
	Paignton, Devon, 8 Southfield Ave.	Maxey, H.
	Rugby, Engineering Research Lab., The British Thomson-Houston Co., Ltd.	Maxted, R.
	Rugby, Kingsley Ave.	Thomas, R. G.
France	Paris VII, Frue Monsieur	de Bagneux, R.
Japan	Kobe, c/o The Kobe Wireless Telephone Station, Sakae-Machi 7	Tada, Y.
New Zealand	Epsom, 532 Manukau Rd.	Baxendale, J.
	Wellington, Box 1032	Smith, C.
South Africa	Durban, 202 Montpelier Rd.	Ford, W. S.
South India	Madras, Madras Fort Radio, Fort St. George	Fry, R.
Territory of Hawaii	Honolulu, 2737 Ferdinand Ave.	Walworth, L. A.

For Election to the Junior grade

Arkansas	Little Rock, 2505 Chester St.	Barnes, H.
Illinois	Chester, 921 Sparta St.	Baronowsky, J.
Indiana	Valparaiso, 703 Monroe St.	Lisor, D. J.
New York	Wolcott, Oswego St.	Harrison, W. M.

* * *

OFFICERS AND BOARD OF DIRECTION, 1931

(Terms expire January 1, 1932, except as otherwise noted)

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Ray H. Manson

Vice President
C. P. Edwards

Treasurer
Melville Eastham

Secretary
Harold P. Westman

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Alfred N. Goldsmith

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C. M. Jansky, Jr.
Lloyd Espenschied
Harry Houck

Serving until January 1, 1933
J. V. L. Hogan
R. H. Marriott

Serving until January 1, 1934
L. M. Hull
A. F. Van Dyck

Junior Past Presidents
A. Hoyt Taylor
Lee de Forest

BOARD OF EDITORS, 1931

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Stuart Ballantine
Ralph Batcher
W. Wilson
G. W. Pickard
L. E. Whittemore

John Hays Hammond, Jr.
Treasurer of the Institute, 1914

John Hays Hammond, Jr. was born in San Francisco, California, April 13, 1888. He received the degree of B.S. from Sheffield Scientific School (Yale) in 1910, and later the degree Sc.D. from George Washington University.

Mr. Hammond established a laboratory at Gloucester, Mass., and there developed and in 1912 demonstrated radio control of high speed ships. Some of these developments were later applied to naval target craft, aircraft, and torpedoes and are considered essential for such purposes. For obtaining highly selective control, he developed the use of double detection and the intermediate frequency as now also used for selective purposes in the broadcast superheterodyne. These selective features were also applied to radio communication systems, for telegraphy, telephony, and multiplex signaling.

Miscellaneous radio inventions of Mr. Hammond related to rebroadcasting, the use of broadcast transmitters for simultaneous telegraphy and telephony, radio typewriters, and automatic radio compasses. In 1928, he established a special purpose radiotelephone system in Italy and was decorated as a Grand Officer of the Crown. In the musical field, his inventions relate to pipe organs, pianos, and high quality sound productions from film and disk records.

Mr. Hammond is a director of the Radio Corporation of America, and president of the Hammond Research Corporation. He is a member of many engineering and scientific societies, became an Associate member of the Institute in 1912 and a Member in 1914.

INSTITUTE NEWS AND RADIO NOTES

October Meeting of the Board of Direction

The October 7, 1931, meeting of the Board of Direction was attended by A. F. Van Dyck, acting chairman; Melville Eastham, treasurer; Austin Bailey, (representing Lloyd Espenschied), Arthur Batcheller, Harry Houck, R. H. Marriott and Harold P. Westman, secretary.

The following transfers and elections were approved. For transfer to the Fellow grade: E. V. Appleton, P. H. Evans, P. K. McElroy, and A. M. Stevens. For transfer to the Member grade: W. R. Ferris, C. A. Lowry, H. O. Peterson, and G. P. Shandy. For admission to the Member grade: E. K. Cohan, F. O. Llamusi, and Dudley Shaw.

Sixty-three applications for the Associate grade and three for the Junior grade of membership were approved.

A. F. Van Dyck was appointed to serve as the Institute's representative on the recently reëstablished Sectional Committee on Preferred Numbers operating under the American Standards Association.

In response to a request that the Institute submit a list of suitable candidates for the annual award of $10,000 established by Popular Science Monthly, the Secretary was instructed to submit the names of those who have in the past been recipients of Institute awards.

Proceedings Binders

Binders for the Proceedings, which may be used as permanent covers or for temporary transfer purposes, are available from the Institute office. These binders are handsome Spanish grain fabrikoid, in blue and gold. Wire fasteners hold each copy in place and permit removal of any issue from the binder in a few seconds. All issues lie flat when the binder is open. Each binder will accommodate a full year's supply of the Proceedings and they are available at two ($2.00) dollars each. Your name, or Proceedings volume number, will be stamped in gold for fifty cents (50¢) additional.

Bound Volumes

The twelve issues of the Proceedings published during 1930 are now available in blue buckram binding to members of the Institute at nine dollars and fifty cents ($9.50) per volume. The price to nonmembers of the Institute is twelve ($12.00) dollars per volume.

Radio Transmissions of Standard Frequency, November and December, 1931

The Bureau of Standards announces a new schedule of radio transmissions of standard frequencies. This service may be used by transmitting stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards and transmitting and receiving apparatus. The signals are transmitted from the Bureau's station WWV, Washington, D.C., every Tuesday afternoon and evening. They can be heard and utilized by stations equipped for continuous-wave reception throughout the United States, although not with certainty in some places. The time schedules are different from those of previously announced transmissions. The only frequency utilized is 5000 kilocycles. The accuracy of the frequency is at all times much better than a part in a million.

The transmissions are by continuous-wave telegraphy at 5000 kilocycles. They are given continuously from 2:00 to 4:00 P.M., and from 8:00 to 10:00 P.M., Eastern Standard Time, every Tuesday throughout November and December (except December 29). The dates are November 3, 10, 17, 24; and December 1, 8, 15, 22.

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the receiving phones. The first five minutes of the transmission consist of the general call (CQ de WWV) and announcement of the frequency. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Information on how to receive and utilize the signals is given in Bureau of Standards Letter Circular No. 280, which may be obtained by addressing a request to the Bureau of Standards, Washington, D.C. From the 5000 kilocycles any apparatus may be given as complete a frequency calibration as desired by the method of harmonics.

Since the start of the 5000-kc transmissions at the beginning of this year the Bureau of Standards has been receiving reports regarding the reception of these transmissions and their use for frequency standardization, from nearly all parts of the United States, including the Pacific coast and Alaska. The Bureau is desirous of receiving more reports on these transmissions, especially because radio transmission phenomena change with the season of the year.

The data desired are approximate field intensity, fading, and the suitability of the transmissions for frequency measurements. It is suggested that in reporting upon field intensities for these transmissions, the following designations be used where field intensity measurement apparatus is not at hand: (1) hardly perceptible, unreadable; (2) weak, readable now and then; (3) fairly good, readable with difficulty; (4) good, readable; (5) very good, perfectly readable. A statement as to whether fading is present or not is desired, and if so, its characteristics such as whether slow or rapid, and time between peaks of signal intensity. Statements as to type of receiving set used in reporting on the transmissions and the type of antenna used are likewise desired. The Bureau would also appreciate reports on the use of the transmissions for purposes of frequency measurement or control.

The Bureau would also appreciate comment from all users of the service on the times of day when the transmissions are most useful. During July, August, and September, the evening transmissions were two hours later than in the schedule announced herein.

All reports and letters regarding the transmissions should be addressed Bureau of Standards, Washington, D.C.

Committee Work

COMMITTEE ON ADMISSIONS

A meeting of the Committee on Admissions was held at 9 A.M. on Wednesday, October 7, and was attended by C. M. Jansky, Jr., chairman; C. N. Anderson, H. C. Gawler, R. A. Heising, A. V. Loughren, A. F. Van Dyck, and H. P. Westman, secretary.

Two of the three applications for transfer to the grade of Fellow were approved and the third tabled pending the arrival of further information. Neither of the two applications for admission to the grade of Fellow was approved, one candidate being recommended for the Member grade and the other for the Associate grade. Of two applications for transfer to the grade of Member, one was approved, and the other applicant recommended for the Associate grade. Four applications for admission to the grade of Member were considered and two approved. The other two were tabled pending the arrival of further information.

MEMBERSHIP COMMITTEE

The Membership Committee met at 5:30 P.M. on October 7 with H. C. Gawler, chairman; David Grimes, C. R. Rowe, J. E. Smith, and A. M. Trogner in attendance.

Further consideration was given to the preparation of a new application form to comply with the provisions in the proposed new Constitution.

COMMITTEE ON NEW YORK PROGRAMS

The Committee on New York Programs held a meeting at the office of the Institute at 7 P.M. on October 5. Those present were Austin Bailey, chairman; J. L. Reynolds, R. M. Williams (representing R. H. Ranger), and H. P. Westman, secretary. A list of subjects was proposed for the New York meetings up to and including March, 1932.

COMMITTEE ON SECTIONS

A meeting of the Committee on Sections was held at 7 P.M. on September 17 at the office of the Institute and was attended by C. W. Horn, chairman; Austin Bailey, R. H. Langley, B. E. Shackelford, and H. P. Westman, secretary.

The committee discussed a number of items to be considered at the meeting of the Committee on Sections to be held in Rochester on Tuesday, November 10, during the Rochester Fall Meeting.

STANDARDIZATION

TECHNICAL COMMITTEE ON ELECTRO-ACOUSTIC DEVICES—IRE

A meeting of the Technical Committee on Electro-Acoustic Devices of the Institute was held on October 8 at the office of the Institute. The meeting was attended by Stuart Ballantine, chairman; L. G. Bostwick, E. D. Cook, E. W. Kellogg, Benjamin Olney, and Beverly Dudley, secretary.

This was the first meeting of the committee to be held since the publication of the 1931 Standards Report and a general discussion of the work confronting the committee within the next few months was held. The possibility of setting up standards of methods of making sound pressure measurements on the output of broadcast receivers was considered. It was thought that it might be possible to define the essential conditions under which such tests are made with sufficient accuracy to permit the obtaining of results by various manufacturers that would be reasonably comparable.

TECHNICAL COMMITTEE ON VACUUM TUBES—IRE

On September 15 a meeting of the Technical Committee on Vacuum Tubes of the Institute was held at the office of the Institute and was attended by B. E. Shackelford, chairman; N. P. Case, H. F. Dart, F. H. Engel, Virgil M. Graham (nonmember), M. J. Kelly, George Lewis, W. M. Perkins, Dayton Ulrey, J. C. Warner, K. S. Weaver, P. T. Weeks, and Beverly Dudley, secretary.

The meeting was devoted chiefly to a consideration of reports by the chairman of a number of subcommittees operating under the Technical Committee on Vacuum Tubes. It is anticipated that preliminary reports of the work of these subcommittees will be available in about two months.

SUBCOMMITTEE ON METHODS OF MEASUREMENTS OF THE TECHNICAL COMMITTEE ON VACUUM TUBES—IRE

A meeting of the Subcommittee on Methods of Measurements operating under the Technical Committee on Vacuum Tubes was attended by F. H. Engel, chairman; J. N. Hanley, H. A. Snow, K. S. Weaver, and Beverly Dudley, secretary, on October 6, 1931, at the office of the Institute.

As this was the first meeting of this subcommittee, the general policies under which it will operate were considered and essential decisions reached regarding the form and scope of the report to be submitted to the Technical Committee on Vacuum Tubes.

The committee then considered the section on "Standard Methods of Testing Vacuum Tubes," as published in the 1931 Standards Report, making a number of recommended changes in it.

Institute Meetings

NEW YORK MEETING

The October 7 New York meeting was held in the Engineering Societies Building, New York City, with R. H. Marriott presiding.

The three papers delivered at this meeting are summarized below:

"Operation of a Ship-Shore Radiotelephone System," by C. N. Anderson and I. E. Lattimer.

This paper reviews the essential physical and operating features of the land and ship terminals employed in giving radiotelephone service between the Bell System and a number of large steamships on north Atlantic routes. The land terminals involved are very similar to those used at present by the American Telephone and Telegraph Company on the point-to-point overseas circuits between New York and London.

Problems encountered in establishing and operating this service are discussed, together with measures applied for their solution. The most difficult problems have arisen in connection with adapting the ship terminal to operation under the limited space conditions encountered on shipboard. These conditions impose undesirable proximities between units of equipment and between antennas.

The coördinating system applied in establishing contacts between the ships and the shore stations and for determining the proper frequencies to use, together with some of the devices employed to assist in this work, are discussed.

Considerable data have been collected over the two years during which this service has been given and a number of charts are included showing variations of received fields with distance, and throughout the course of the day, also the grades of circuit obtained at different distances. During the first six months of 1931, commercial grades of circuit were obtained in about 85 per cent of the contacts.

Results of frequency measurements on the Ocean Gate transmitter and on some of the ship transmitters, over a six-months period, are shown in terms of percentage deviation from the assigned frequency.

"Radiomarine Communication System," by I. F. Byrnes

The coastal and shipboard station facilities used in the Radiomarine Communication System are described in this paper. Radio, in the marine field, was first utilized primarily because of the safety-of-life feature. This is still the major function, but in addition radio has become a business necessity aboard ship and now performs a variety of services.

An important by-product of radio communication, the direction finder, is now recognized as a valuable navigating aid, and installations are found on a large number of vessels. The standard Radiomarine direction finders are also described in the paper.

Coast station service to shipping is provided by a total of sixteen stations located at strategic points throughout the United States. Some of these stations are high power installations used for long-distance communication, while others are of lower power and are primarily maintained for coastwise or short-distance services.

"The Development and Application of Marine Radio Direction Finding Equipment by the United States Coast Guard," by C. T. Solt

The various problems dealt with in the evolution, development, and practical application of radio direction finding equipment by the United States Coast Guard are discussed. The equipment in use at the present time is described. Difficulties encountered with marine equipment due to the electrophysical properties of vessels are explained. The methods employed in overcoming these difficulties are described.

Some notes on deviation are presented along with curves and photographs showing the results obtained on various types of vessels.

Deviation as a function of frequency is discussed in brief.

The material presented is based on data obtained from more than one hundred direction finder installations on vessels of various types and sizes ranging from 75-foot motor boats to cutters of 3000 tons displacement.

A brief description of aircraft equipment and an account of the results obtained therewith are included.

The object of this paper is to present a résumé of the results obtained with modern equipment under the actual conditions encountered in service use, accompanied by such notes and comments by the author as are deemed of interest to those concerned with the development, improvement, and application of marine and aircraft radio direction finders. The fundamental principles underlying the art of direction finding by means of radio are not recounted as it is realized the reader has available numerous current publications on the subject.

This paper is published by permission of the Commandant, United States Coast Guard. The data presented have been obtained during the development, improvement, and installation of equipment used on vessels and aircraft of the

Coast Guard. All of the equipment described was manufactured in accordance with specifications prepared and issued by that Department.

The meeting was attended by four hundred and fifty members and guests, a considerable number of whom entered into the discussions which were held after the presentation of each paper.

ATLANTA SECTION

A meeting of the Atlanta Section was held on June 29 at the Atlanta Athletic Club, Chairman Harry Dobbs, presiding. After a short business session, a paper on "Vacuum Tube Voltmeters" was presented by H. L. Wills, a consulting engineer.

The paper was not only illustrated with circuit drawings but a vacuum tube voltmeter was set up and used in making several representative measurements.

Several of the ten members and guests in attendance participated in the discussion.

A buffet supper was served prior to the meeting.

The August meeting was held on the 20th. This meeting also was held at the Atlanta Athletic Club under the chairmanship of Harry Dobbs.

After an informal dinner, the meeting was called to order and the speaker of the evening, C. F. Daugherty, chief engineer of WSB, presented a paper on "Some Problems of Present-Day Broadcasting." The speaker covered his subject thoroughly and explained fully the very complicated system of control necessary in the changing of programs. The paper was well illustrated by charts and circuit diagrams and was discussed by a number of the eighteen members and guests in attendance. As a part of the discussion, W. Van Nostrand presented some interesting information regarding the National Broadcasting Company studios in New York City.

CINCINNATI SECTION

The September meeting of the Cincinnati Section was held on the 15th of the month at the Hotel Sinton-St. Nicholas, under the chairmanship of Dorman D. Israel.

The paper of the evening, "Iron-Core-Tuned Radio-Frequency Inductances," was presented by W. J. Polydoroff of the Johnson Laboratories.

The author outlined in general the design of the conventional tuned circuits together with the mathematical requirements essential to give uniform gain in selectivity over a band of frequencies. The principles underlying the use of iron-core-tuned inductances together with the history of some first attempts at their utilization and the results obtained were then given. The types of materials required for suitable cores and the treatment necessary was then covered. The paper was concluded with some data on the performance of single stage amplifiers of different types showing the effect of the size and permeability of the iron-core particles. A number of slides of models of receivers utilizing this inductance and their over-all performance characteristics were included by way of illustration.

Messrs. Felix, Israel, Kilgour, Nichols, and Rockwell, of the fifty-five members and guests at the meeting, entered into the discussion of the paper. Prior to the meeting an informal dinner was attended by sixteen.

CONNECTICUT VALLEY SECTION

The September 17 meeting of the Connecticut Valley Section was held at the Hotel Garde, Hartford, Connecticut, under the chairmanship of R. S. Kruse.

A paper on "Mechanical Analogies of Electrical Circuits" was presented by L. F. Curtis, Chief Engineer of the United American Bosch Corporation.

Of the thirty-two members and guests who attended the meeting seven were present at an informal dinner which preceded it.

LOS ANGELES SECTION

The September 15th meeting of the Los Angeles Section was held in the Transmitting Rooms of Broadcast Station KFI, at Buena Park, Calif., T. E. Nikirk, chairman, presiding.

Instead of presenting a formal paper, the evening was devoted to a trip through the 50-kilowatt transmitting station used by KFI. As this is the only broadcast station of this power on the Pacific Coast and has but recently opened, it was of considerable interest to the one hundred and twenty members and guests who attended the meeting. The staff of the station conducted small groups through the station and gave considerable data on the design and operating characteristics of the equipment.

PITTSBURGH SECTION

The September 22 meeting of the Pittsburgh Section held at the Fort Pitt Hotel was presided over by J. G. Allen, chairman.

A paper on "Some Factors in Power Tube Design" by I. E. Mouromtseff and H. V. Nobel, members of the Westinghouse Research Laboratory was presented by Mr. Mouromtseff. The paper covered the problems connected with power tube design and limitations. Methods of calculating the power output were demonstrated and the actual approach to theoretical power output was discussed, the limiting factors being pointed out. The important limits were shown to be safe plate dissipation, grid emission, charging current to grid at high frequencies, filament design, magnetron effects of thick filaments, and operating voltage limits which concern mechanical construction within the tube as well as the dielectric stresses. The paper was concluded with the brief discussion of the future of very high power tubes, and it was stated that the chief limitation at this time to the development of such tubes appears to be economical rather than technical.

H. V. Nobel led the discussion which followed the paper and which was entered into by a number of the forty-one members and guests in attendance.

SAN FRANCISCO SECTION

The September 10th meeting of the San Francisco Section was held at the Bellevue Hotel, San Francisco.

The resignation of C. H. Suydam as chairman was accepted and Ralph M. Heintz was elected chairman. C. V. Litton was elected vice chairman to replace Mr. Heintz who formerly held that office.

A paper on "Some Problems Encountered in the Design and Production of Broadcast Receivers" was presented by Harold F. Elliott.

The author covered not only the technical problems involved in designing and placing in production a broadcast receiver, but also the human problems which enter into the situation.

The meeting was attended by forty-nine members and guests, thirty of whom attended the informal dinner which preceded it.

WASHINGTON SECTION

A meeting of the Washington Section was held on September 10 at the Bureau of Standards under the chairmanship of L. P. Wheeler.

The paper of the evening on "Communication with Quasi Optical Waves" was presented by Eduard Karplus, assistant engineer, General Electric Company. This paper has been published in the October issue of the PROCEEDINGS and need not, accordingly, be abstracted here.

The discussion was entered into by Messrs. Hanson, Oulds, Page, Wheeler and several others of the one hundred and twenty members and guests who attended the meeting. Forty of those in attendance were present at the informal dinner which preceded the meeting.

Personal Mention

R. M. Arnold, formerly chief engineer of the United Air Cleaning Corporation is now chief engineer of the radio division of the Grigsby-Grunow Company.

W. M. Bailey has left RCA Victor Company to join the engineering department of the Dubilier Condenser Corporation.

E. D. Blodgett was transferred from the RCA Victor Company of Massachusetts to the Camden plant.

C. E. Brigham is now chief engineer for the Brandes Corporation, formerly being chief engineer for Kolster Radio Corporation.

L. M. Clement formerly with the Westinghouse Electric and Manufacturing Company is now a radio engineer for the Federal Telegraph Company at Newark, N. J.

Lieutenant L. R. Daspit, U.S.N. has been transferred from the U. S.S. Fulton to the U.S.S. Gilmer.

S. I. Davis is now assistant supervisor of sound engineering for Warner Bros. Theaters, Pittsburgh, Pa., formerly being in the radio engineering department of the Westinghouse Electrical and Manufacturing Company.

W. G. H. Finch is now secretary and chief engineer of the American Radio News Corporation in New York City.

E. L. Garceau, previously in the engineering department of Wired Radio, has become an electrical engineer at Harvard Medical School in Boston.

F. G. Kear formerly an assistant physicist at the Bureau of Standards is now in the electrical engineering department at the Massachusetts Institute of Technology.

J. B. Knight, Jr., recently with the De Forest Radio Company of Passaic has joined the engineering staff of the Federal Telegraph Company at Newark, N. J.

A. A. Leonard previously chief engineer of the Automobile Radio Corporation has joined the research department of the Philadelphia Storage Battery Company, Philadelphia.

W. W. Macalpine formerly in the engineering department of the International Communication Laboratories has become director of research for Communications Patents, Inc., of Ampere, N. J.

Formerly with the RCA Victor Company at Camden, A. G. Mankie has joined the engineering department of Leeds and Northrup Company at Philadelphia.

A. C. Matthews, Jr., has left the United Research Corporation to join the staff of the Freed Radio and Television Corporation of Long Island City, N. Y.

L. M. Perkins is now chief engineer of the Erie Resistor Corporation of Erie, Pa., having previously been in the engineering department of the General Motors Radio Corporation.

Lieutenant T. C. Ragan has left Harvard University to serve aboard the U.S.S. Saratoga.

H. J. Russell is now in the research department, Marconi Works, Chelmsford, Essex, England, having previously been with the Canadian Marconi Company at Montreal, Canada.

W. W. Saunders has been transferred from the Palo Alto, Calif., to the Newark, N. J., plant of the Federal Telegraph Company.

Formerly with Grigsby-Grunow Company, H. W. Schaefer has become radio engineer for the Hawley Products Company at St. Charles, Ill.

Robert Serrell has left the Camden plant of RCA Victor to join the engineering department of the General Electric Company at Schenectady.

E. P. Shultz, engineer for RCA Photophone, has been transferred from New York City to Hollywood, Calif.

S. B. Slavin has become a transmitting engineer of the Radio Corporation of America at Bolinas, Calif., formerly being associated with the General Electric Company at Oakland, Calif.

C. H. Suydam, previously acting chief engineer of the Federal Telegraph Company of Palo Alto, Calif., has joined the International Communications Laboratories at Newark, N. J.

Formerly in the Department of Lands and Forests, Sioux Lookout, Canada, J. E. Watson has joined the staff of Silver-Marshall in Canada.

R. Weese, previously chief radio engineer for the Victor Talking Machine Company of Montreal, Canada, has become general manager of the Erie Resistor Company of Canada, Ltd.

D. O. Whelan, formerly with the RCA Victor Company at Camden has become president of the RCA Institutes in New York.

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PART II
TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

THE ADJUSTMENT OF THE MULTIVIBRATOR FOR FREQUENCY DIVISION*

By

Victor J. Andrew

(Formerly, Westinghouse Electric and Manufacturing Co., Chicopee Falls, Mass. At present, University of Chicago, Chicago, Ill.)

Summary—*In a multivibrator controlled by a voltage of another frequency bearing a harmonic relationship to the multivibrator frequency, the effect of varying the control voltage is analyzed, and a method for determining the best value of this voltage is described. Methods of coupling the control voltage are shown in which frequency division by an odd integer will occur more readily than by an even integer, and vice versa.*

WITHIN the last few years numerous applications, particularly in frequency measuring equipment, have been found for a circuit capable of frequency division at radio frequencies. The difficulties encountered in frequency division are considerably greater than those in the inverse process of frequency multiplication.

Let f represent a frequency which we wish to divide by an integer n, in order to obtain a frequency f/n. The method usually used consists in operating an oscillator tuned approximately to the frequency f/n, and then introducing voltage of the frequency f into the oscillator circuit in such a way that the oscillator is controlled at exactly f/n. It is also possible to control the oscillator at a frequency of mf/n, where m and n are any small integers. However, the tendency to control decreases rapidly as m or n is increased. Control is a very simple matter when the product of m and n does not exceed 10. When the product is larger, more elaborate control circuits and more careful adjustments are required. The case with which we are chiefly concerned is that in which $m=1$, or simple frequency division.

Any relaxation oscillator, and the multivibrator in particular, have proved well suited to frequency division.[1,2] However, considerable care must be exercised in the adjustment of the multivibrator to prevent variations of the battery voltages or the control voltage, aging of tubes, etc., from causing it to change frequency, either to another possible controlled frequency, or to an uncontrolled frequency.

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* Decimal classification: R146.2. Original manuscript received by the Institute, June 10, 1931. Revised manuscript received by the Institute, July 29, 1931.

[1] J. K. Clapp, "Universal frequency standardization from a single frequency source," *Jour. Opt. Soc. Amer. and Rev. Scien. Instr.*, 15, 25; July, 1927.

[2] W. A. Marrison, "A high precision standard of frequency," Proc. I. R. E., 17, 1103; July, 1929.

The nature of oscillation in the multivibrator was described in the original paper by the inventors, Abraham and Bloch,[3] and both oscillation and control as a frequency divider were clearly described by Hull and Clapp.[4] However, oscillation and control will be briefly reviewed here before describing a method for determining the correct control voltage and some new variations in the control circuit.

Fig. 1 shows a simple uncontrolled multivibrator circuit. The multivibrator consists of two tubes, the plate circuit of each being connected to the grid circuit of the other by the usual resistance—capacity combination used in amplifier circuits. Each tube in itself operates as an amplifier.

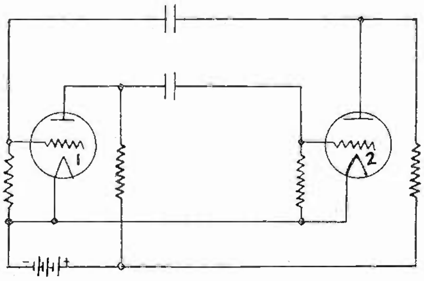

Fig. 1—Simple multivibrator circuit.

Imagine a slight negative impulse on the grid of tube 1. This is amplified and appears as a positive impulse in the plate circuit, and is transmitted to the grid of tube 2. Here it is again amplified, and returns to the grid of tube 1 as a negative impulse. Thus the potential of grid 1 is unstable, and continues to fall rapidly, until one of the tubes ceases to function as an amplifier. This occurs when grid 1 becomes so far negative that plate current ceases, or when grid 2 becomes sufficiently positive to prevent further amplification, depending on the grid bias and other circuit and tube constants. We assume the former for simplicity. In Fig. 2 the solid and dotted curves represent the potentials of grids 1 and 2 respectively. The curve from *A* to *B* shows the rapid fall in potential of grid 1. The circuit remains in a comparatively quiet state from *B* to *C*, while the charge on the grid slowly leaks off through the grid to filament resistor. More exactly, the charge on the coupling condenser, in excess of the normal charge from the plate battery, leaks off through one grid and one plate resistor in series. At *C*, the increasing

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[3] H. Abraham and E. Bloch, "Mesure en valeur absolue des periods des oscillations electriques de haute frequence," *Ann. d. Phys.*, **12**, 237; September–October, 1929.

[4] L. M. Hull and J. K. Clapp, "A convenient method for referring secondary frequency standards to a standard time interval," Proc. I. R. E., **17**, 252; February, 1929.

grid potential (decreasing negative potential) allows the plate current to reappear, and tube again functions as an amplifier. The increase becomes rapid from C to D, this time being terminated by grid blocking in tube 2. The discharge of grid 2 through its resistor completes one cycle of oscillation. It is seen that the time required for one alternation increases with the size of the coupling condenser, and with the grid and plate resistors through which the condenser discharges. The frequency is therefore proportional to $1/RC$, where the four resistors are each proportional to R, and the two capacities are each proportional to C. This expression is found to hold only approximately, since the tube characteristics also have a direct effect on the frequency, and the battery voltages an indirect effect, in that variations in the supply voltages alter the tube parameters.

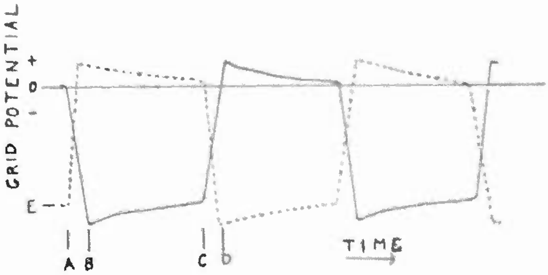

Fig. 2—Wave form of the simple multivibrator.

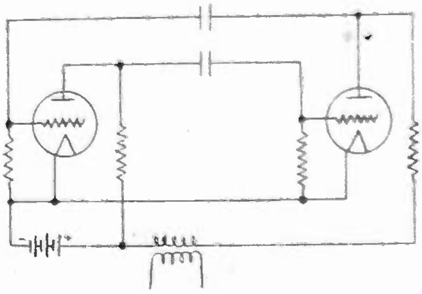

Fig. 3—Multivibrator for control at any order of frequency division.

The control frequency is effective in the multivibrator circuit when it reaches the grid of the tube which is blocked off. The control voltage may be introduced into the plate circuit of the other tube (Fig. 3). This method is convenient when choke or resistance coupling to the preceding amplifier is used and all three tubes are operated from the same plate battery.

In Fig. 4 the solid curves show the normal multivibrator alternation, copied from Fig. 2, and a sinusoidal control voltage of about six times the natural frequency of the multivibrator. The dotted curve shows the superposition of these two. Point E in Figs. 2 and 4 represents the boundary value of grid potential between grid blocking and amplification. The dotted curve, representing grid potential when the control voltage is present, reaches the potential E at the time F. This particular alternation is therefore terminated at F instead of at C. This termination is determined by the phase of the control voltage, and always occurs at or just before the peak of the positive alternation. If the control voltage is applied to the grid of only one of the multivibrator tubes, as shown in Fig. 3, every other alternation, or every cycle, of the multivibrator will be terminated by a positive alternation of the control voltage. If n cycles of the control voltage occur during one cycle of the multivibrator, we have control at f/n, where n is a small integer, either odd or even.

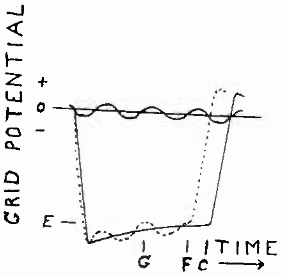

Fig. 4—Wave form of controlled multivibrator.

It will be noticed that the control voltage is small compared to the multivibrator voltage. A sufficient increase in the control voltage will cause the multivibrator alternation to terminate at G instead of F. The multivibrator will therefore change in frequency from f/n to $f/(n-1)$. If the control voltage is negative at C, where the multivibrator alternation normally ends, the alternation may be slightly prolonged. The multivibrator frequency is then slightly decreased to control it. This however can occur only with a feeble control voltage. Usually control is accompanied by an increase in the multivibrator frequency.

Fig. 5 shows the relationship between the values of control voltage and coupling capacities of the multivibrator. The ordinate might be coupling resistances or the reciprocal of the natural frequency of the multivibrator instead of the coupling capacities. Usually the coupling capacities are the most convenient element to vary for adjustment of the natural frequency of the multivibrator. The two capacities are assumed to be kept equal. With the control voltage equal to zero, the multivibrator frequency varies continuously with variations of the capacity. With other conditions constant there is one value of capacity which gives a particular frequency. A, B, D, F, and G represent the capacities which give the frequencies $f/3$, $3f/8$, $2f/5$, $3f/7$, and $f/2$ respectively, where f is the frequency to be divided, or the control frequency. If we increase the control voltage to a small value W, the multivibrator is controlled at the above frequencies with the capacity varied slightly either way. The smaller the product mn, the greater is the possible capacity variation without losing control.

With any value of capacity and control voltage that fall within the area $HAINPQ$, the multivibrator is controlled at $f/3$. The area STU is the most desirable region for control. It is so chosen that a 50 per cent increase or a 75 per cent decrease of the control voltage, or a 3 per cent variation of capacity does not throw the multivibrator outside the limits of control. If quantitative information is available concerning the variations which are likely to cause the multivibrator to get out of control, such as a decrease of control voltage due to run down batteries, these four boundaries should be determined so that there is an equal probability of the multivibrator's going out of control across any one of them, and then this probability should be decreased until the bounded area approaches zero. A simpler method is to locate some central point such as V. With no control voltage, the capacity is adjusted so that the multivibrator is on $f/3$. The control voltage is then increased

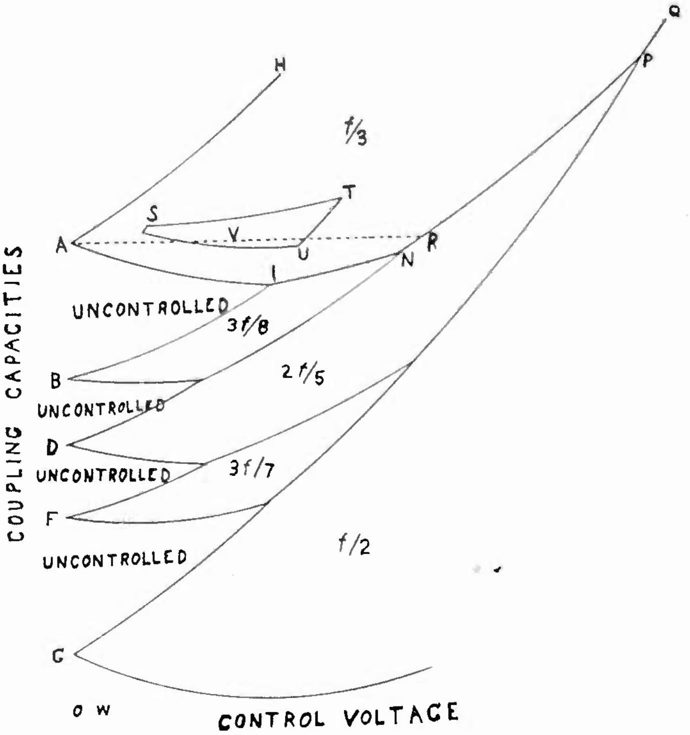

Fig. 5—Relationship between values of coupling capacity, control voltage, and frequency of controlled multivibrator.

until the multivibrator changes frequency at R. The control voltage is then reduced to about half.

The area $NRAI$ is the small region previously referred to in which the multivibrator is controlled by decreasing its frequency. In the larger area, $HARPQ$, the frequency is increased. The other areas in the figure are marked "uncontrolled" or the controlled frequency is given. In the uncontrolled areas the frequency varies continuously with the the capacity just as if the control voltage were absent, except in very small areas where control occurs with mn products larger than those shown.

Such a system of curves may be drawn through points obtained by setting either the control voltage or the capacity, and varying the other until the value is found where the transition between different states of the multivibrator occurs. These particular curves are only qualitative.

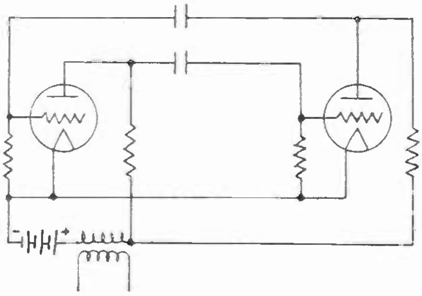

Fig. 6—Multivibrator for control at even orders of frequency division.

As pointed out above, the circuit shown in Fig. 3 is capable of frequency division by n, where n is either even or odd. The circuit in Fig. 6 is one which is often used. In this circuit the control voltage operates on the grids of both multivibrator tubes, and in the same polarity on each. The elements of the multivibrator circuit are completely symmetrical. The successive alternations are terminated alternately by each of the two tubes. Each alternation is terminated by a positive alternation of the control voltage. Thus each multivibrator alternation must contain an even number of alternations of the control voltage, and n must be an even number.

Fig. 7 is similar to Fig. 6 except that the control voltage is applied to tube 2 in the opposite polarity from tube 1. One control alternation terminates the multivibrator alternation in tube 1, a control alternation of opposite polarity terminates the next multivibrator alternation in tube 2. Each multivibrator *alternation* therefore contains an odd number of control *alternations*. Since the circuit is symmetrical, the two multivibrator alternations contain the same number of control alternations. The multivibrator *cycle* contains an odd number of control cycles, and n is odd.

The two preceding paragraphs describe a multivibrator which theoretically is perfectly symmetrical. In practice, sufficient symmetry may be obtained so that control occurs much more easily at even than at odd values of n, and vice versa. The opposite kind of frequency division is still possible, and may be encouraged by intentional dissymmetry in the circuit. Thus, with the circuit of Fig. 6, each *alternation* of the multivibrator may contain an even number of *alternations* of the control voltage, but one of them may contain two more alternations than the other. The complete multivibrator *cycle* then contains an *odd* number of control voltage *cycles,* and n is an odd number. This method of obtaining an odd value of n was described by Hull and Clapp.[4]

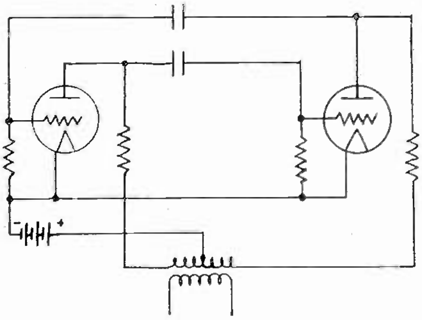

Fig. 7—Multivibrator for control at odd orders of frequency division.

These circuits which make it possible to divide frequency with much stronger control at even or at odd integers are particularly useful when division is to be made by such a large number that it is difficult to keep the multivibrator properly controlled, as the percentage difference between successive points of strong control is doubled.

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[4] *Loc. cit.*

Proceedings of the Institute of Radio Engineers
Volume 10, Number 11 *November, 1931*

NEW METHODS OF FREQUENCY CONTROL EMPLOYING LONG LINES*

By

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(R.C.A. Communications, Inc., New York City)[1]

Summary—*The practical difficulties encountered in commercial operation of short-wave transmitters, due to the great number of radio-frequency stages required for crystal control, are summarized. The objections to crystal control for some transmitters operated on frequencies above 35,000 kilocycles are given. Methods are described for meeting these objections through frequency control by long radio-frequency transmission lines, which have inherently large volt-ampere capacity and which make possible a considerable reduction in operating costs and improvement in reliability. Methods for applying the lines to the control of oscillator frequencies by using them as relatively constant low power factor resonant circuits and as aperiodic means for feeding regenerative energy from anode circuits to grid circuits are described. A method is given for obtaining both the advantages of crystal oscillators as frequency standards and the economies and reliability of long line transmitter frequency control. Applications of the methods described to experimental and commercial transmitters are mentioned.*

INTRODUCTORY

ONE OF the most difficult problems connected with the development of high-frequency transmitters has been that of providing sufficiently accurate control of the transmitted frequency. In obtaining satisfactory frequency stability, it has been necessary to add so much to transmitters that they are deficient in economy of operation and reliability.

The almost universally adopted method for controlling the frequency of high-frequency transmitters is to produce oscillations in relatively low power master oscillators which are so carefully designed, so well shielded, and so lightly loaded that they are inherently very constant in frequency. The small output from these oscillators is then amplified through successive stages of unilateral amplifiers to the power required for the antennas.

In the United States and Germany it is common practice to employ piezo-electric quartz crystals in the master oscillators. These piezo-electric crystals provide equivalent tuned electrical circuits of very low power factor and fixed dimensions. They make the master oscillators

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[1] The authors of this paper are located at the Transmitter Development Laboratory of R.C.A. Communications, Inc. at Rocky Point, New York. This laboratory is a part of the engineering department under C. H. Taylor, vice president and H. H. Beverage, chief engineer.

much less subject to frequency variations from outside influences and serve to make them more or less permanent standards of frequency. In these respects, crystal oscillators have great advantages over other devices used for frequency control.

The disadvantages of crystal oscillators lie in their practical limitation to frequencies of less than about 5000 kilocycles and in their inherently small power capacity. These limitations ordinarily require a number of stages of vacuum tube frequency multipliers and amplifiers to reach the frequency and power required for the antenna.

To illustrate the effect of these limitations upon the design of transmitters, it may be noted that one type of modern 40-kw high-frequency transmitter has a total of eight radio-frequency stages, including the crystal oscillator, intermediate amplifiers, and power amplifier. Seven of these stages are used primarily for holding the output frequency constant. Their presence greatly increases the cost of operating and the probability of failures in service.

In the newly opened field of commercial communications between 35,000 and 100,000 kilocycles, there is serious objection to the use of crystal control for many applications and there has been a need for some simpler method. The objections to crystal control in this band are briefly outlined in the following.

(1) From the standpoint of preventing interference, there is little need at the present time for extremely accurate frequency control above 35,000 kilocycles because the spectrum is not crowded and the range of these frequencies is limited to a few hundred miles. Services may be duplicated many times on the same frequencies, in different geographical locations without mutual interference. Very accurate frequency control, should therefore be required only in congested areas such as may exist around large cities.

(2) Since noise levels are low in the band above 35,000 kilocycles, particularly when efficient directive antennas are used, there is less need for great frequency selectivity at the receiver and a wide pass band, which will tolerate considerable transmitter frequency variation is permissible.

(3) The range of frequencies above 35,000 kilocycles is rather sharply limited by shading from curvature of the earth and, since increasing transmitter power produces relatively little increase in range, a simple inexpensive transmitter is capable of reaching almost to the maximum distance. The addition of crystal control to such a low power, high-frequency transmitter would greatly increase its complexity and cost without any corresponding benefit in many cases.

For the reasons which have been outlined, the engineers of R.C.A.

Communications, Inc., have sought to devise new methods of frequency control capable of approaching the piezo-electric crystal in accuracy but less subject to inherent limitations. There have resulted new methods of frequency control, employing electrically long radio-frequency transmission lines, which have already found commercial application and which promise considerable usefulness in the future. The purpose of this paper is to present a brief outline of the development up to the end of 1930.

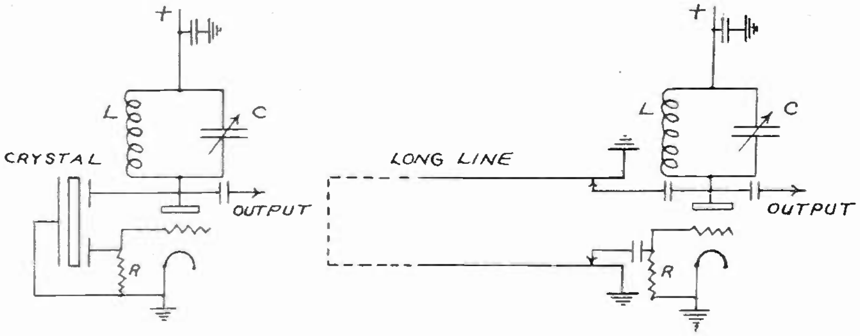

FIG. 1

METHOD FOR APPLYING LONG LINES TO FREQUENCY CONTROL

There are, in general, two methods of applying long radio-frequency transmission lines to control the frequency of oscillators. The first of these methods is to use long lines as resonant circuits which are applied to control the frequencies of oscillators in much the same manner as piezo-electric crystals.

The second method employs long lines, for regenerative coupling between anode and grid circuits, in which the line impedances are matched at the grid circuit ends. In this case the lines carry waves traveling in only one direction, from anode circuits to grid circuits. There is little, if any, reflection and the lines may be considered aperiodic. Since the velocity of waves on the lines is constant, any change in oscillator frequency will shift the phase of voltages at the ends of the lines and so shift the phase of the excitation to the oscillator vacuum tubes with respect to the alternating-current anode voltages. This, in turn, shifts the phase of the anode currents with respect to the anode voltages in a direction to oppose the shift of frequency.

RESONANT LONG LINE FREQUENCY CONTROL

When properly designed and constructed, a long radio-frequency transmission line provides a relatively constant, low power factor circuit of large volt-ampere capacity which may be used to stabilize the frequency of high power oscillators in the same ways that crystals can be applied to low power oscillators. Since the equivalent operating cost for even extremely well-built lines is quite low compared with the cost of the vacuum tube stages eliminated by their use, it will be apparent that long line control, if sufficiently accurate for practical purposes, should have considerable economic advantage.

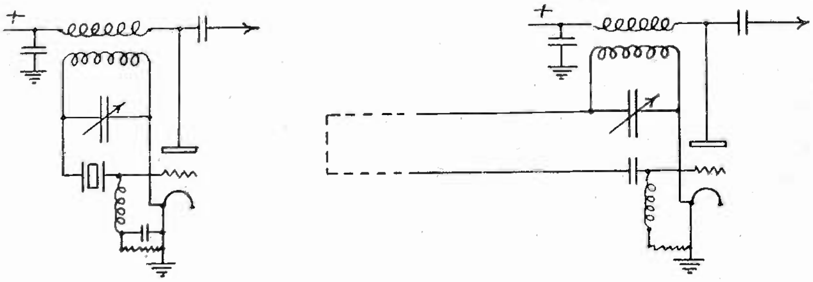

Fig. 2

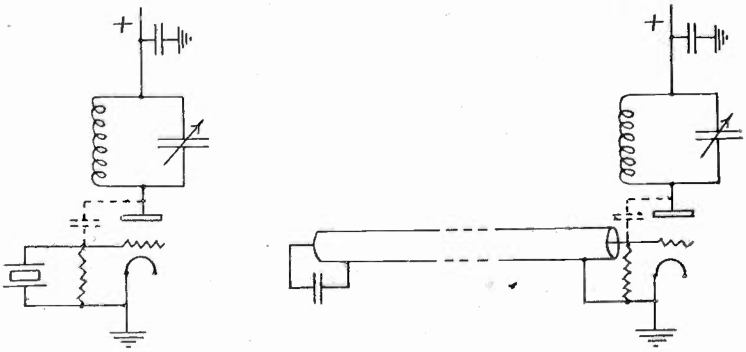

Fig. 3

Figs. 1, 2, and 3 show three well-known crystal oscillator circuits and their corresponding long line controlled circuits. The action of these circuits will be evident to any radio engineer familiar with crystal controlled oscillators and the properties of lines.

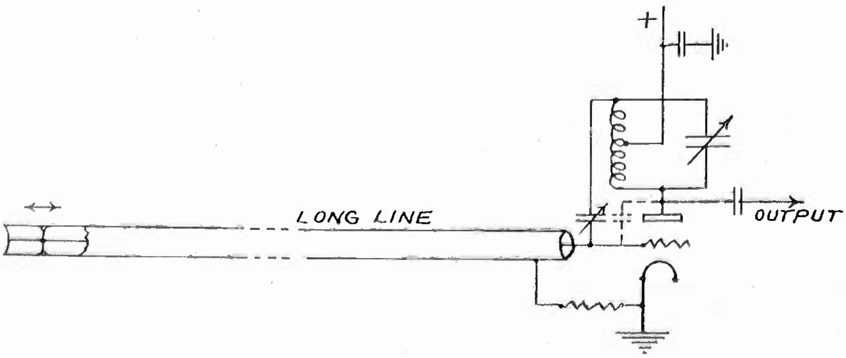

Fig. 4

Fig. 4 is similar to the long line controlled circuit of Fig. 3 except that a neutralizing condenser has been added for balancing some of the interelectrode capacity of the vacuum tube as an aid to controlling the regeneration. For oscillators operated at low frequencies, the condenser might be used in parallel with the vacuum tube capacity in order to increase the regeneration.

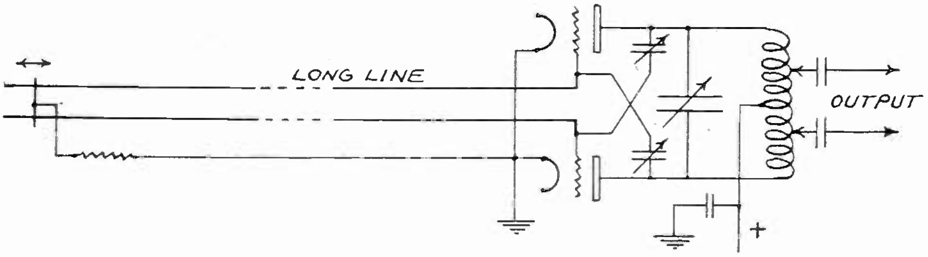

Fig. 5

Figs. 5 and 6 show two ways of applying resonant long line control to push-pull oscillators. It will be evident that the figures show only the elements of oscillator circuits essential to understanding the principles used. Obviously, many detail arrangements other than those shown may be used.

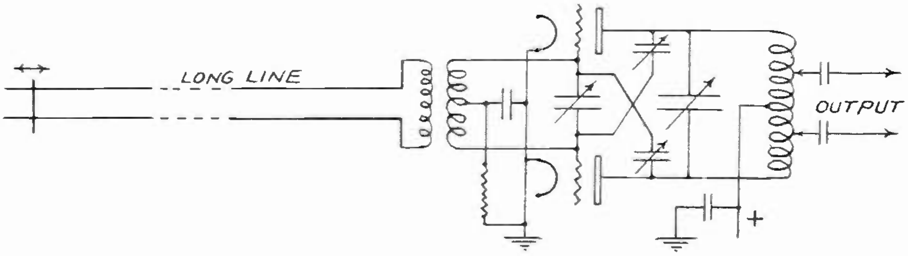

Fig. 6

Fig. 7 is a schematic diagram of a circuit which we used to demonstrate long line frequency control on commercial transmitter WIK, which operated on a frequency of 13,930 kilocycles. In this demonstration, two 20-kw water-cooled tubes were operated as oscillators, with

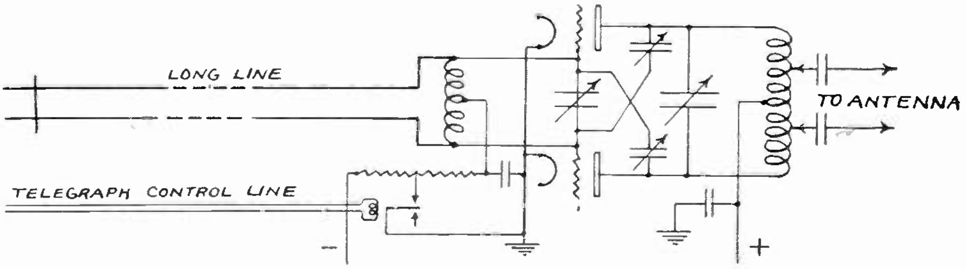

Fig. 7

long line frequency control, delivering their output directly to an antenna. The frequency controlling line was made up of two No. 6 B & S copper wires, 10.25 wavelengths long, stretched under the roof of the building in which the transmitter was located. Although there was considerable frequency modulation in the radiation from the transmitter, due to vibration of both transmitter and line by Alexanderson alternators and other machinery in the same room, the control of average frequency was good enough to indicate that the method would be capable of commercial application. In fact, the transmitter continued in commercial operation with long line frequency control for several months.

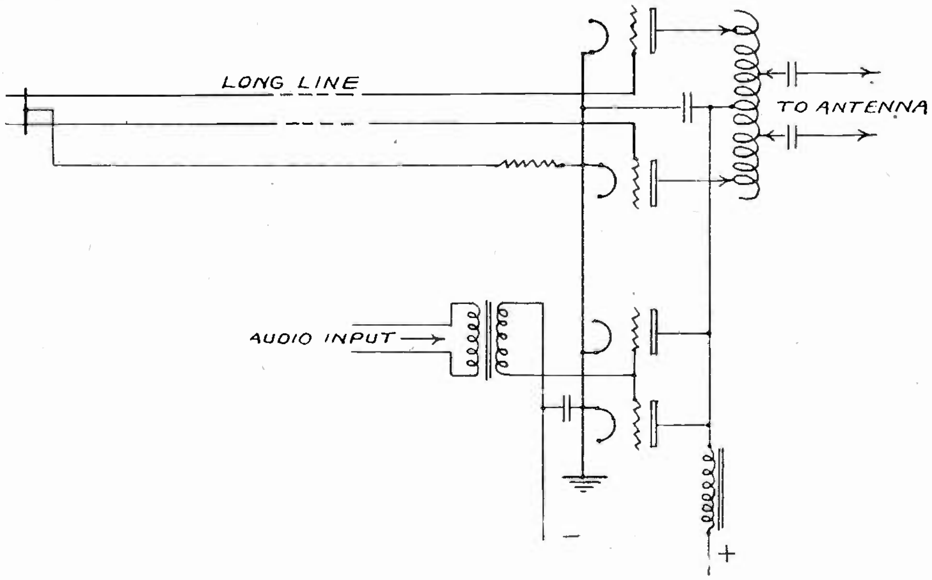

Fig. 8

It is interesting to note that the transmitter, which was an early model, had been causing considerable operating difficulty due to frequent failures of tubes and circuits in the crystal controlled exciter unit. When the exciter was eliminated by application of the long line, the transmitter became almost perfectly reliable from the standpoint of continuous operation without equipment failures.

Fig. 8 is a schematic diagram for two long line frequency controlled transmitters which we built to demonstrate the practicability of interconnecting the Hawaiian Islands with telephone circuits operated on frequencies above 35,000 kilocycles.[2] These transmitters have been used as the basis for designing commercial equipment supplied to the Mutual Telephone Co. of Honolulu by the R.C.A. Victor Co.

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[2] Beverage, Peterson, and Hansell, "Application of frequencies above 30,000 kilocycles to communications problems," Proc. I.R.E., 19, 1313–1334; August, 1931.

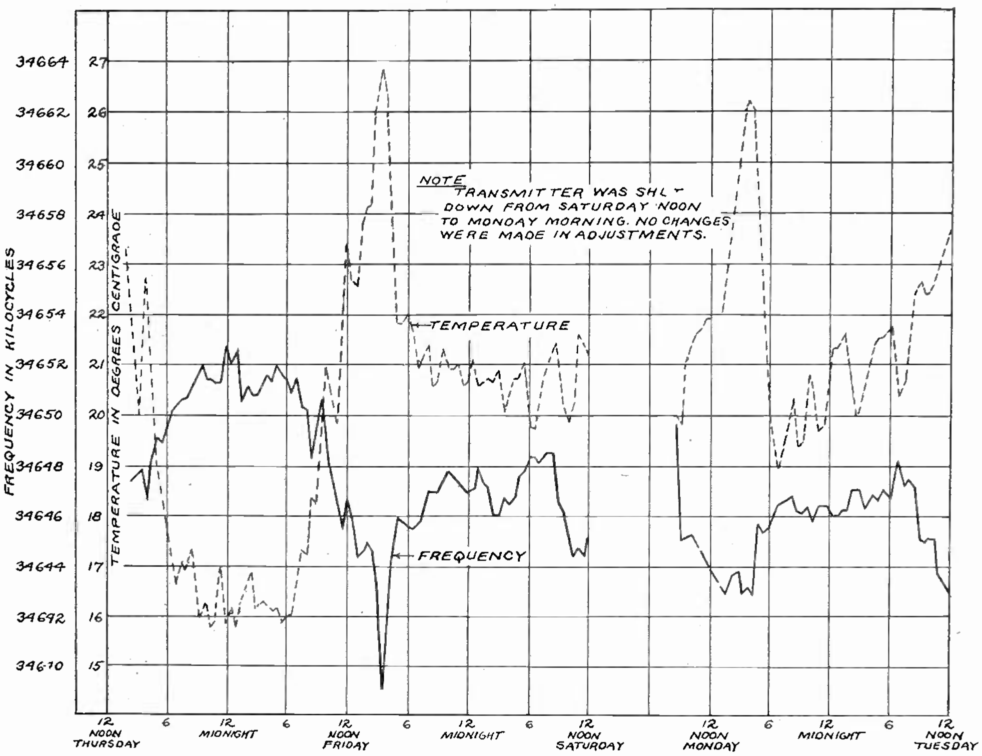
FREQUENCY IN KILOCYCLES
34664
34662
34660
34658
34656
34654
34652
34650
34648
34646
34644
34692
34610
TEMPERATURE IN DEGREES CENTIGRADE
27
26
25
24
23
22
21
20
19
18
17
16
15
NOTE
TRANSMITTER WAS SHUT DOWN FROM SATURDAY NOON TO MONDAY MORNING. NO CHANGES WERE MADE IN ADJUSTMENTS.
TEMPERATURE
FREQUENCY
12 NOON THURSDAY
6
12 MIDNIGHT
6
12 NOON FRIDAY
6
12 MIDNIGHT
6
12 NOON SATURDAY
12 NOON MONDAY
6
12 MIDNIGHT
6
12 NOON TUESDAY

FIG. 9

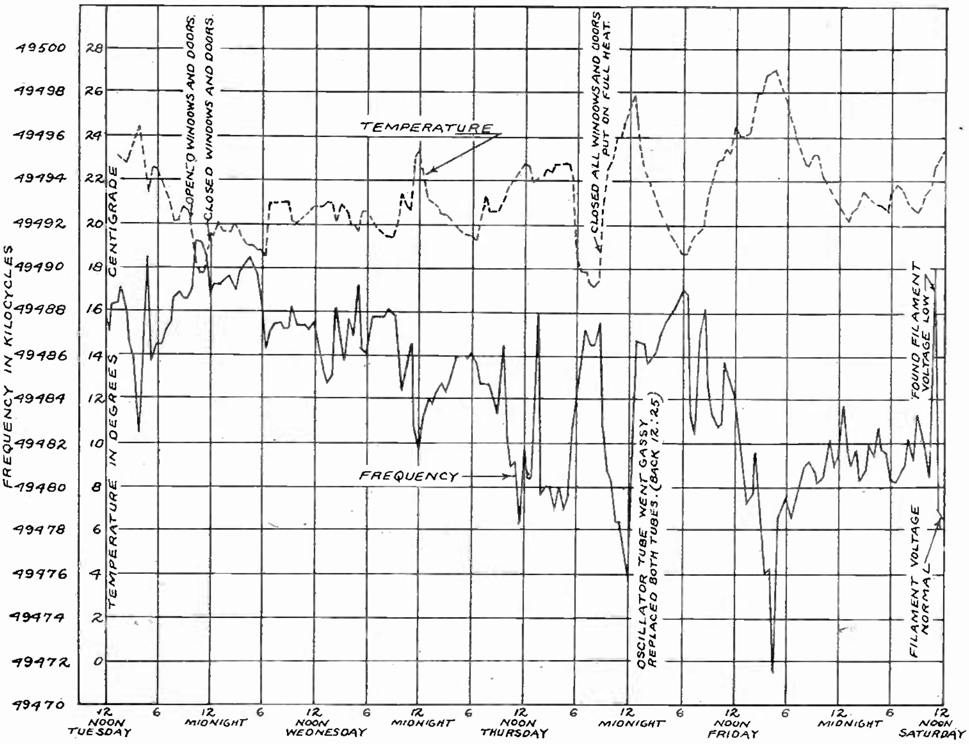
FREQUENCY IN KILOCYCLES
49500
49498
49496
49494
49492
49490
49488
49486
49484
49482
49480
49478
49476
49474
49472
49470
TEMPERATURE IN DEGREES CENTIGRADE
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
OPENED WINDOWS AND DOORS.
CLOSED WINDOWS AND DOORS.
TEMPERATURE
CLOSED ALL WINDOWS AND DOORS PUT ON FULL HEAT.
FREQUENCY
OSCILLATOR TUBE WENT GASSY REPLACED BOTH TUBES. (BACK 12:25)
FOUND FILAMENT VOLTAGE LOW
FILAMENT VOLTAGE NORMAL
12 NOON TUESDAY
6
12 MIDNIGHT
6
12 NOON WEDNESDAY
6
12 MIDNIGHT
6
12 NOON THURSDAY
6
12 MIDNIGHT
6
12 NOON FRIDAY
6
12 MIDNIGHT
6
12 NOON SATURDAY

FIG. 10

Figs. 9 and 10 show typical frequency variations of these transmitters when operated at about 35,000 and 50,000 kilocycles. The frequency variations shown in the curves were measured by comparison with the R.C.A. frequency standard in the receiving station at Riverhead.

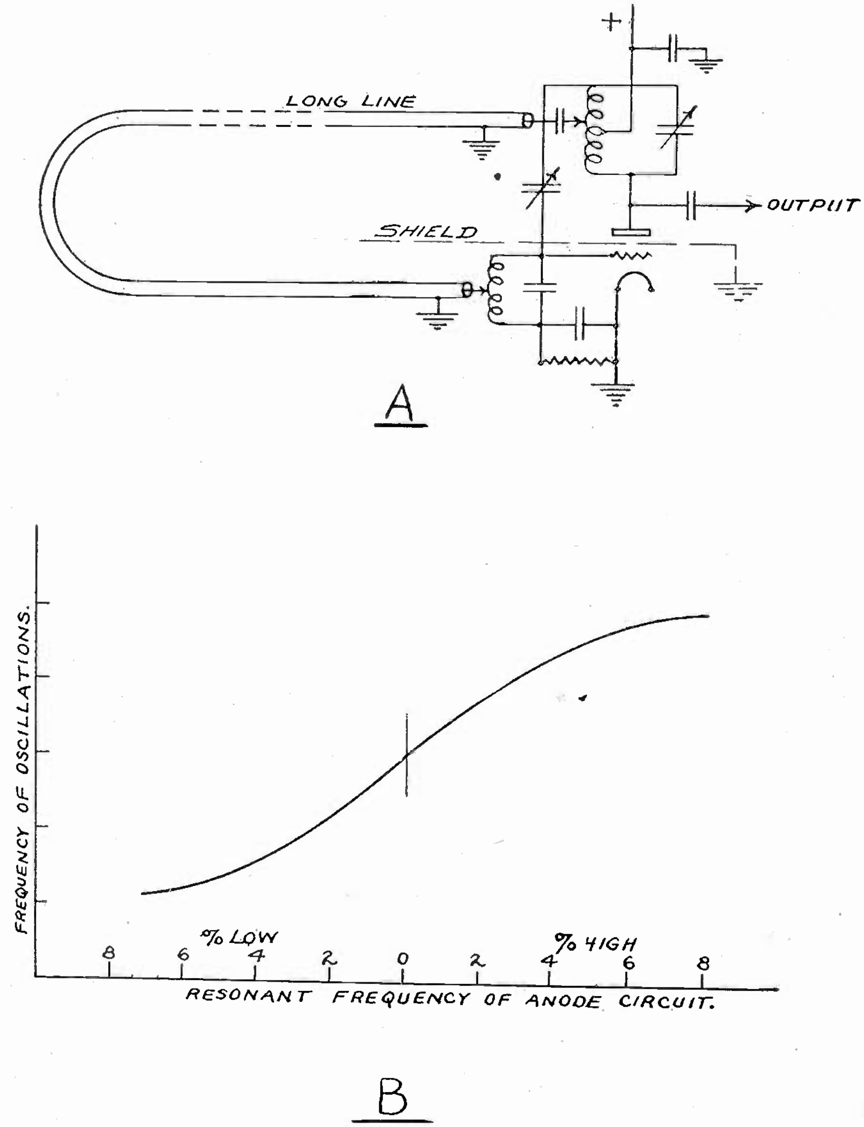

Fig. 11

The figures also show temperature variations of the long line, which were purposely made quite large by varying the temperature of the room in which the transmitter and line were operated. It will be evident that the line temperature was the largest single factor causing frequency variations. The particular line used had a frequency/temperature coefficient of about 28 cycles per million per degree Centigrade at 35,000 kilocycles. This increased to about 40 cycles per million per degree Centigrade at 50,000 kilocycles.

Even with line temperature variations of about 10 degrees Centigrade, it will be noted that the transmitter held its frequency to within about plus and minus 0.02 per cent. Obviously, the frequency stability could be improved by keeping the line at a more constant temperature, by using a line having a lower temperature coefficient or by providing automatic compensation for temperature variations.

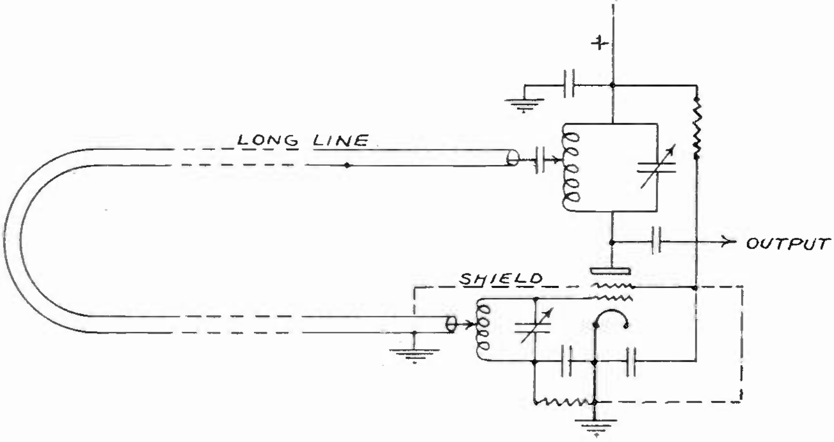

FIG. 12

APERIODIC LONG LINE FREQUENCY CONTROL

Most oscillators, including those which have been described, depend for their control of frequency upon the time constant of electrical or mechanical oscillating systems. The usual vacuum tube oscillators have no means of stabilizing their frequencies other than the natural periods of their circuits and when it is attempted to hold their frequencies constant, the elaborate precautions taken to hold the vacuum tube voltages constant, the rigid design of parts and the care given to making the circuit losses low and load small, have no other purpose than to keep the natural periods constant.

The use of quartz crystals or long resonant lines in the control of frequency is an advantage chiefly because they give equivalent oscillating circuits of fixed dimensions and low losses, so that their natural periods of oscillation are more constant than those of the conventional oscillating circuits.

In most vacuum tube oscillators, the phase of the alternating-current voltages applied to the grids of the vacuum tubes is substantially opposite to that of the alternating-current voltages on the anodes. If reactions from external sources pull the oscillators off their proper frequencies, there is no means of utilizing the vacuum tubes to add energies out of phase with the oscillator voltages in a way to oppose the reactions and reduce the frequency shifts.

The aperiodic long line method of frequency control, such as that shown in Figs. 11, 12, and 13 gives us a system in which the vacuum tubes are utilized to correct the frequency by causing the grid voltage to shift in phase relative to the anode voltage when there is a shift in frequency. This shift in phase is in such a direction as to make the anode current add energy of the proper phase to oppose the frequency shift. In an oscillator of this type, if the increment of current added to the circuit by the tube each cycle is made relatively large, the frequency of the oscillations does not depend upon the natural period of the oscillating circuit but is chiefly dependent upon the electrical length of the line.

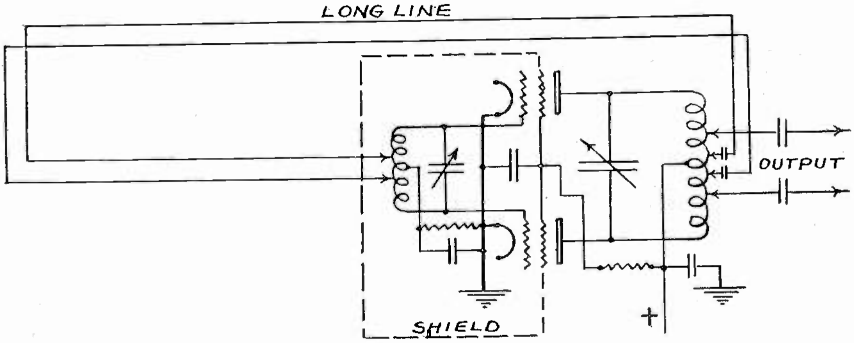

FIG. 13

Since the shift in phase of the grid potential is most effective in preventing frequency variation when the anode current is large relative to the current circulating in the anode oscillating circuit, it is evident that the amount of circulating current should be kept small by using a large inductance——capacity ratio.

It is also evident that the ratio of anode current to circulating current will be increased by increasing the load on the output circuit of the oscillator. This is an exceedingly fortunate circumstance because the aperiodic long line controlled oscillator has its constancy increased by increasing the load upon it whereas other types of oscillators must be run at very light loads followed by relatively great amplification in order to obtain frequency stability.

In Fig. 11-A there is shown a single tube aperiodic long line controlled oscillator in which undesired coupling between anode and grid circuits is eliminated by appropriate shielding and neutralizing of coupling through the interelectrode capacity of the tube. Desired coupling between anode and grid circuits for producing oscillations is obtained by joining them together through a long transmission line. In this circuit, provision is made for obtaining a constant effective load resistance in the grid circuit by employing a grid-leak source of biasing potential. The long line is then tapped on the grid circuit at such a point that the effective resistance presented to the line is equal to its characteristic impedance. Under this condition, there is practically no reflection from the end of the line and the electrical waves which are introduced from the anode circuit travel continuously from the input to output ends of the line and are absorbed by the grid circuit at the output end. As previously stated, the function of the line in this case is to control the phase of the grid excitation, with respect to the alternating-current anode voltage, in a way to oppose variations in frequency.

It is interesting to note that, in such an oscillator, the ratio of alternating anode current to the current circulating in the output circuit increases with increasing phase shift. As a result, the effectiveness of the long line in preventing frequency variation, increases on either side of the point of zero phase shift and the line is least effective at the point of maximum oscillator efficiency. Fig. 11-B shows qualitatively the way in which the line governs the frequency around the point of maximum efficiency.

Another interesting observation is that a line of a given length will hold the frequency of an oscillator to within about the same number of cycles of the correct value when the oscillator is operated at any frequency. This is because the number of waves on the line increases in proportion to the frequency and therefore its percentage accuracy of control increases in the same proportion.

Fig. 12 shows a circuit similar to that in Fig. 11 except that a screen-grid tube has been used in the oscillator. It has a practical advantage in that no neutralizing adjustment is required.

Obviously, the circuits of Figs. 11 and 12 can also be applied to push-pull oscillators and Fig. 13 illustrates one such circuit. The circuits shown in all three figures have been used experimentally with various modifications. For example, the circuits of Fig. 12 have been applied to development models of aircraft and marine transmitters and those of Fig. 13 have been successfully applied to a 40-kw short-wave transmitter used in a series of telephone experiments.

PRACTICAL TYPES OF LINES

(a) Open Wire Line

One of the most satisfactory types of line to use, where space is a small consideration, is a pair of bare copper wires similar to the lines used in connecting a transmitter to an antenna. These lines have quite low attentuation and a low characteristic impedance, both of which are advantages. If such a line is used for frequency control, it should be indoors and held reasonably constant in temperature. An outdoor line is not very satisfactory chiefly because of the effect of wind and rain on its electrical velocity.

(*b*) *Concentric Conductor Line*

Another very satisfactory type of line is one in which concentric conductors are used. In this type of line, the outer conductors may be kept at ground potential and serve as a shield for the inner conductor which carries the waves. Such a line may be folded up into a relatively small space and in this respect has many practical advantages. It is most suitable for application to a single tube oscillator.

(*c*) *Solenoid Lines*

A third type of line may be constructed by winding wire in the shape of a long solenoid. Such a line requires a relatively small amount of space, which is a great advantage where the amount of space available is limited. However, it has the disadvantage of a high characteristic impedance rendering it more difficult to apply to oscillator circuits in a satisfactory manner. This high characteristic impedance together with the necessity for some insulating support, also results in higher attenuation, limiting the maximum length of line which may be used. In designing solenoid lines, it is best to keep the diameter small in comparison with the length of waves on it or there may be difficulty due to reflection caused by rapidly changing characteristic impedance near the end terminals. This difficulty may be decreased by placing each terminal at a little distance in from the end of the winding.

(*c*) *Mechanical Lines*

The principle of long line control may readily be carried out by using mechanical waves together with means for converting electrical to mechanical energy and back again. For this purpose, we may use, as long lines, piezo-electric crystals or bars of magnetostrictive material. We may also use longitudinal, transverse, or torsional waves in any solid or liquid material with ordinary electromagnetic methods for converting the energy. In fact, the modifications of mechanical long line frequency control are remarkably numerous.

LONG LINE CONTROL WITH CRYSTAL OSCILLATOR MONITOR

It will be noted that the long electrical line is fundamentally a less satisfactory frequency standard than a piezo-electric quartz crystal and that it would not be practical to transport long line controlled oscillators between standardizing laboratories and operating stations. Consequently, it is believed that long lines cannot replace piezo-electric crystals as standards of frequency.

We may obtain the advantages in operation given by long line control, together with the ability to predetermine transmitter frequencies in the laboratory, if we use both devices in transmitting stations. This has been done experimentally with results which promise considerable commercial advantages.

The method which has been developed utilizes a crystal oscillator, with frequency multipliers, the output of which may be used for periodic or continuous comparison with the long line controlled transmitter. The power level required in this unit is quite low so that it may be made relatively small and inexpensive even though designed with extreme care to obtain and hold very exact frequencies.

CONCLUSION

Although it is too early to predict the extent to which long line control will be applied commercially, it seems apparent that its use can make possible a considerable saving in transmitter operating costs and an improvement in their reliability. At the same time, there should be no reduction in accuracy of frequency control and there may even be an improvement where crystal monitoring units are continuously used. In such instances, the long line may be utilized to prevent rapid frequency variations and the monitoring unit to hold the mean frequency extremely constant.

In the present types of crystal controlled transmitters, there is a tendency to operate the crystal oscillators at relatively high power levels to keep down the number of amplifier stages and this detracts from their ability to hold constant frequency. There is no need for doing this in the monitor units which will be used with long line controlled transmitters and their accuracy can therefore be improved.

ACKNOWLEDGMENT

In conclusion, we wish to acknowledge the services of Mr. O. E. Dow, Mr. T. J. Boerner, and Mr. G. E. Pray, who have spent considerable time on the development of the methods which have been described. We also wish to acknowledge the contribution made to the development by the Riverhead Receiving Laboratory of R.C.A. Communications, Inc., headed by Mr. H. O. Peterson, in furnishing one of the crystal monitoring units mentioned in this paper.

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SOME OBSERVATIONS OF THE BEHAVIOR OF EARTH CURRENTS AND THEIR CORRELATION WITH MAGNETIC DISTURBANCES AND RADIO TRANSMISSION*

By

Isabel S. Bemis

(American Telephone and Telegraph Company, New York City)

Summary—*This paper presents correlations between the abnormal earth currents noted during magnetic storms and transoceanic radio transmission on both long and short waves. The radio transmission data were collected on the telephone circuits operating between New York and London and between New York and Buenos Aires. The earth current data were collected on two Bell System lines extending approximately a hundred miles north and west from New York. The results of this work establish facts which have been known in a general way for some time.*

The direction of flow of abnormal earth currents in the neighborhood of New York seems to be along a northwest-southeast line. Coincident with such abnormal currents are periods of poor short-wave radio transmission. However, on long waves, daylight transmission over transatlantic distances is improved. On the short-wave circuit to Buenos Aires, transmission is adversely affected but only to a moderate extent.

IT HAS been known for several years that the facility with which radio transmission can be effected over considerable distances is somehow related to the occurrence of magnetic storms. It has been known for a very much longer time that associated with magnetic storms are still other phenomena, notably auroras and earth currents, which appear to be related to conditions on the sun.

Plausible theories for the magnetic and electric state of the earth frequently assume a more or less well defined conducting layer of high electronic content some 150 kilometers above the surface of the earth. This, of course, is equivalent to the so-called Kennelly-Heaviside layer used to explain certain characteristics of radio transmission. Convection currents in this layer are assumed to explain the diurnal variation of the earth's magnetic field and also similar variations in the normal currents flowing in the earth's crust. The abnormal variations in the earth's magnetic field commonly known as magnetic storms, are considered to be due to large changes in the ionic and electric content of the Kennelly-Heaviside layer, presumably produced by large influxes of either electrons or of ultra-violet light from the sun. These influxes supposedly extend over several days and may not be immediately

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* Decimal classification: R113.5. Original manuscript received by the Institute, April 14, 1931. Presented before Sixth Annual Convention of the Institute, Chicago, Illinois, June 4, 1931.

equalized. During the equalizing process, long period transients are set up in the layer which act inductively on the earth below.

In the Bell System's development of transatlantic telephony considerable correlation has been noted between radio transmission and magnetic storms. This work has covered a period of about seven years and has been reported from time to time.[1] About three years ago, the scope of this work was extended to include correlations with earth potential variations. This paper reports the more important results observed during this latter period.[2]

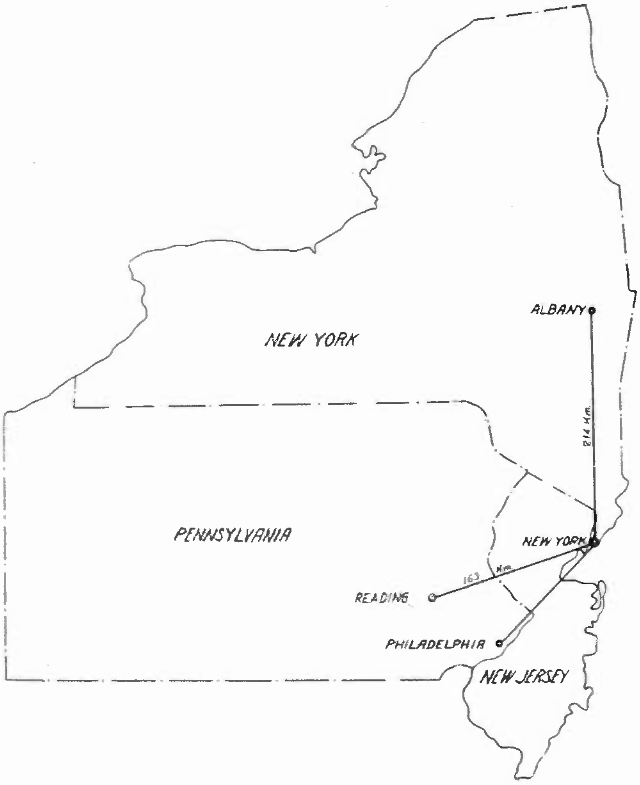

Fig. 1—Lines on which earth current observations were made.

As a first step in this investigation automatic voltage recording

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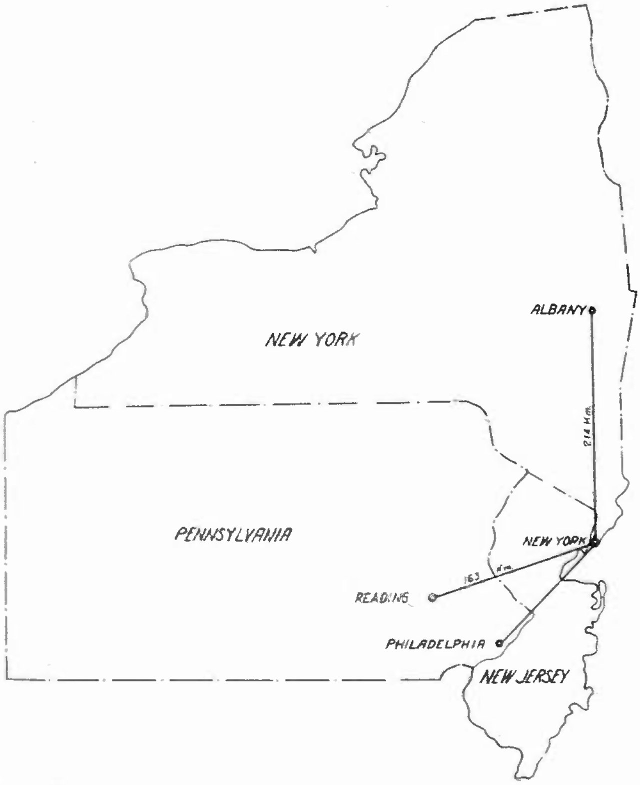

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equipment was connected to two grounded telegraph circuits, running from New York City to Reading, Pennsylvania, and from New York City to Philadelphia. About a year later the New York-Philadelphia circuit was changed to New York-Albany to give a more nearly north-south connection (Fig. 1). Earth current and radio phenomena, like many others of this kind, require a large amount of data extending over long periods of time for purposes of correlation. In view of the relatively short period covered by this report, it should be considered only as a statement of progress and not the final summary of a completed study.

The voltages set up in the two circuits are recorded by an Engelhard double recorder having a resistance of approximately 192,000 ohms which is alternately connected to the two circuits by an automatic switching device. The voltages on the Reading circuit are indicated in red and those on the Albany circuit in black, so that the two may be compared. A record is made on the same circuit every 20 seconds.

In Fig. 2 is shown a sample chart obtained by the recorder during the early part of July, 1928. At the left the record may be regarded as practically normal, the small variations being due to stray currents such as those caused by trolleys. On a normal record there is a quiet period early in the morning when commercial activity has ceased which lasts from about 1:00 A.M. until 5:00 or 6:00 A.M. E.S.T., after which the small variations begin to appear again. On July 7, abnormal earth currents began about 6:00 P.M. E.S.T., and by 9:30 P.M. the disturbance was so severe as to cause the pointer to be deflected off the scale. This was the most active "storm" included in this study and was accompanied by magnetic and auroral disturbances over a large part of the earth.[3]

When an earth current disturbance begins, the earth potentials reverse in direction at periods varying from a few minutes or even seconds to a few hours. In some cases, the deflections appear intermittently all day even though the voltages may be small, while in others they last only for a short time on several successive days with quiet periods between. In the abnormal period, from July 7–10, 1928, the record was continuously disturbed from 6:00 P.M. on July 7 until 10:00 A.M. the following day and on the two successive days for periods of a few hours, finally becoming quiet on July 11.

A typical record for a moderate disturbance is shown in Fig. 3. In this case, abnormal voltages appeared on July 31, and ended on August 2, 1929. The first indication of unusual earth current activity was

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[3] See *Terr. Mag.*, 33, 167–169; September, 1928, and 257–259; December, 1928.

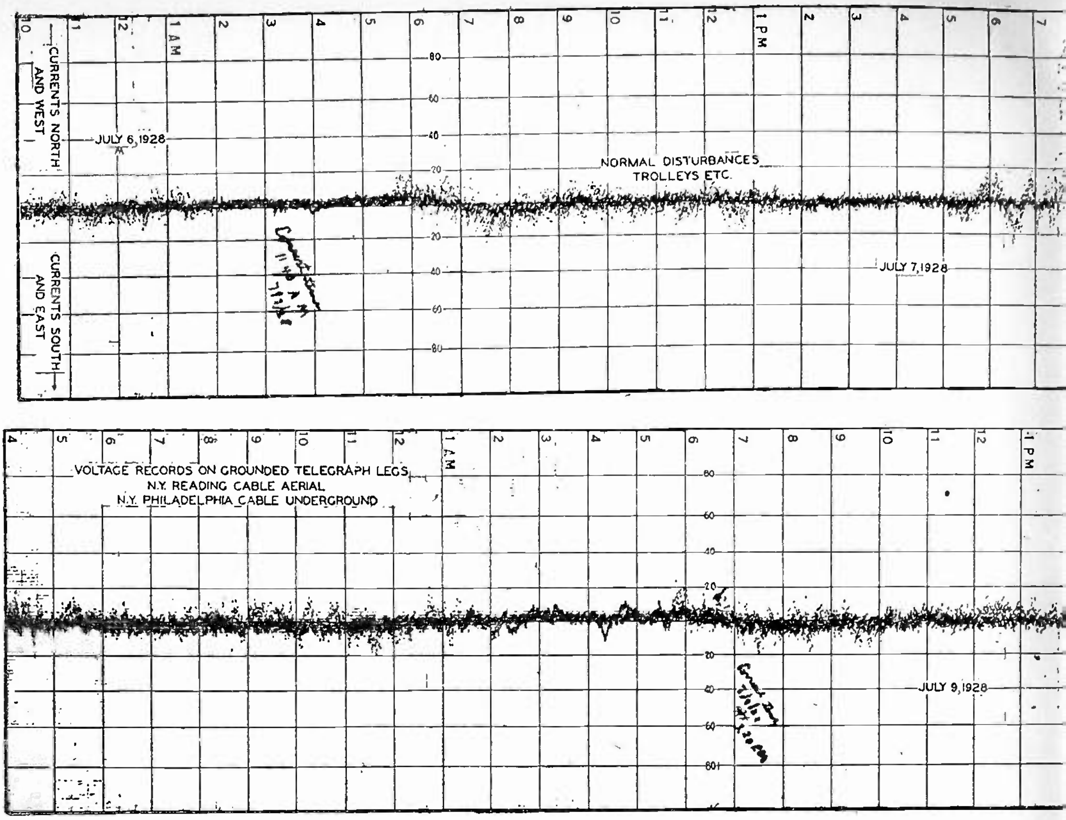


Fig. 2—Voltage record obtained on grounded telegrap

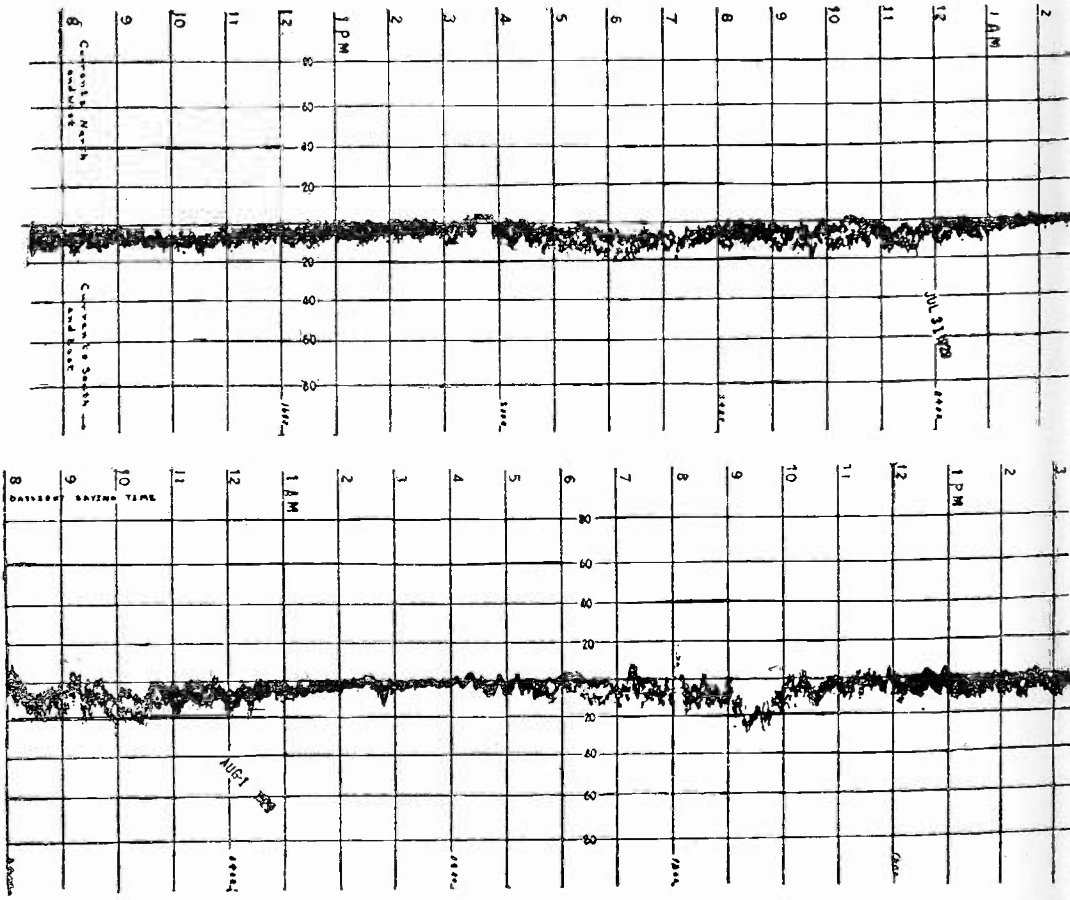
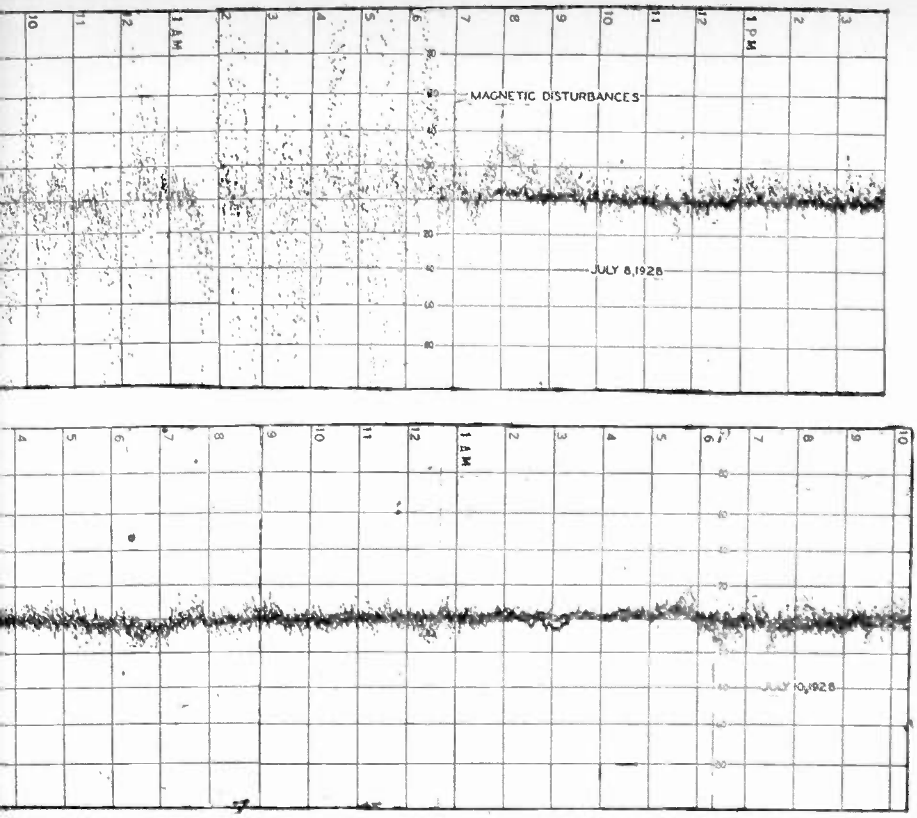
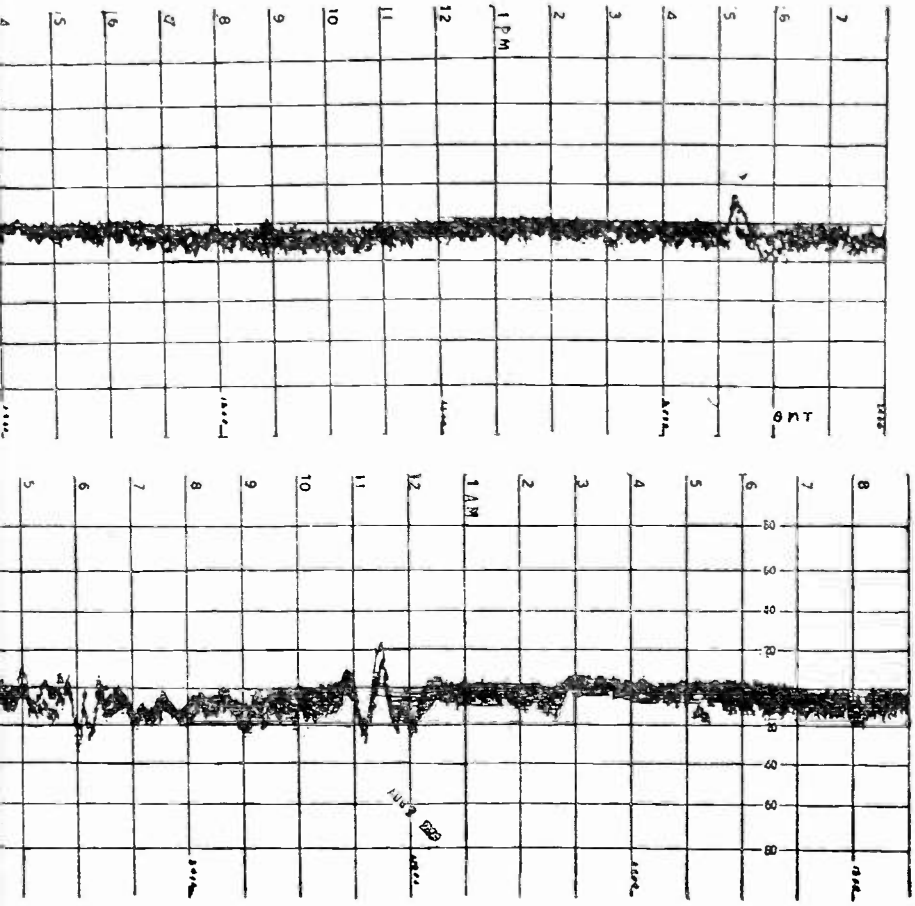


Fig. 3—Voltage record obtained on grounded telegraph



its near New York, N. Y., in July, 1928.



its near New York, N. Y., in August 1929.

where the volt-hour is the product of the average deflection in volts (all taken in a positive sense) times the number of hours it lasted.

It will be seen that all the major variations and some of the minor ones in the magnetic curve are accompanied by earth current disturbances. However, on some of the days when only small peaks in magnetic character occurred, for example, April 4, 1929, there was no apparent increase in the earth potential on the two lines under observation. It should be noted, also, that the amplitudes of the two curves do not entirely agree. While days of major magnetic activity (above

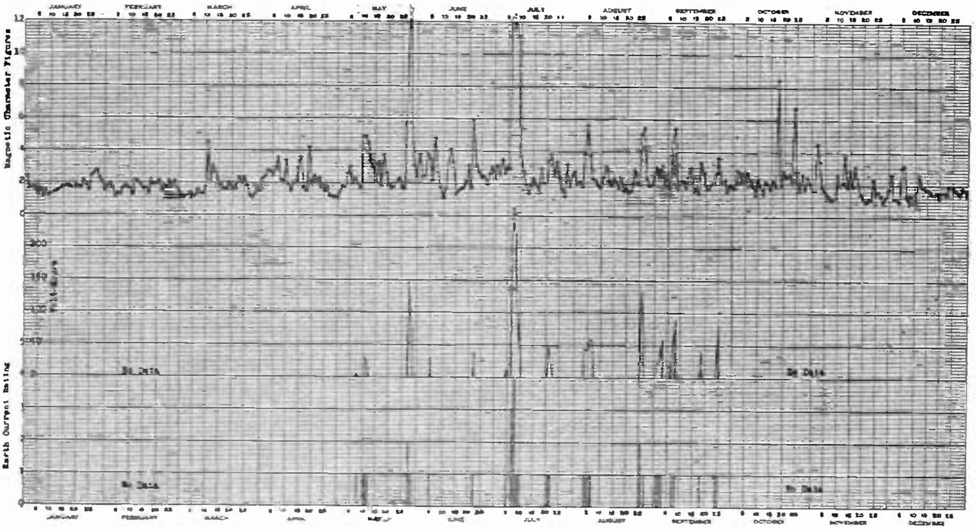


Fig. 5—Variation of magnetic and earth current data—1928.

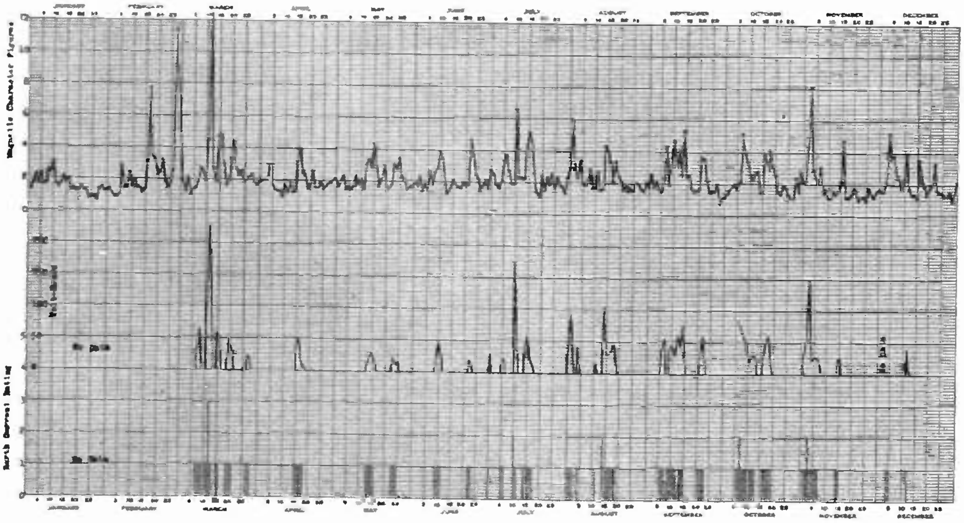


Fig. 6—Variation of magnetic and earth current data—1929.

six) are invariably accompanied by a major disturbance of earth currents, on the days of lesser magnetic activity (four to six) the earth current variations may run from 20 to 150 volt-hours. Similarly the volt-hour figures for the storm of May 28, 1928, are only slightly higher than those for August 26, 1928, though there was a large change in the magnetic activity. The disturbance on December 4 and 5, 1929, was probably of a higher rating than one, but as the recorder was not working continuously we have no knowledge of the magnitude of the activity and the rating serves merely to indicate that there were abnormal earth currents at that time.

It should be noted also in passing that the number of disturbed days per month in both the earth's magnetic field and earth currents vary considerably from year to year. In the five months for which we have data in 1928 there were three days on which over 100 volt-hours were obtained. During the same months of 1929 there were only two days with over 100 volt-hours but there were one and a half times as many days of moderate disturbances. In 1930 there were seventeen days of over 100 volt-hours and four times as many moderately disturbed days as in 1928 for the same period.

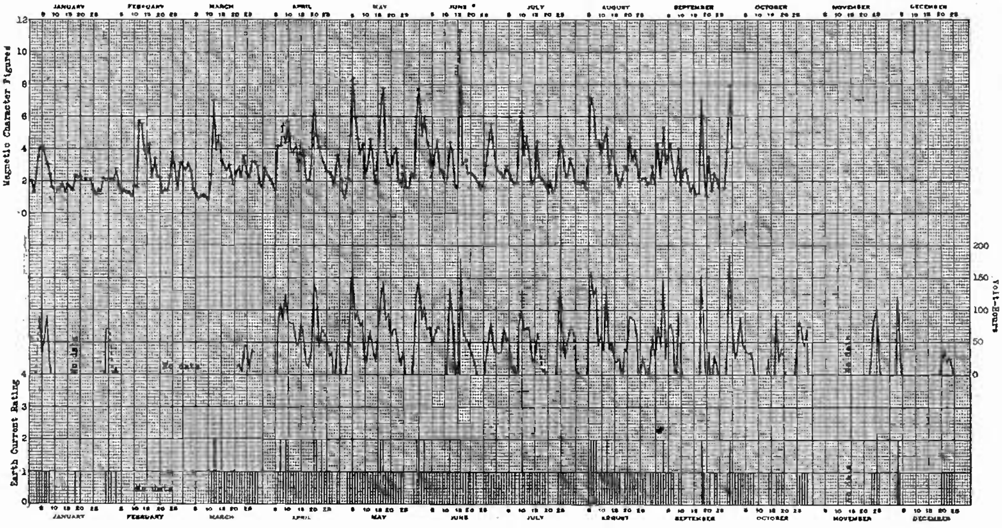


Fig. 7—Variation of magnetic and earth current data—1930.

Fig. 8 shows the similarity of behavior of earth current variations and magnetic character for several days preceding and following the day of maximum disturbance. For convenience, on days when there were no abnormal earth current variations the volt-hours are regarded as zero. The curves for three storms are considered, two severe ones of July 8, 1928, and March 12, 1929, and one minor disturbance of August 26, 1928. The solid lines indicate the variation of the magnetic character and the dashed lines the earth potentials. Small differences in the magnetic character curve are normal variations from day to day and do not denote storms in all cases

The curves for March 12, 1929, show three groups of disturbed days with the beginning of a fourth. The two curves follow each other almost exactly. This is true also of the curves for July 8, 1928. In the case of August 26, 1928, the peak in the abnormal earth potential came one day before that of the magnetic character but both were back to normal on the same day.

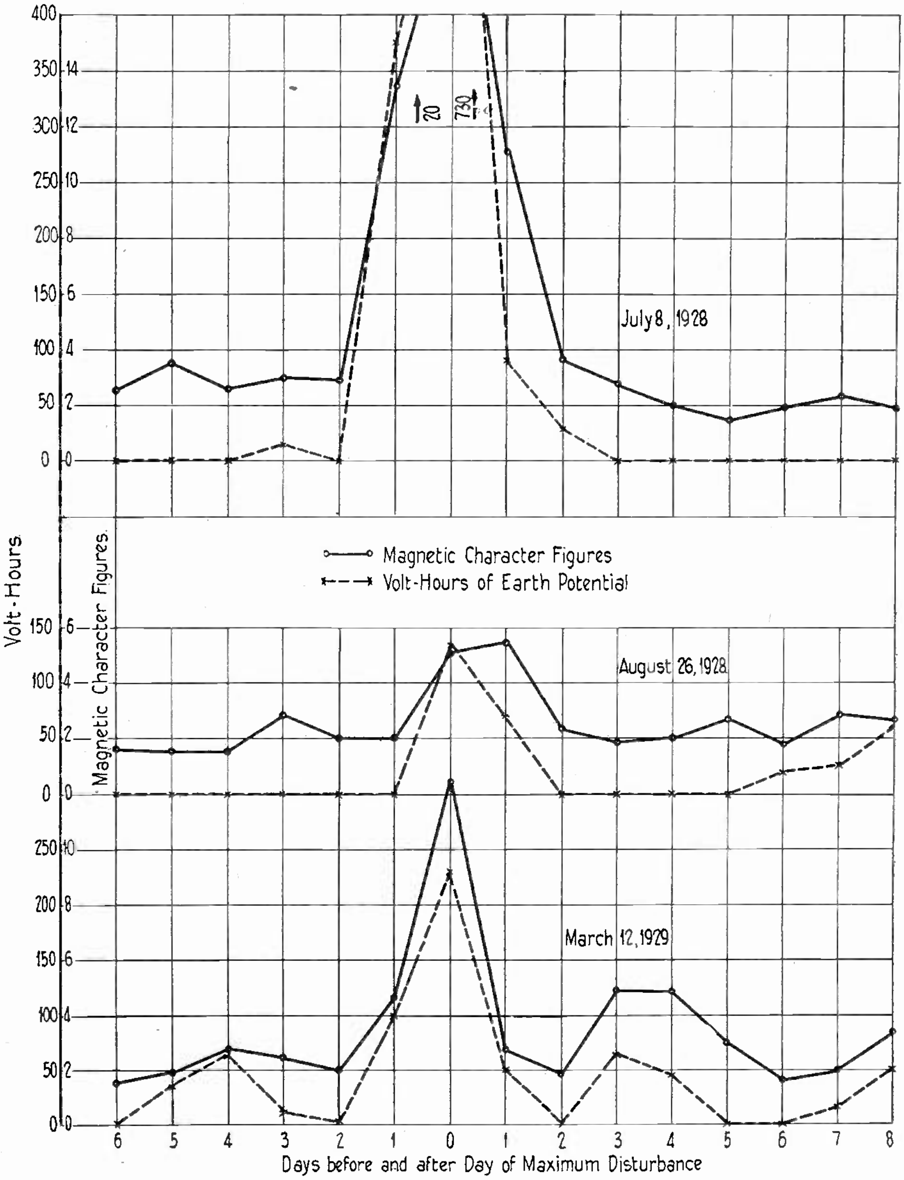


Fig. 8—Comparison of earth potential and magnetic variations before and after the day of maximum disturbance.

It is interesting also to compare the hourly course of the variations of earth potential and magnetic activity. For this purpose the same group of storms centering around March 12, 1929, was chosen. But in this case the variations of the horizontal intensity (in gammas) of the earth's magnetism as measured at Cheltenham, Maryland, are used for comparison (Fig. 9).[7] March 10 can be considered as a normal day. The horizontal intensity drops to a minimum around 11:00 A.M. and noon and rises to its previous level in the late afternoon. The earth current record shows very little deflection from 2:00 A.M. until 5:00 A.M. At 6:00 A.M. there begins to be some scattering of the points from stray currents of commercial origin which lasts until commercial traffic lessens sometime after midnight. The values of earth potential are the peaks which occurred in each direction during periods of one hour beginning with midnight. Positive values denote currents in the wire line directed toward New York and negative values those away from New York. The sharp peaks at 5:00 A.M. and 9:00 A.M. on March 11 mark the beginning of abnormal earth currents. After this there was a lull until 10:00 P.M. when the agitation of the recorder needle increased and continued off and on all the next day. It should be understood

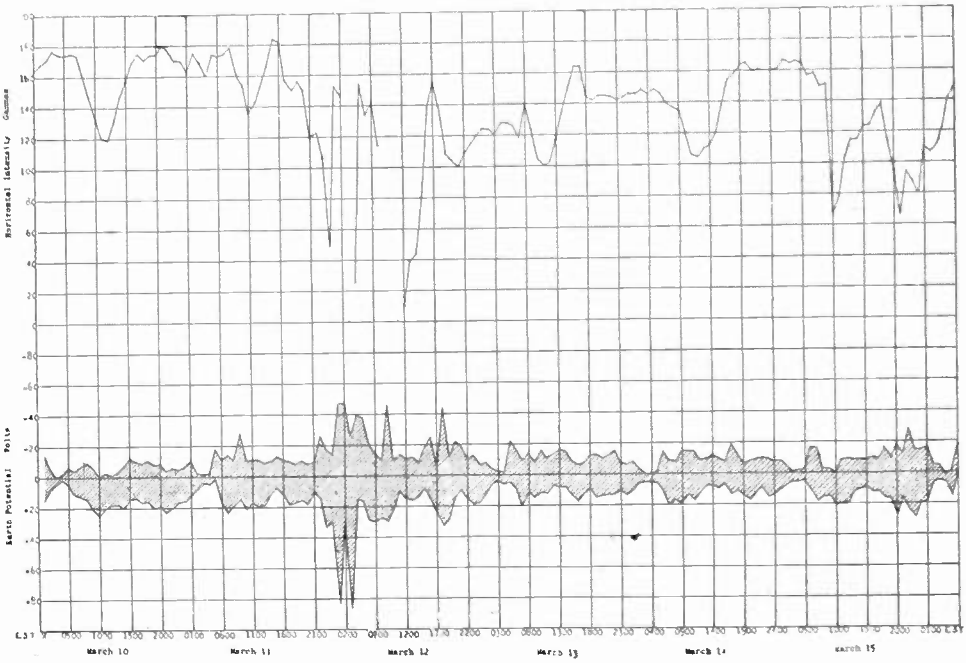


Fig. 9—Comparison of the behavior of the horizontal component of the earth's magnetic field as measured at Cheltenham, Md., and earth potential at New York, N. Y.

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[7] Magnetic data were very kindly supplied by the U. S. Coast and Geodetic Survey, Washington, D. C.

that the diagram is not an actual plot of the record obtained but merely represents the range through which the variations fluctuated. The deflection may be at the peak in one direction at a certain time and ten minutes later reach the peak in the opposite direction. Throughout the disturbance there is a continual swinging back and forth between the limits indicated. The horizontal intensity of the earth's magnetic field apparently began to be disturbed slightly before unusual activity in earth currents was noted but the two became quiet at about the same time. On March 15, a second disturbance started as is shown by the increased variation in the two curves.

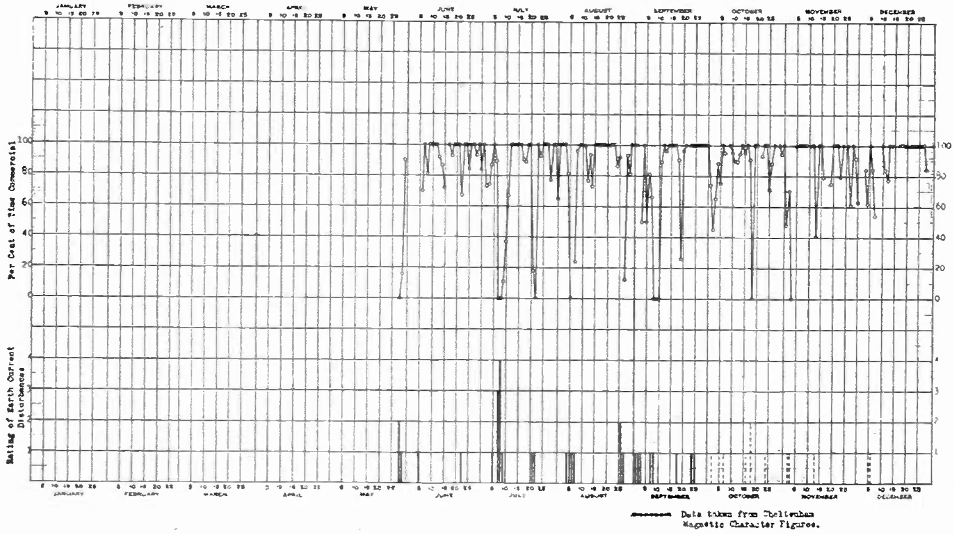

Fig. 10—Correlation of commercial circuit time on the New York to London 18-megacycle channel with earth current disturbances—1928.

In the majority of cases the first appearance of unusual earth current activity in our records takes place in the late afternoon and early evening or in the early morning. In only four cases out of 36 do we find the disturbance beginning at any other time. This is also true for the reappearance of earth currents on successive days. They usually begin at night and die out around 5:00 A.M. and do not reappear until late afternoon or early evening. This is in general agreement with Maunder's times of beginnings of magnetic storms as recorded by Chree.[8]

RELATION BETWEEN DAYS OF ABNORMAL EARTH CURRENTS AND RADIO TRANSMISSION

In Figs. 10 and 11 are shown the percentage of commercial time, which has been obtained during the normal operating period on one of the 18-megacycle transatlantic radio channels from west to east, to-

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[8] C. Chree, Studies in Terrestrial Magnetism, 1912.

gether with the rating of earth current disturbances for 1928 and 1929. These indicate quite clearly that, in the majority of cases, days of poor transmission coincide with days of abnormal earth currents. Apparently short-wave radio transmission is as seriously affected at times when minor earth currents appear for several days as in the period beginning August 4, 1928, as it is when the earth current disturbance is very severe, July 7, 1928. The disturbance of October 18, 1928, which lasted just one day, shows plainly the effect on radio transmission of an upset in the earth's magnetic elements. The radio circuit was commercial 90 per cent of the time on the day before the storm, was zero per cent on the day of the storm, and 100 per cent on the day following. Although short-wave radio transmission is so adversely affected at times of earth current storms, it should be noted that only a few of such storms are of sufficient intensity to affect materially the operation of grounded telegraph circuits.

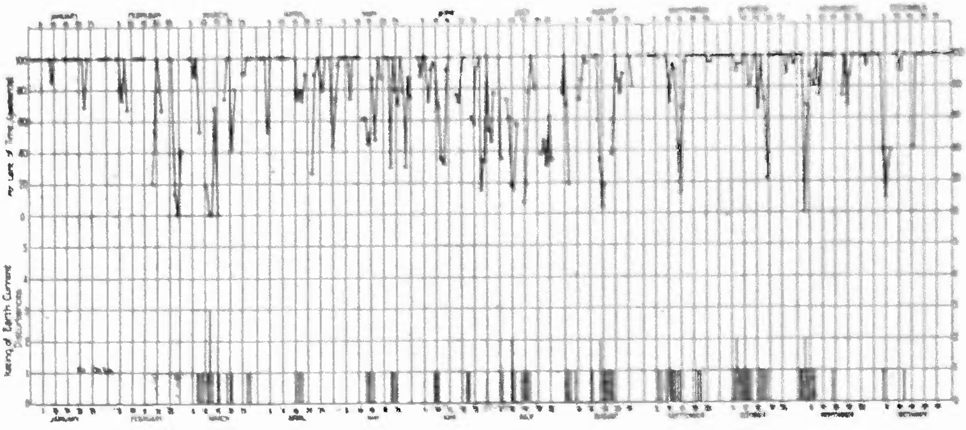

Fig. 11—Correlation of commercial circuit time on the New York to London 18-megacycle channel with earth current disturbances—1929.

The effect on daylight long-wave fields, when received over transatlantic distances at times of magnetic and earth current disturbances, appears to be the opposite of that on short waves as indicated by Figs. 12 and 13. Here we have moving averages of the field strength of radio signals on both long and short waves plotted with the rating of earth current disturbances and magnetic character figures. The long-wave field strengths are those of radio signals from Rocky Point, Long Island, on a frequency of 60 kilocycles as measured at Cupar, Scotland.[9] The 18-megacycle fields from Deal, New Jersey, were received at New Southgate, England. In general, the effect of magnetic disturb-

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[9] Measurements of the long-wave field strengths throughout this period were supplied by the British General Post Office.

ances is to increase the long-wave daylight fields for several days following the storm, while the short-wave fields are decreased at the time of the storm and gradually return to normal. This is in agreement with the results of others.[10] In examining the figures, it should be noted that the average fields on long waves were high in the summer and fall months of 1928, when the magnetically disturbed days were more numerous and decreased in the winter months, becoming high again in February and March, 1929, with a fresh outbreak of disturbances. This was followed by a gradual lowering of the fields until July when they began to climb again in agreement with the increase in the number of magnetically disturbed days.

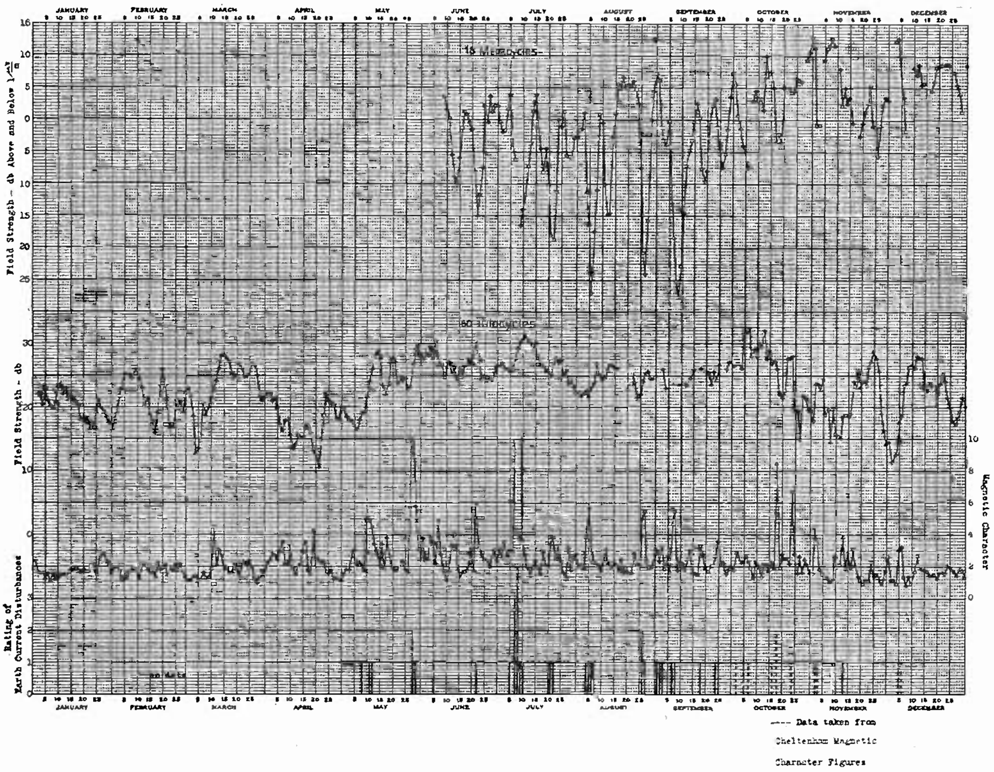

Fig. 12—Variation of field strength of radio signals, magnetic character figures, and earth current disturbances—1928. 18-megacycle signals from Deal, N. J., were measured at New Southgate, England. 60-kilocycle signals from Rocky Point, L. I., were measured at Cupar, Scotland.

Superposed on the individual storm effects on short waves is a long gradual swing. The average fields are low in the summer months and high in the winter months reaching a maximum in January. This appears to be independent of the number of disturbed days.

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[10] C. N. Anderson, "Notes on the effect of solar disturbances on transatlantic radio transmission," Proc. I.R.E., **17**, 1528–1535; September, 1929; I. J. Wymore, "The relation of radio propagation to disturbances in terrestrial magnetism," Proc. I.R.E., **17**, 1206–1213; July, 1929.

The typical effect of individual storms on short-wave field strengths is shown in Fig. 14 for two periods of disturbed days, July 8, 1928, and August 26, 1928. This gives the average daily deviation of the field strength above and below the monthly average field strength for a period of five days before and after the day of maximum earth current variations. The August disturbance lasted for parts of two days, dying out at 6:00 A.M. on the second day. The radio transmission was poor for three days and reached a value above the average the second day after the abnormal earth currents ended. In the July case the earth current disturbance lasted for four days and the radio transmission took a more gradual return to normal. In all cases, the immediate effect accompanying disturbed days is a lowering of the field strengths on short waves oftentimes beyond the limit of measurement. For the July case the scale of the volt-hours was reduced in order to bring the peak of the curve within the limits of the figure.

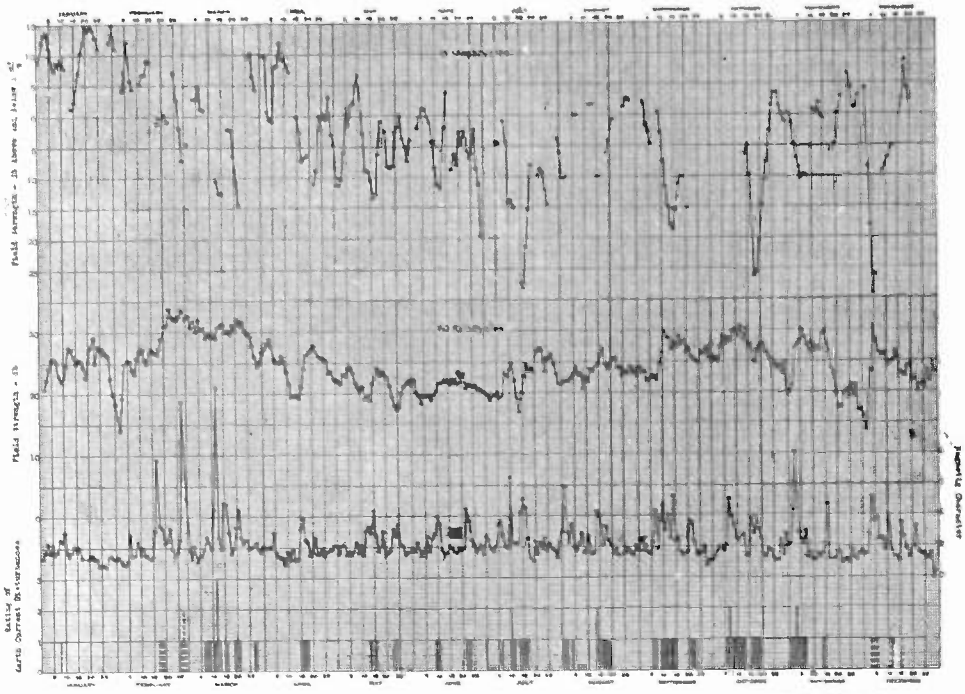

Fig. 13—Variation of field strength of radio signals, magnetic character figures, and earth current disturbances—1929. 18-megacycle signals from Deal, N. J., were measured at New Southgate, England. 60-kilocycle signals from Rocky Point, L. I., were measured at Cupar, Scotland.

A more general curve of the behavior of short-wave radio transmission occurs in Fig. 15. This is the same kind of data as plotted in Fig. 14, but is an average for several groups of magnetically disturbed days.

The dashed curve represents the average variation of short-wave field strength for a period of days before and after nine minor earth current disturbances, that is, disturbances with a rating of one. The solid curve is the average for eight disturbances with a rating of two or over. In both cases the disturbed days have been chosen so that they were not preceded by an abnormal period which might influence the values of the field strength. In all cases the zero day is that of maximum variation of earth currents. During both moderate and severe disturbances

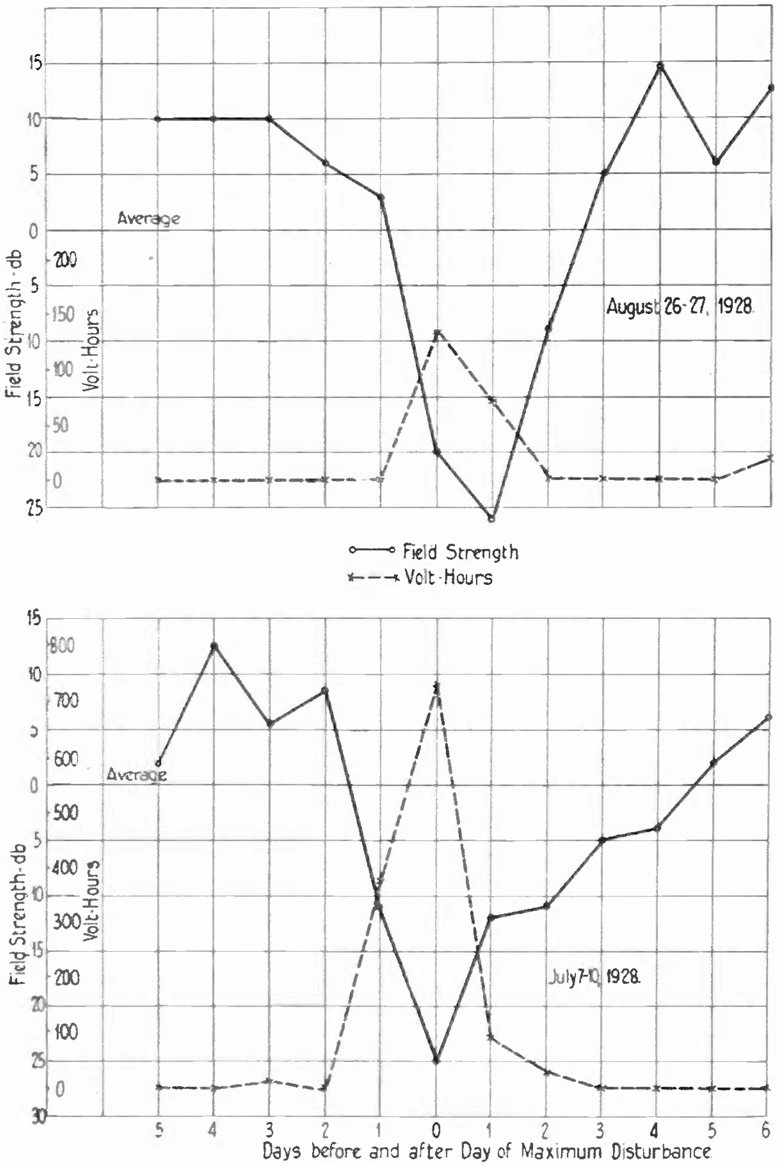

Fig. 14—Typical examples of the behavior of 18-megacycle field strengths between New York and London at times of earth current disturbances.

the field strength drops to a minimum on the day of maximum earth current activity but for moderate disturbances the recovery is more rapid, the fields being above the average by the fourth day after the storm while the second and third days after are only slightly below the average. For major disturbances, however, the minimum is lower and the recovery more gradual, the fields not reaching above the average until the sixth day. It should also be noted that four days before a major disturbance there is an unusually high value of field strength. This is apparently not the case with minor disturbances. As more data are accumulated we shall be better able to judge whether this is really significant.

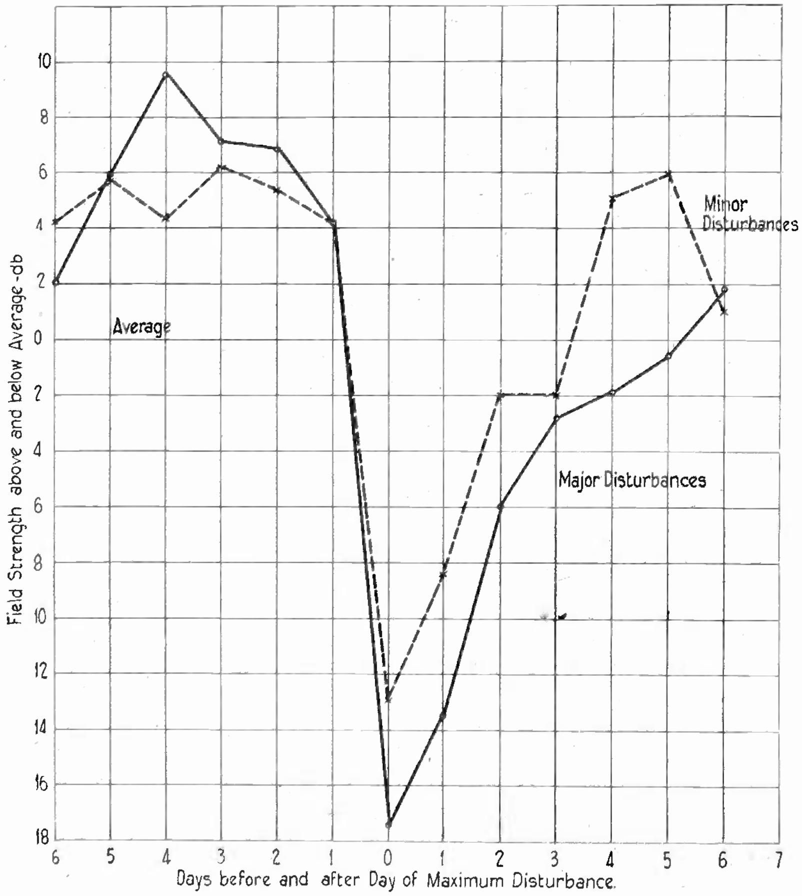

Fig. 15—Average behavior of 18-megacycle field strengths between New York and London during major and minor disturbances of earth potential.

Approximately a year ago field strength measurements were begun on a radio circuit from Hurlingham, Argentina, to Netcong, New Jersey. From the available data it appears that the South American circuit is not so seriously affected at times of earth current disturbances as the transatlantic circuits. Figs. 16 and 17 give the percentage of commercial time for 1930 on the short-wave radiotelephone circuits to Europe and South America. The curve for the circuit to Europe gives for each day the percentage of time one channel was commercial in both directions on any of the short wavelengths and shows very few days during the year when there was a commercial short-wave circuit 100 per cent of the time. This shows quite clearly the effect of changes in the transmission medium as evidenced by the appearance of abnor-

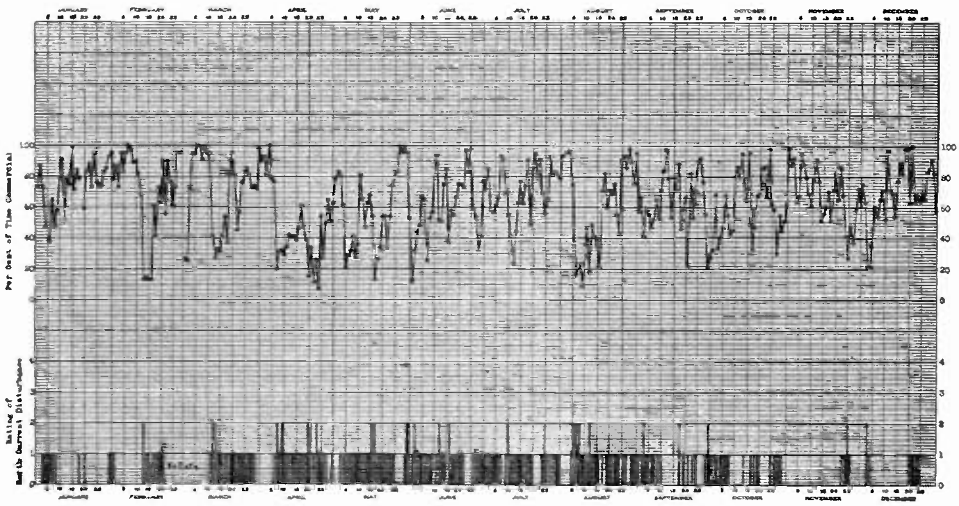

Fig. 16—Correlation of commercial circuit time on one New York to London short-wave channel with earth current disturbances—1930.

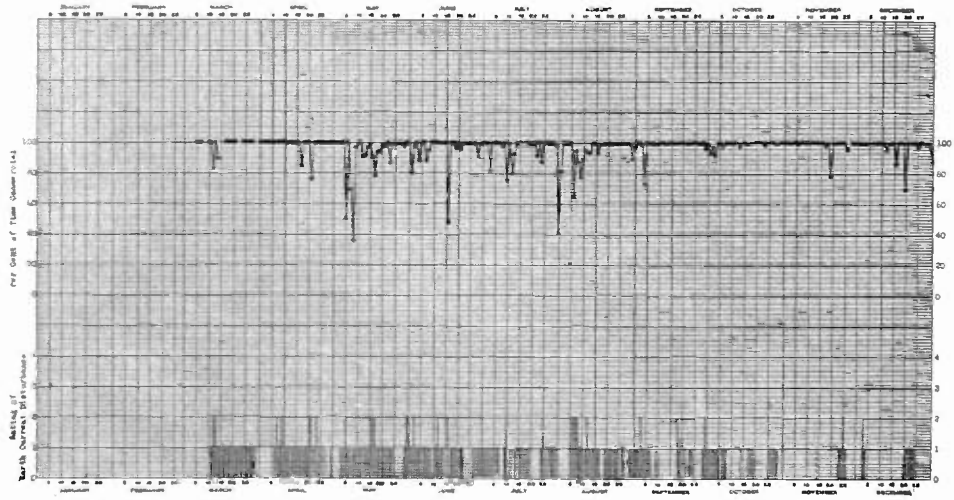

Fig. 17—Correlation of commercial circuit time on the New York to Buenos Aires short-wave channel with earth current disturbances—1930.

mal earth currents. On the other hand, the percentage of commercial time two ways on the circuit to South America was not affected by magnetic and earth current disturbances to such an extent as the transatlantic circuits. There were only seven days during this period on which the circuit was commercial less than 70 per cent of the time.

This difference in reception from different directions has also been noted by Marconi[11] who says that "it frequently occurs that when the Canadian communication fades out for some hours on end, the other services to Australia, India, and South Africa, which use similar wavelengths, continue working with undiminished efficiency."

From the data so far examined it appears that there is a definite relation between abnormal earth current disturbances and variations in magnetic phenomena and radio transmission. This would suggest that they are all effects of the same cause. The most important tendencies of earth currents indicated so far are: that they tend to oscillate along a line approximately northwest-southeast in the vicinity of the lines under observation; that abnormal earth currents occur simultaneously with unusual disturbances of the earth's magnetic field and in some cases at least occur simultaneously and flow in the same direction at remote points on the earth; and that the first appearance of unusual earth current activity is in the early evening or early morning. The correlation of radio transmission with abnormal earth currents shows days of poor transmission on short wavelengths coinciding with days of abnormal earth currents while the opposite effect is obtained on daylight long-wave circuits over transatlantic distances. On the other hand short-wave circuits to South America are not so seriously affected as the transatlantic circuits. However, further study will be required to confirm the tendencies indicated.

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[11] G. Marconi, "Radio communication," PROC. I.R.E.. 16, 40–69; January, 1928.

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DEVELOPMENT OF A CIRCUIT FOR MEASURING THE NEGATIVE RESISTANCE OF PLIODYNATRONS*

By
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Summary—*Pliodynatron oscillators are assuming greater importance in engineering work. As the value of the negative resistance of a tube having dynatron characteristics is a measure of its utility it was necessary to design a test circuit which would quickly and accurately measure this property without recourse to the older and more laborious method of plotting the E_p-I_p curve of the tube and calculating its negative slope over the operating range. The test circuit is an adaptation of the Wheatstone bridge.*

THE term "pliodynatron" has been applied to tubes having dynatron characteristics in which a control grid has been placed between the filament and the other elements in order to control the negative resistance characteristic. Thus any screen-grid tube in which the screen grid is held more positive than the plate and the control grid used to regulate the negative resistance, may be called a pliodynatron.

A. W. Hull has shown[1,2] that, for a dynatron oscillator to operate, the numerical value of negative resistance of the tube must be equal to or less than the apparent parallel resistance of the tuned circuit to which it is connected, that is: $-R=L/CR$ or $-R<L/CR$. From these simple and interesting relations it is seen that an accurate knowledge of the negative resistance of the tube presents a means of easily measuring the resistance of tuned circuits, of rating the tubes according to their utility as dynatron oscillators, and of determining many other interesting factors.

In the past, it has been general practice to plot the E_p-I_p curves of each tube for various screen- and control-grid potentials and to calculate the negative resistance of the tube from the slope of tangent to the curve at the operating point, or from the slope of the chord of the curve over the operating range. This method is very slow, most laborious, and not particularly accurate.

As a first attempt to facilitate this measurement, a microammeter shunted by a bucking battery was placed in the plate circuit of the pliodynatron. The plate voltage was varied by small increments and resulting current change was measured. This method proved to be im-

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* Decimal classification: R262.9. Original manuscript received by the Institute, May 6, 1931. Revised manuscript received by the Institute, June 30, 1931.

[1] A. W. Hull, Proc. I.R.E., 6, 5; February, 1918.

[2] A. W. Hull, E. F. Hennelly, F. R. Elder, Proc. I.R.E., 10, 320; October, 1922.

practical because of the instability of the plate current. In order to overcome this difficulty, the subject test set was devised to operate in such a manner that the unstable plate current was no longer a factor in the measurement.

The complete test circuit is shown in Fig. 1. A small 500-cycle generator (G) develops an a-c potential across the resistors *ba* and *db*. At the instant that point *b* is more positive than point *a*, the drop across the resistor *ba* causes a slight increment in applied plate potential. Due to the dynatron effect an increment in plate potential causes a decrement in plate current. This decrement in plate current develops a potential across the resistor *cb* such that *c* is positive and *b* is negative. At this instant, however, the same generator current which caused *b* to be positive with respect to *a*, has caused *d* to be positive with respect to *b* and the value of the resistance *cb* may be adjusted so that the potential developed across it just balances the potential developed across *db* and no signal will be heard in the phones.

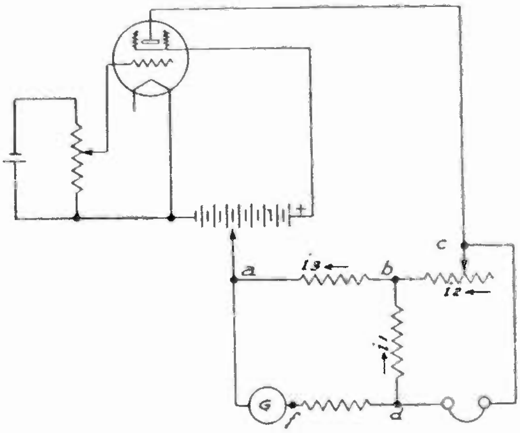

Fig. 1

At the balance it is evident that:

$$i_1 R_{db} = i_2 R_{cb} \tag{1}$$

also,

$$(i_1 + i_2) R_{ba} + i_2 R_{cb} + (-R) i_2 = 0 \tag{2}$$

where

R = negative resistance of the tube

then,

$$i_1 R_{ba} + R_{ba} \left(\frac{R_{db}}{R_{cb}} \right) i_1 + i_1 R_{db} + (-R) \frac{R_{db}}{R_{cb}} i_1 = 0 \tag{3}$$

or,

$$R=\frac{R_{ba}}{R_{db}}\times R_{cb}+[R_{ba}+R_{cb}]. \tag{4}$$

It will be noted that the resistance of the generator R_{fd} does not enter into the final equation (4) and therefore has no other effect on the measured value of negative resistance than to modify the output potential of the generator. The measured value of negative resistance is dependent on the generator potential only in so far as the chord of the portion of the dynatron curve covered by the generator potential differs in slope from the tangent to the curve at the center of the portion covered.

In practice, the generator potential need only be sufficient to produce a sharp minimum signal in the phones at the balance point. When using a two-stage amplifier in connection with the phones, a generator potential of 0.25 volt is ample.

A possible ratio for R_{ba}/R_{db} is 100/1 and (4) becomes

$$R=100\ R_{cb}+100+R_{cb}$$

A ratio giving a more simple solution is 99/1 in which case (4) becomes

$$R=99\ R_{cb}+99+R_{cb}$$

or,

$$R=100\ R_{cb}+99 \tag{5}$$

A decade resistance box may be used for R_{cb}.

For precise measurements, the negative resistance is given by (5) but in practice the last term is usually neglected.

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METHODS FOR MEASURING INTERFERING NOISES*

By
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Summary—*This paper outlines various methods of measuring interference, particularly in radiotelephony, which have been found useful in the Bell System.*

A NUMBER of different methods for measuring interference have been developed, several of which are summarized below. The choice of the method to be used in any particular case appears to depend upon the character of the interference, whether steady or irregular in character, upon the type of signaling which is interfered with; i.e., telegraph, telephone, television, etc., and upon the conditions under which the measurement is made. The purpose for which the information is to be used is of importance too, since noise data of a kind very useful in practical circuit operation might be of little value, for example, in scientific studies of static.

The following is a résumé of some of the various methods of measuring noise which the Bell System has found useful in telephone work. Some of these are especially applicable to radiotelephony, while others are of more general utility.

"WARBLER METHOD" FOR MEASURING NOISE

This method was developed in connection with work on long-wave single side-band telephony. The apparatus involved is described in a paper by Bown, Englund, and Friis.[1] The use of the method is discussed in a paper by Espenschied, Anderson, and Bailey.[2] The method consists in introducing into the antenna of a field strength measuring set a local signal of adjustable amplitude whose frequency traverses a narrow range of a few hundred cycles back and forth at the rate of several times per second. This frequency together with the static is heterodyned down to voice frequency in the measuring set so that the two are heard together. Measurement consists in reducing the amplitude of the tone until it can scarcely be recognized in the presence of the static. Under this condition the equivalent field strength of the tone as determined from the calibration of the measuring set is a

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* Decimal classification: R270. Original manuscript received by the Institute, May 9, 1931. Delivered at a meeting of the American Section of the U.R.S.I., May 1, 1931, Washington, D. C.

[1] Bown, Englund, and Friis, "Radio transmission measurements," PROC. I.R.E., **11**, 115; April, 1923.

[2] Espenschied, Anderson, and Bailey, "Transatlantic radiotelephone transmission," PROC. I.R.E., **14**, 7; February, 1926.

measure of the amplitude of the static, expressed in microvolts per meter.

This method has been found very useful for studies of static, particularly for the comparison of the directive effectiveness of various types of antenna systems in reducing static.

USE OF TRANSMISSION MEASURING SET FOR MEASURING NOISE

The warbler method is inherently limited to the case where the operator is present at the receiving station. In long-distance point-to-point radiotelephone circuits it is important to measure the noise from the radio link as received at the central terminal point. To do this we have found it convenient to employ a transmission measuring set of a kind which is widely used in the Bell System plant for measuring repeater gains and circuit losses. This instrument in effect consists of a variable attenuator and a vacuum tube voltmeter equipped with an indicating instrument having a moderately sluggish needle. A description of measuring sets of this kind will be found in a paper by F. H. Best.[3] This type of measurement is, of course, much better adapted for the purpose of adjusting and maintaining radiotelephone circuits than it is for scientific studies of static as such.

OBSERVATIONS OF SHORT-WAVE STATIC

With the development of short-wave radiotelephone circuits there has come a need for a method of measuring static for the same purposes as the warbler method is employed on the long waves. No established practice has been developed but the following method has been found valuable. This method employs the short-wave field strength measuring set which has been developed by the Bell Telephone Laboratories. It consists in adjusting the gain of the measuring set to a point where individual static crashes produce definitely readable peaks on the output indicating meter. The operator records the amplitudes of all individual readable peaks over a period of one minute. The average of the 10 highest peaks during this period is taken as the net reading. The method is, of course, highly empirical since it depends upon the selectivity and overloading characteristics of a particular receiving set and the dynamic characteristics of a particular indicating instrument. It has been found very useful for comparative purposes, however, where these instruments are available. A description of the field strength measuring set employing these measures will be found in a paper by H. T. Friis and E. Bruce.[4]

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[3] F. H. Best, "Measuring methods for maintaining the transmission efficiency of telephone circuits," *Jour., A.I.E.E.*, 43, 136–144. February, 1924.

[4] H. T. Friis and E. Bruce, "A radio field-strength measuring system," PROC. I.R.E., **14**, 507; August, 1926.

INTEGRATION METHOD OF MEASURING STATIC

Methods have been developed for integrating static impulses over short intervals of time, and for recording or observing these integrated values. One such method which employs a fluxmeter is described in a paper by H. T. Friis.[5] In another method of this type which has been used to some extent, the static impulses are made to charge a condenser having resistance in series. The condenser is then discharged at short intervals to provide the desired indication.

DIRECTIVE NOISE MEASUREMENTS

In connection with studies of the effectiveness of directive antennas in reducing noise from static, particularly on long waves, the direction of arrival of static impulses is of great importance. We have found it desirable to set up a direction finding arrangement whereby the direction of arrival of individual static crashes can be observed. This matter is discussed in two papers by A. E. Harper.[6] The static crashes are viewed on a cathode ray tube screen laid out somewhat like a compass screen. Statistical data from such measurements have been quite useful in antenna design and may be of some possible value in connection with weather reporting.

NOISE STANDARD OR BUZZER METHOD

A method which has been widely employed in the past for measuring noise on telephone circuits, but which is gradually being superseded by other methods, consists in the use of a buzzer, whose output is rich in harmonics extending through the voice frequency range, and which has a shunt arranged so that the amount of this output delivered to a telephone receiver can be varied. The measurement consists in adjusting the shunt until the noise from the buzzer is judged to be equal in interfering effect to that being measured. This method is, of course, more adaptable to measuring steady noises than intermittent noises.

CIRCUIT NOISE METER

There has recently come into use a type of instrument in which an attempt is made to secure direct readings of circuit noise in terms of its effect on telephone service. This instrument, which has been called a "circuit noise meter," consists of an amplifier, a frequency weighting network, a rectifier, and an indicating meter. The frequency weighting network passes various noise frequencies with an efficiency approxi-

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[5] H. T. Friis, "A static recorder," *Bell Sys. Tech. Jour.* 5, 282; April, 1926.

[6] A. E. Harper, "Some measurements on the directional distribution of static," PROC. I.R.E., 17, 1214; July, 1929; "Correlation of directional observations of atmospherics with weather phenomena," PROC. I.R.E., 17, 1185; July, 1929.

mately comparable to their relative interfering effects upon telephone conversation. One such instrument consists of a combination of an amplifier containing the frequency weighting network, and a suitable transmission measuring set. Another instrument of this type is being provided which is self-contained and portable. In this latter instrument the dynamic characteristics of the indicating meter are being designed to give indications on noises of short duration which are in some degree comparable with the effects of these types of noise on the ear. There are also being developed circuit noise meters for measuring noise on wire circuits carrying radio broadcast programs. For this case the frequency weighting curve is substantially a curve of equal loudness for the ear at a loudness level in the range experienced by a listener to a broadcast program.

THRESHOLD OF AUDIBILITY METHOD

Another method of determining noise which is sometimes used for program circuits is to reduce the maximum program volumes to the threshold of audibility and then to reduce the noise in the absence of the program to the threshold. In this way there can be determined the ratio of maximum program volume to the noise, a ratio which is frequently of considerable utility; and if the maximum program volume is known the absolute value of the noise may also be approximately determined. Room noise conditions, of course, have an influence upon such measurements.

ACOUSTIC DISTURBANCES—ROOM NOISE

There is also available a meter method for measuring room noise and sounds in general. The meter for this purpose is known as a "sound meter." This sound meter is somewhat similar to the circuit noise meter which has been described. It comprises, in addition to the amplifier, frequency weighting network, rectifier, and indicating meter, a sound pick-up in the form of a condenser microphone. The sound meter is described in a paper by Castner, Dietze, Stanton, and Tucker,[7] The use of a somewhat similar meter is described in a paper by Williams and McCurdy.[8] Another method for measuring room noise, also described in this latter paper, consists in the application of a controllable amount of a tone of varying pitch (warbler tone) to a special type of receiver which is provided with slots permitting the room noise to reach the ear. The measurement consists in adjusting the warbler tone until it can barely be recognized in the presence of room noise.

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[7] Castner, Dietz, Stanton, and Tucker, "An indicating meter for the measurement and analysis of noise," was presented at the Northeastern District Meeting of the A.I.E.E. (April 29–May 2, 1931) Rochester, N. Y.

[8] Williams and McCurdy, "A survey of room noise in telephone locations," *Trans. A.I.E.E.*, **49**, 1393; *Bell Sys. Tech. Jour.* p. 652, October, 1930.

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THE BROADCAST INSTALLATIONS IN THE NEW "HOUSE OF RADIO"*

By

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(Reports from the Laboratory of the Reichs-Rundfunk Gesellschaft, Berlin, Germany.)

Summary—*In January, 1931, the new "House of Radio," Berlin-Charlottenburg, Masurenallee, was opened. The broadcast equipment there partly consists of installations of novel design, and is described herein in a detailed manner.*

IN THE first place, the arrangements made between the German Reichs Post Office and the Reichs-Rundfunk-Gesellschaft with reference to joint broadcast operation, and in the second place the principle of controling the performances in the very place of reception; viz., in a control room adjoining the studio,[1] decided the design of the new plant. As it would have been of little use to provide for the apparatus required for the amplification of the microphone currents in each of these control rooms it was decided that all of the amplifiers would be concentrated at a centrally located station.

Fig. 1. shows the ground plan of the building. In the center of the marginal building there are the large broadcast studios 1, 2, 2a, 3, 3a, and in the marginal building itself the two speaker's rooms, 4 and 5, and a gramophone recital room 6. The amplifier room is marked 7, while 8 is the adjacent switch room. Nine is the gramophone record studio; 10, 11, and 12 are additional rooms of operation. The other studios (totaling fifteen) are situated on the other floors.

The required number of eight amplifiers results from the necessity of handling at the same time three broadcasts and three rehearsals, the remaining amplifiers being considered as spares.

The centralization of so many amplifiers rendered it desirable not to mount the amplifiers on tables, as in the past, but to arrange them in the shape of racks. The new amplifiers have been designed by the Reichs Broadcast Company in coöperation with the Telefunken Company.

The amplification plant which has here been erected is, in our belief, the first broadcast station in Europe which operates with no batteries at all, but is fed by generators only. The attendance and handling of the plant is thus extremely simplified, apart from the fact that the first cost for the generators was considerably lower. The difficulties

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* Decimal classification: R612.1. Paper originally received by the Institute, June 1, 1931. Published in *Elec. Tech. Zeit*, No. 18, April 30, 1931.

[1] G. Lubszynski, *Rundfunk-Aufnahme, Rund. Jahrb.*, 254, 1930.

which had to be overcome in the case of generator operation are in the first place their comparatively high internal resistance over batteries, and in the second place the so-called "ripple." The internal resistance causes the voltage to be dependent on the load and alters the attenuation within the amplifier (reaction or coupling with reversed phase). Besides, the operation of several amplifiers from a common source of current with high internal resistance involves a mutual influence termed cross-talk.[2] In the cited work there has already been shown a method of how to eliminate these troubles, consisting chiefly in isolating each individual amplifying stage.

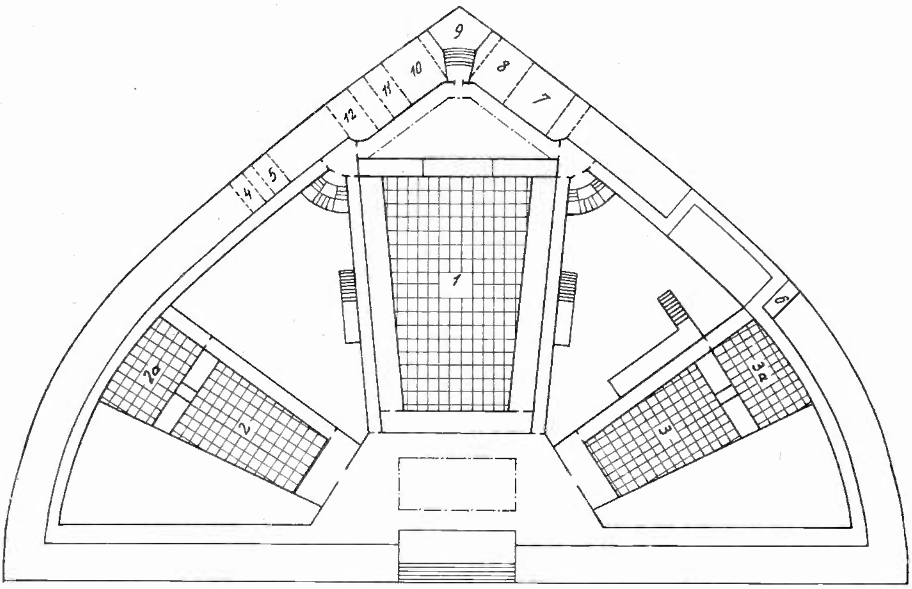

Fig. 1—Ground plan of the ground floor; the rooms marked by dotted lines are situated on the first floor.

The other difficulty, the dependence on the load, has largely been overcome by compounding. The ripple of 2 per cent still present with generators will cause no perceptible influence on the substantial filtering means provided for in the single stages. An additional filtration outside the amplifier had to be introduced for the filament current.

Every amplifier is subdivided into single, separated stages. This arrangement is made with a view to conform easily to any alteration of the service. An amplifier of this kind, therefore, will hardly become antiquated. If, for instance, microphones of other types are to be used in the future, the input stage has simply to be altered; if a lower power amplification ratio is sufficient, one amplification stage may readily be removed, and so on.

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[2] G. Lubszynski, "Principles on the use of common sources of current for several amplifiers," *Elek. Nach. Tech.*, **6**, 500–504; December, 1929.

Fig. 2 shows the arrangement of the amplifiers. Either rack contains four sets of amplifiers suspended on strong rubber tapes to prevent microphonic noises in the valves due to vibration. As shown in the diagram, each set of amplifiers consists of a number of cast boxes in which the individual amplification stages are housed. Thus an excellent electrical screening of the separate stages from each other will be obtained. Every amplifier is fitted with filtering means for the filament current, the filters being installed on the floor below the amplifiers.

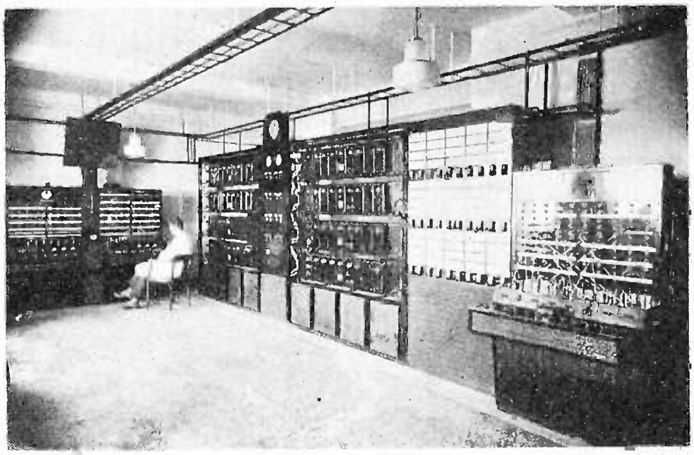

Fig. 2.—Amplifier room.

Fig. 3 shows a single set of amplifiers. They are mounted in a common frame and can be exchanged; thus any combination of stages may be connected in series. Fig. 4 shows the connection of the amplifier in the combination as it is in use at the present moment. The input is constituted by a transformer. The direct current is cut off from the primary side by a choke-condenser combination which at the same time forms a correction of the frequency characteristics for the bass frequencies. By connecting the center of the chokes to ground and providing a protective winding in the transformer a perfect symmetry of the input terminals will be obtained. Across the secondary of the transformer is a potentiometer followed by four similar resistance amplification stages. The amplification of each of these stages is tenfold. The

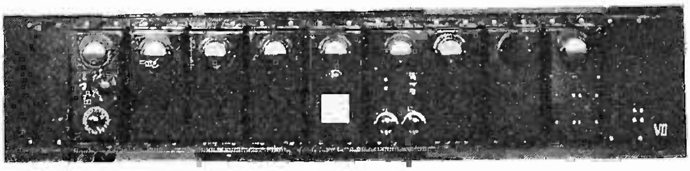

Fig. 3.—A set of amplifiers.

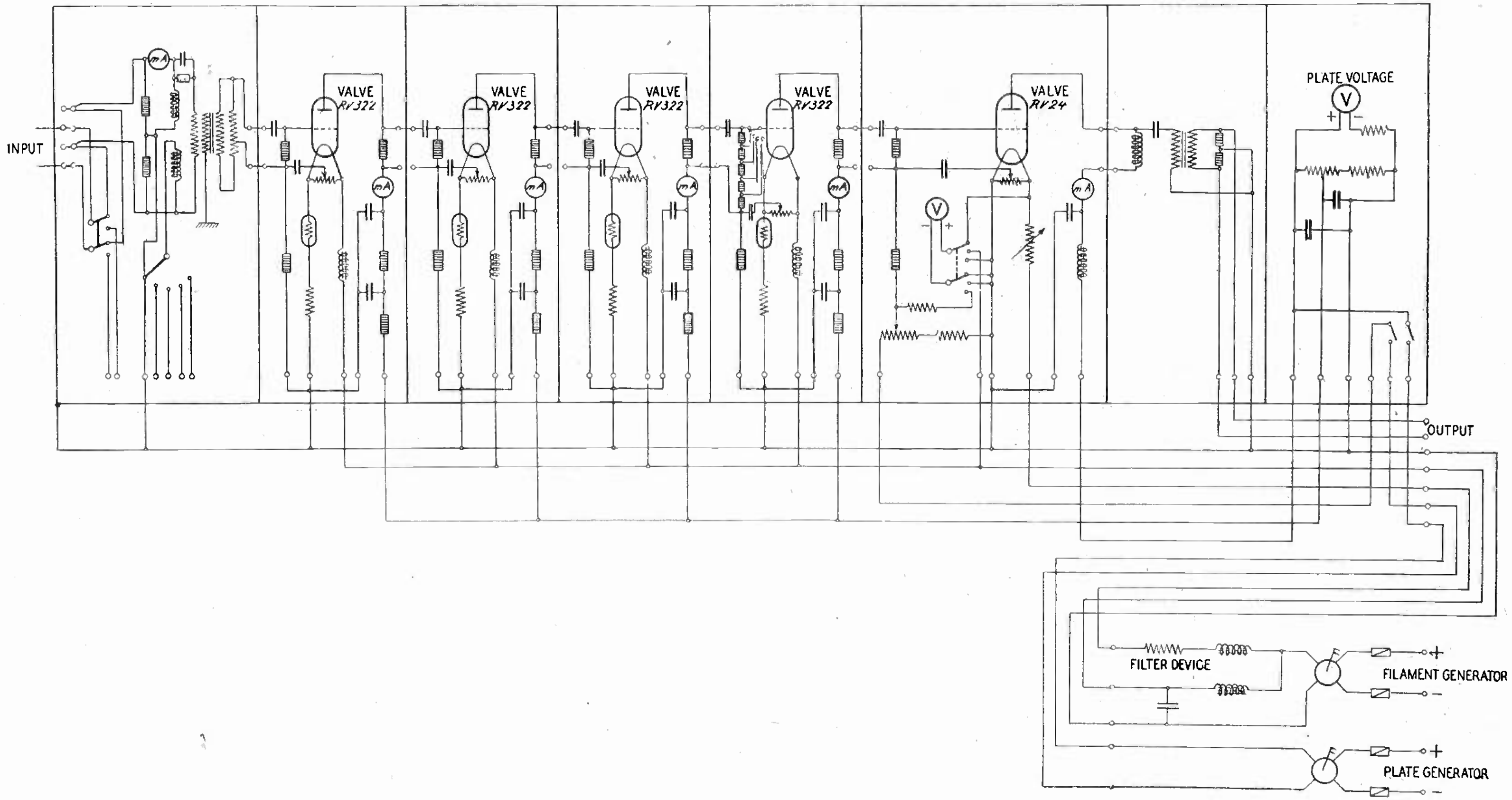

Fig. 4.—Scheme of the main amplifier.

valves used are the RV-322 type which are relatively free from microphonic effects. Filament and plate voltages are supplied with a filtering means, likewise the grid potential. The fourth stage has, in addition to the preceding stages, a step switch to adjust to the desired amplification ratio. The last stage consists of an RV-24-type valve. Filament current and grid potential may be controlled by regulators. The output of the amplifier is constituted by a transformer, the direct current again being cut off and a symmetry of the output terminals obtained by grounding the center. The maximum amplification is 20,000 at an input resistance of 200 to 800 ohms and an output resistance of 60 ohms. In a final box is the high tension switch, the plate voltmeter, and a potentiometer from which the plate voltage of the preliminary valves is tapped.

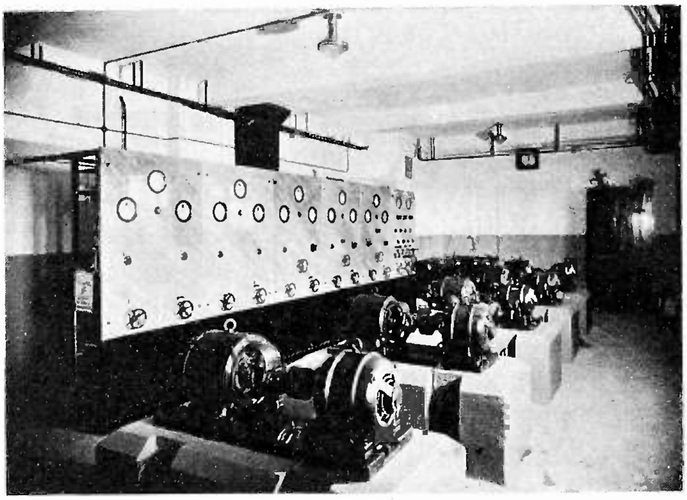

Fig. 5.—Engine room.

Fig. 5 shows the power room containing the generators required for the supply of current. In the foreground there are the two anode converters and the three filament converters, in the background the switchboard. Five panels are used for switching the machines, the sixth panel is designed as a charging switchboard for charging eight auxiliary batteries of 6 volts each and for charging portable batteries. These auxiliary batteries are used for the provisional operation of the receivers and control sets of modulation described later on. The battery room is situated in the basement behind the switchboard.

The anode generators are designed for a voltage of 800 volts. They are driven by three-phase current and deliver 3.5 amperes maximum and are regulated in such a manner that the voltage between no load and full load; viz., no matter how many amplifiers are cut in, remains constant at 800 volts. That has been obtained by providing the generator with a compound winding. All of the eight amplifiers are fed from one generator. The second generator is used as a spare. The same arrangement has been made with the filament generators which are set to a constant voltage of 30 volts and deliver 80 amperes maximum. One generator is normally used for heating the amplifiers, the second

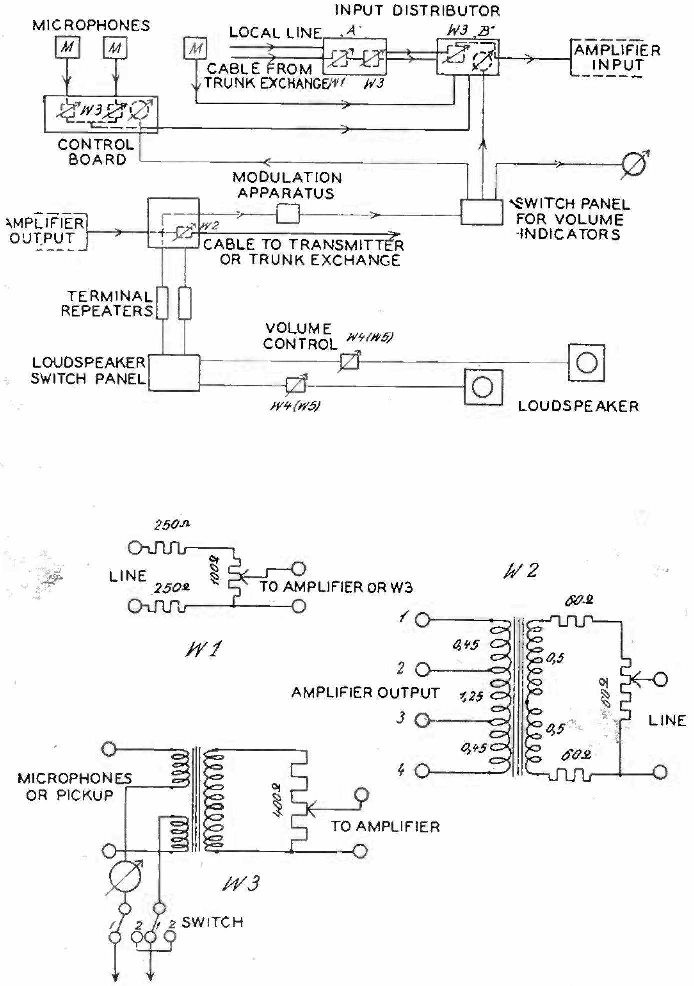

Fig. 6.—Details of the line system.

for charging batteries, and to operate the auxiliary apparatus, the third as a spare generator. All of the generators are driven by three-phase current and are arranged to be started across star-delta switches. The constancy of voltage is essential, particularly for the 30-volt generators used for heating the valves, as otherwise the filament voltage would be altered by switching on and off amplifiers and the valves would thus become useless.

From the power room in the basement the feeders run vertically up to the amplifier room in the first story and to the switchboard situated between the amplifier racks. (See Fig. 2). This switchboard carries only the switches cutting in the filament and plate current for each amplifier. The plate voltage is applied directly to the amplifiers, for the filtering means provided in the amplification stages is sufficient to eliminate fully superimposed alternating currents from the direct current of the generator.

In the amplifier room the control lines leading to the amplifiers meet from all sides. There are provided 38 microphone lines and 26 transmission lines coming in from outside, plus 14 spare lines. In addition, loud speaker lines originate from a central room providing the whole building with broadcast reception from Berlin and Zeesen (one loop each into each story) and 26 separate loud speaker lines to the control rooms and other observation rooms. Besides, about 60 lines used for the control instruments for the modulation, lead to the aforementioned rooms. A diagram of the whole line system is shown in Fig. 6. The great number of these lines rendered it necessary to arrange the wiring in such a manner that no mutual interference could take place. The principle of wiring was such as to unite only lines of equal voltage level and to run all wiring of different levels at as great a distance as possible from one another. Besides, lines carrying low voltages, particularly the input lines of the amplifiers, have been laid in double lead-covered cables especially immune against interference. The low level input lines all terminate on the left of the amplifiers, while the output lines of the amplifiers branch off to the right.

Within the building the following arrangement has been made to avoid any interferences with the lines (Fig. 7). The lighting circuit lines have been laid along the inner wall of the corridor, thus leaving the two outer walls of the marginal building for weak current lines. All of the telephone and bell circuits have been laid along the street wall, the microphone lines along the yard wall. In order to obtain a wide space between the power lines and the weak current lines, power lines have been laid horizontally only in every second corridor and the transmitter lines in an intermediate corridor. The vertical wiring has also been run at as great a distance as possible. The loud speaker lines carrying about 30 volts of alternating potential could be laid along the inner wall of the corridors together with the power lines. To allow a quick change of lines and a tracing of faults in the case of interferences, microphone and loud speaker lines have not been run under plaster, but placed on plaster mouldings suiting the architecture of the corridor (Fig. 8).

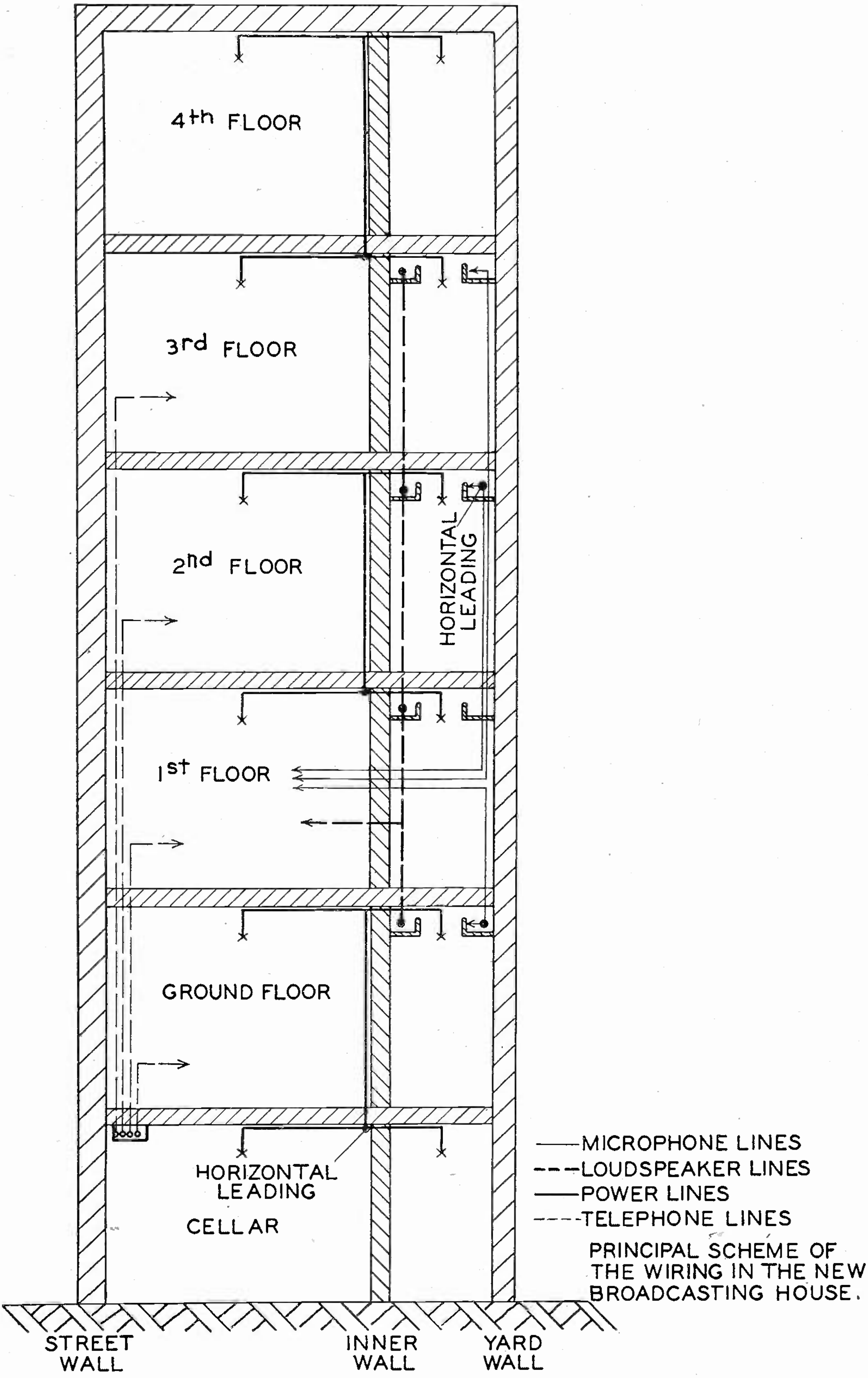

Fig. 7.—Wiring diagram of the line switchboards in the house.

By agreement with the German Post Office the speech levels transmitted on the Post Office lines are laid down. It was, therefore, necessary to terminate properly the incoming Post Office lines and to bring down the incoming voltage to a value adapted for our amplifiers, furthermore to provide the output lines with a proper attenuation element allowing us to set them to the level desired.

To accommodate all of the input lines two input switchboards (Fig. 6) are provided, one switchboard (switchboard *A*) accommodating all Post Office lines according to the above mentioned principle to unite similar levels of voltage. To this type belong the transmission lines coming from the trunk exchange and the lines carrying voltages of some tenths of a volt coming from a studio in town or from any other place of pick-up outside the house. The second switchboard unites all of the microphone lines; i.e., all transmitter lines coming from the studios of the house and carrying voltages of the order of 1 millivolt. Switchboard *A* contains the controlling devices *W*1 by means of which the Post Office lines are terminated and which are used for bringing down the voltage level to a value adapted for the amplifiers, and also the controlling devices *W*3 which are used for controlling the volume during a performance.

Fig. 8.—Plaster moldings.

The eight output lines of the amplifiers lead to the output switchboard *C*, (Fig. 2 on the right) which carries the terminating elements *W*2 which are situated at the beginning of every output line. In addition to the transmission lines leading to the transmitter or trunk exchange, respectively, the controlling instruments (modulators and terminal amplifiers) are here switched on. The single controlling instruments and loud-speakers are connected to special panels. (Fig. 9).

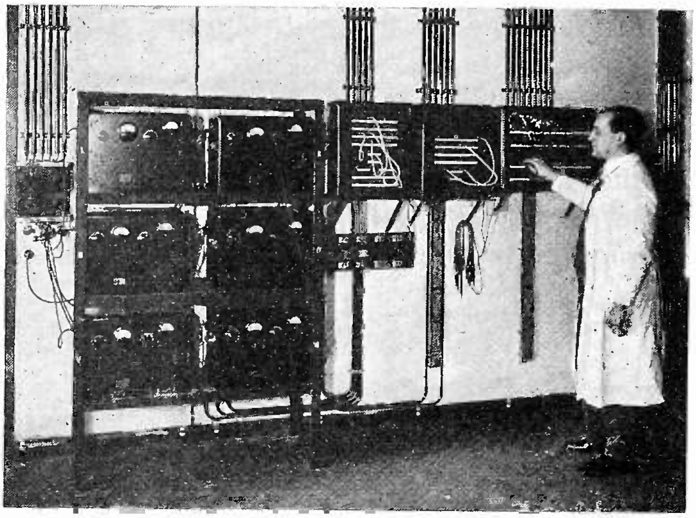

Fig. 9.—Fifteen-watt amplifier and switchboards.

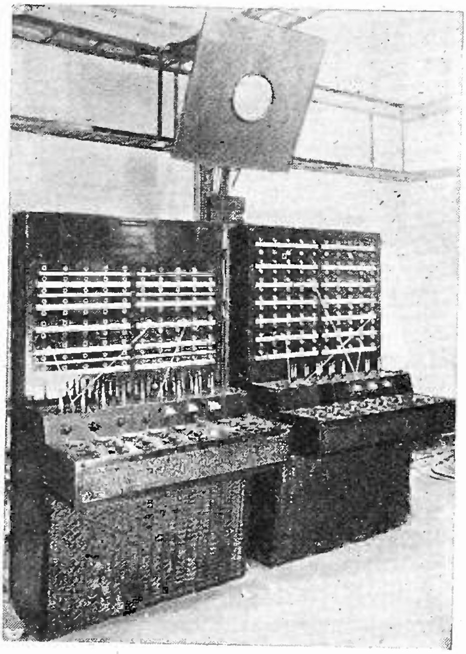

Fig. 10.—Input switchboards.

Thus every performance may be checked by means of the controlling instruments on switchboards *A* and *B* (Fig. 10), unless the performance is checked in the control rooms described hereunder. The observation in the amplifier room will, for instance, take place when the performance is relayed to another broadcast company. For watching the modulation of the amplifier each switchboard is furnished with a set of instruments with which the degree of modulation of the amplifier may be measured. For acoustic checking a loud speaker, whose volume may be controlled by means of a device below it, is provided above the switchboard. To be able to check acoustically several performances independent of one another, two soundproof cabinets are provided in the amplifier room, each containing a control table with controlling devices (Fig. 11). From here the whole amplifier room can be surveyed through double windows. Thus, three programs at a time may be checked from the amplifier room.

Fig. 11.—Cabinet amplifier room.

With nearly all performances originating in the house the amplifier is watched and modulated in close proximity to the studio. For this purpose control rooms are provided next to each studio; these rooms are sealed off from the studio acoustically, but allow vision of the whole studio through a double window. The soundproof sealing-off from the studio is obtained by the control room being constructed as a brick cubicle within the building and entirely insulated from the building by absorbing material consisting chiefly of tar board. The double windows consist of two glass panels, one 15 and the other 25 mm thick. These are inserted in a sturdy wooden frame. The size of the glass panes is such that no covibration of the entire pane can take place. The interior of the control room is lined with a sound-absorbing material in order that the acoustics of the control room match those of the studio.

In front of the windows there is a control desk similar to those used for sound films containing all sorts of mixing controls (Fig. 12). Here also are modulation indicators, which indicate the modulation of the amplifier and a loud speaker with which the performance may be heard. The communication between the manager's office and the artists in the studio during rehearsals is obtained by a "talk-back" device consisting of microphone, amplifier, and loud speaker.

Fig. 12.—Control room.

With the instruments of observation both the average modulation and the peak value of the speech voltages occurring behind the amplifier may be measured. While the approximate magnitude of the modulation may be read from the deflection of a pointer of one instrument, the second instrument indicates at once if the maximum permissible value of the modulating voltage has been exceeded.

It is intended to introduce a third instrument (minimum indicator) from which one may determine when the permissible minimum value of the modulating voltage (which is stipulated by the noises of the entire transmitting plant) is passed.

Beside these three instruments there are loud speakers at every place of observation. These loud speakers can be connected either to a 15-watt amplifier which amplifies the speech voltages from the line, or to a second 15-watt amplifier which is controlled by a radio receiver, and third in series with one of the 30-watt amplifiers of the general receiving plant. Thus, the quality of the transmission may be checked at every listening place, both before the operating amplifier and on two different radio receivers. In case of any interference with the "check" reception, therefore, one is at once able to change over to the receiver for the house.

To insure continuous operation, a private telephone system which is separate from the other telephone plants is provided to interconnect all of the working rooms to one another and to the central station adjacent to the amplifier room. In this central station terminate all of the communication lines leading to the transmitters, the lines leading to the trunk exchange, and the communication lines arranged for outside transmissions, reports, etc. This private exchange has automatic telephones enabling connection at any time to an existing call; thus the called party is always within reach of the telephone.

To indicate the beginning and end of the performances, luminous signals are provided in the studios, flashing simultaneously with an indicator board placed in the amplifier room near the output switchboard. Signaling takes place in the following manner: when starting a performance, the speaker who announces the performance gives from the studio the luminous signal "on," whereupon the operator in charge of the amplifier room switches on the red signal "silence." In the studio and its surroundings flash red lamps indicating that the transmitter is switched on and that the performance must not be disturbed. If for one reason or another; e.g., because the preceding program has not yet been finished—and the signal "silence" cannot be given, the operator in charge of the amplifying room gives the green signal "wait," whereupon the speaker may phone with the operator about the beginning of the performance. After the performance is finished, the signal "off" is given from the studio and the operator in charge of the amplifying room cuts off the silence signal after the transmitter line has been disconnected from the operating amplifier.

To maintain an orderly service and to check the continuous working order of the instruments it is essential to examine and measure the instruments at frequent intervals. To that end considerable apparatus enabling such tests within a short time are provided in the switch room adjoining the amplifier room. Besides well-known instruments used for testing the lines for insulation and line resistance, the equipment used for measuring the frequency characteristics of various pieces of equipment is of special importance.

The photo-audio generator is used to generate any frequencies ranging between 50 and 10,000 cycles of constant amplitude,[3] which are applied to the equipment to be tested, while the output voltages of this instrument are directly recorded by means of an amplifying voltmeter and a recording ammeter. The complete measurement of any instrument lasts but three minutes.

In this way it is possible to measure the whole transmitting plant, from microphone to transmitter. (A receiver which gives all audio frequencies without distortion is being used for reception tests.)

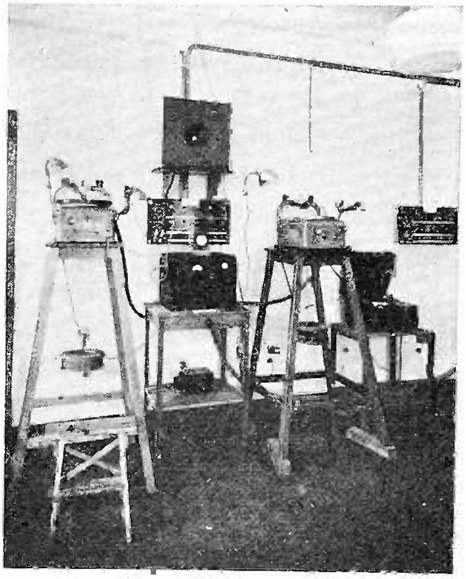

Fig. 13.—Disk recording.

In order to test the sensitivity and quality of a microphone there are special instruments in the test room and in the adjacent microphone testing room, which is rendered immune against reverberation. The apparatus used for open-air performances, such as portable amplifiers, etc., are submitted to a thorough test in a special room prior to their being used.

Of equal importance as the purely measuring tests of the instruments is the audible, acoustic observation. For this purpose recording apparatus enabling every recital to be placed on records are provided in the disk recording room (Fig. 13). This is of special importance for audition studios, for no method is reported so far which allows one to measure the acoustics of studios accurately in all details. So after each change in the acoustics of the room in question a record is made and

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[3] Schäffer-Lubszynski, *Elek. Nach. Tech.*, 8, 213–217; May, 1931.

the final results compared. Furthermore, the recording machines will be used for recording important or interesting productions.

The Reichs-Rundfunk-Gesellschaft is not only in charge of the maintenance of the Berlin amplifier room, but also of the maintenance of the other broadcast companies. That is why a central office is established in Berlin which handles all purchases, examines all new or novel equipment as to its suitability for broadcasting, and has charge of the development of the installations. The necessary laboratories and testing rooms are housed in the third story of the marginal building. Microphones, loud speakers, amplifiers, and receivers, as far as they are required for broadcast service, are here examined. Special devices required by a peculiar kind of service also are developed here.

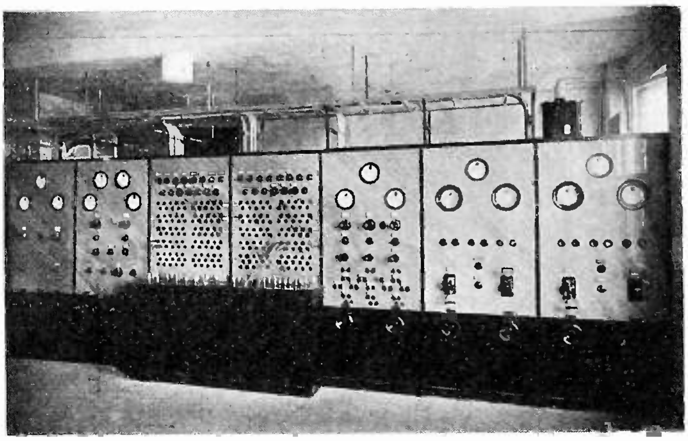

Fig. 14.—Switchboard for the generators in the laboratory.

A special generator room is provided for the laboratories, supplying the required operating voltages; close by is an accumulator room housing three 20-volt batteries of 108 ampere hours each and three 450-volt batteries of 3 ampere hours each. Furthermore, voltages are supplied by a 30-volt generator, an 800-volt generator, and two high tension generators of 2000 and 4000 volts, respectively; in addition, twice 220 volts direct current are available at each place from a converter and three-phase current of three times 220 volts from the mains. A plug switchboard (Fig. 14) is used for distributing these voltages to the laboratories; the required voltages can be applied to one of the eight room distributors by means of this plug distributor. From these room distributors (Fig. 15) the voltages may be applied to the various small switchboards at the various working places.

Of interesting equipment there might still be mentioned: A Faraday cage used for high-frequency tests; a measuring room containing fixed testing and calibrating devices for high and low frequency; a room for oscillographic tests and the development of photos; a room particularly immune against reverberations for sound tests; a special studio for testing acoustic phenomena; measuring devices for improving the cutting and playing of records; and finally, a test transmitter with artificial aerial.

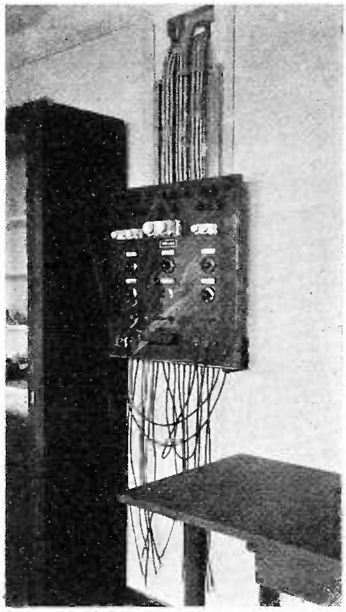

Fig. 15.—Room switchboards.

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Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

VACUUM TUBES AS HIGH-FREQUENCY OSCILLATORS*

By
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Summary—*The problem of tubes for generating power at wavelengths below five meters is discussed. The theory of the triode and split-anode magnetron is considered with particular reference to the limitations imposed by operation at short wavelengths. Essential data are given for examples of each type of tube, showing the power that can be obtained at various wavelengths.*

Introduction

In VIEW of the increasing importance of alternating voltages of very high frequency, a presentation of essential data on vacuum tubes particularly suited for the generation of such voltages should be of value. The object of this paper is to present such data and to discuss the tube limitations. The problem of power generation is discussed without reference to such questions as radiation or reception. The subject matter is concerned mainly with the wavelength band from three-quarters to five meters.

I. Wavelengths Above 1.5 Meters

Theory

At the present time, the best method of generating continuous wave power above 1.5 meters is that of using triodes in regenerative circuits. In this type of circuit part of the ouput energy is fed back to the control circuit to supply the exciting voltage. Tubes with one or more control elements may be used, although the use of the triode is most common. The fundamental principles of operation are the same for all these types of tubes so for the sake of simplicity, the discussion will be limited to the triode.

Fig. 1 (a) shows a typical circuit arrangement using the triode as an oscillation generator. Fig. 1(b) illustrates the current and voltage relations in such a circuit. It will be noticed that the amplitude of the plate voltage variation, e_p, approaches the supply voltage, E_b. The second characteristic is the wave shape of the plate current. Plate current flows for less than half a cycle during the time when the plate potential has its minimum values. As a result, the tank circuit, L, R_t, C, receives energy from the tube only during the time the plate current is flowing. Since the resistance, R_t, is dissipating energy continuously, the

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* Decimal classification: R133. Original manuscript received by the Institute, April 9, 1931. Presented before Sixth Annual Convention of the Institute, June 6, 1931, Chicago, Illinois.

maintenance of oscillations necessitates the storage of sufficient energy in the tank circuit so that all the losses can be supplied with only a small reduction in voltage, until the next plate current pulse. D. C. Prince[1] has shown that for good oscillator stability the ratio of energy stored to energy lost per cycle should be at least 2. This is equivalent to a ratio of volt amperes in the tank circuit to watts output of 4π, or a decrement in the tank circuit of 0.25.

In Fig. 1(a) the effective load resistance in the plate circuit is approximately $K \times L/R_tC$ ohms, where K is the ratio of the turns between the filament and plate taps to the total turns of the inductance L. In practice, this load resistance is varied by choosing various values of L, R_t, and C and keeping K approximately constant. If the load resistance is high (10^4 to 10^5 ohms), the tube operates with low power input and high efficiency. As the resistance is lowered, the power input increases and the efficiency decreases; consequently the plate loss increases rapidly. Since every tube has an inherent maximum safe plate dissipation, the load resistance cannot be reduced below a certain value except by lowering the power input. If the grid is to be properly excited, this can only be accomplished by a reduction of plate voltage.

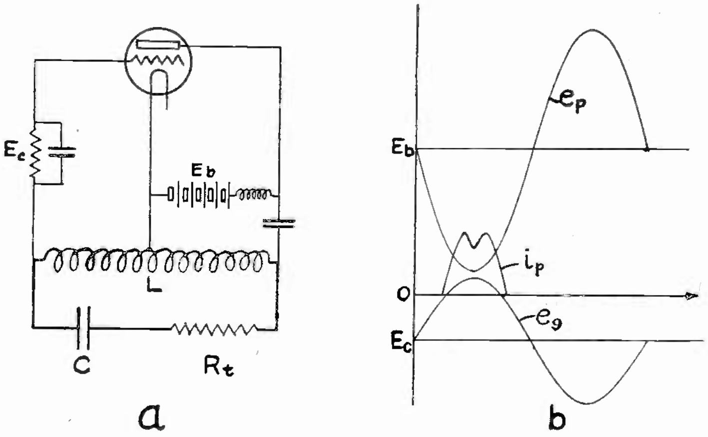

Fig. 1

The lowest value of load resistance at which a tube can be operated at full plate voltage without exceeding the rated plate dissipation can be calculated approximately from (1)

$$R = \frac{E_b^2}{W} \, \frac{(1 - \eta)A^2}{2\eta} \tag{1}$$

where W is the plate loss in watts, η the efficiency and A the ratio,

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[1] D. C. Prince, PROC. I.R.E., **11**, 301, 1923.

e_p/E_b. At the limiting value of load resistance the efficiency, η, averages approximately 0.65 and the factor, A, 0.80 to 0.90. Substituting these average values reduces (1) to

$$R = 0.2 \frac{E_b^2}{W} \text{ ohms.} \tag{2}$$

As an example, the UX-852 with a normal plate voltage of 2000 and a maximum plate disspation of 100 watts requires a load resistance of about 8000 ohms.

It has been assumed so far that the plate current pulse is symmetrical about the minimum plate voltage point. This is the condition for maximum efficiency and output. In the case of a phase shift, the theoretical output must be multiplied by the cosine of the angle of shift. Thus, if the phase shift were 90 degrees, the output would be zero. In long-wave circuits it is easy to keep this angle small.

Limitations Encountered at the Shorter Wavelengths

When an attempt is made to operate a triode at ultra-high frequencies, one or more of the preceding requirements cannot be met. For wavelengths above 10 meters the circuit of Fig. 1(a) is usually satisfactory. For wavelengths below 10 meters the necessity for further reduction of inductance and capacity eventually eliminates the external tank capacity and leaves only the interelectrode capacity of the tube. Beyond this point the frequency can be controlled only by the external inductance. When this inductance has been reduced to the shortest possible connection between the grid and plate tube terminals, the absolute minimum of wavelength has been reached. This minimum wavelength will be designated by λ_0. The circuit then becomes that of Fig. 2.

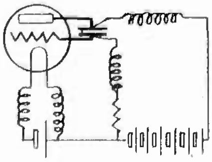

Fig. 2

When the external tank condenser has been removed and operation is confined to a given frequency, there is no further control over the decrement of the tank circuit other than by a variation of the ohmic resistance of the conductors or the resistance reflected into the tank circuit by radiation and coupled loads. This is readily seen from the formula for decrement:

$$\delta = \pi R_t \omega C \tag{3}$$

where C now represents the interelectrode capacity of the tube. R_t increases with frequency because of increased radiation and skin effect in the conductors; consequently δ rapidly takes on larger values as the frequency is raised. In the case of most tubes, δ becomes so large that oscillations cannot be obtained at wavelengths down to λ_0. In such tubes, reduction of λ_0 by placing the oscillating circuit entirely within the bulb is of no practical value. This shows that the first essential of a high-frequency oscillator is low interelectrode capacity, not only because of the necessity for a low λ_0, but also to keep δ low.

As λ_0 is approached, there is also no further control over the plate load resistance other than by varying the effective resistance in the tank circuit. This can be seen from (4).

$$R = \frac{K}{R_t \omega^2 C^2} \text{ ohms.} \tag{4}$$

It is obvious that R decreases very rapidly with wavelength. For wavelengths below four meters this usually results in a value of R less than that given by (2). As a consequence, the efficiency becomes continually lower and, since the plate dissipation is limited, the output decreases. Equation (4) also shows that the plate load resistance increases as the interelectrode capacity is reduced.

Another limitation on the operation of triodes at very short wavelengths is the finite time required by the electrons to traverse the filament-plate space. This time is a direct function of the spacing and an inverse function of the plate-to-filament voltage. It is equivalent to a change of phase angle between the a-c plate current and voltage, and results in a reduction of output.

Summarizing, the requirements of a triode suitable for short-wave generation are:

(1) λ_0 must be less than the desired wavelength.

(2) The interelectrode capacities must be low.

(3) The allowable anode dissipation must be as large as possible.

(4) The time of transit of electrons between filament and plate should be kept as low as possible by use of small spacings and high operating voltages.

(5) The plate and grid leads and seals must be heavy enough to carry the large currents encountered at these wavelengths without overheating.

It can be shown that these requirements are more and more nearly met as the plate diameter is increased. The plate diameter cannot be increased without limit because of the increased inductance of the leads between grid and plate and the increased space-charge loss produced by the relatively greater importance of end effects. The practical limit of plate diameter is reached when it is approximately equal to the effective length of the plate. At the present time for outputs above about 500 watts, requirement (3) is best met by the use of a water-cooled plate. For the maximum power output, it is essential that the filament electron emission be sufficient to make the plate-current space charge limited at all times.

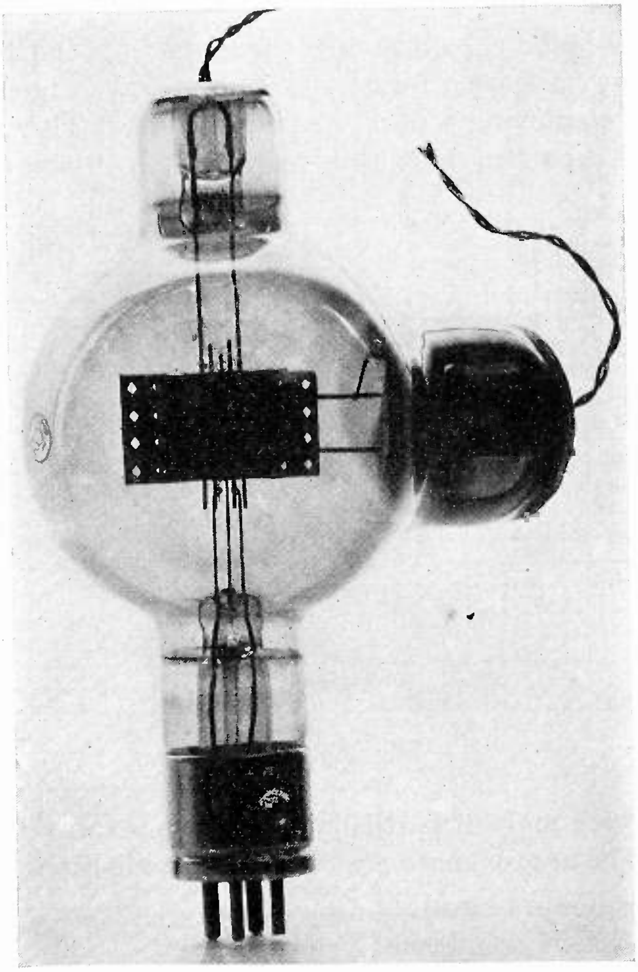

Fig. 3

Tubes for Operation Between 1.5 and 5 Meters

In this section data will be given on two triodes which are satisfactory for use between 1.5 and 5 meters. The first of these, the UX-852, is illustrated in Fig. 3. This is a three-element, air-cooled transmitting tube, employing a thoriated tungsten filament and designed to have low interelectrode capacities and high insulation between elements. Fins are used on the plate to aid in the dissipation of heat. The approximate direct interelectrode capacities are:

Plate to grid................	3 $\mu\mu$f
Grid to filament..............	2 $\mu\mu$f
Plate to filament.............	1 $\mu\mu$f

Fig. 4 shows the output obtainable from the UX-852 below five meters. This output is found by subtracting the losses from the input.

Fig. 5 shows a special form of three-element, water-cooled transmitting tube employing a pure tungsten filament. This tube has low interelectrode capacity, short lead lengths and is capable of large plate dissipation which make it particularly suitable for wavelengths below five meters. The approximate direct interelectrode capacities are:

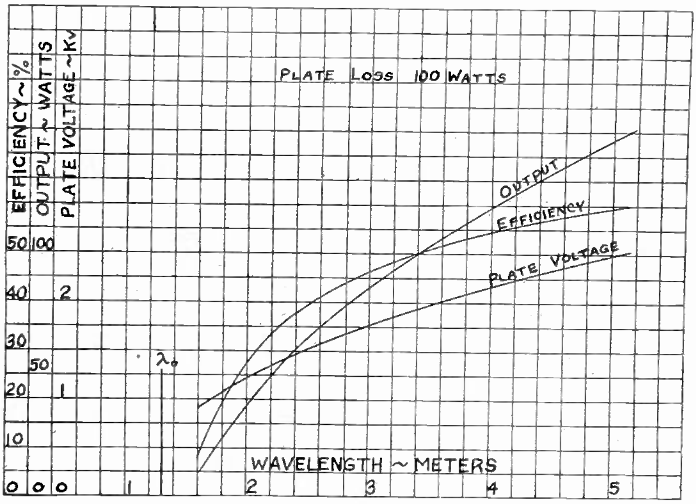

Fig. 4

Plate to grid................	8 $\mu\mu$f
Grid to filament..............	5 $\mu\mu$f
Plate to filament.............	1.5 $\mu\mu$f

Fig. 6 shows the ouput obtainable from this tube below five meters.

The data shown on Figs. 4 and 6 were taken in a circuit similar to that of Fig. 2. These curves illustrate the theoretical points brought out earlier in this paper.

Use of Screen-Grid Tubes for Very Short Wavelengths

It is sometimes thought that screen-grid tubes, because of their low grid-to-plate capacity, are ideally suited for short-wave oscillators. However, in a screen-grid tube, the effective capacity added to the os-

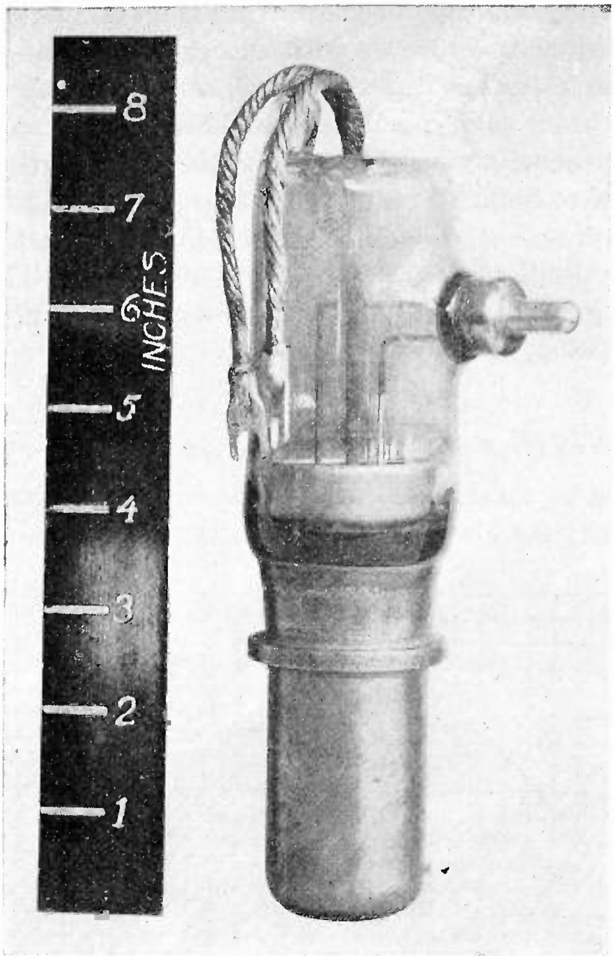
8
7
6
5
4
3
2
1
INCHES

Fig. 5

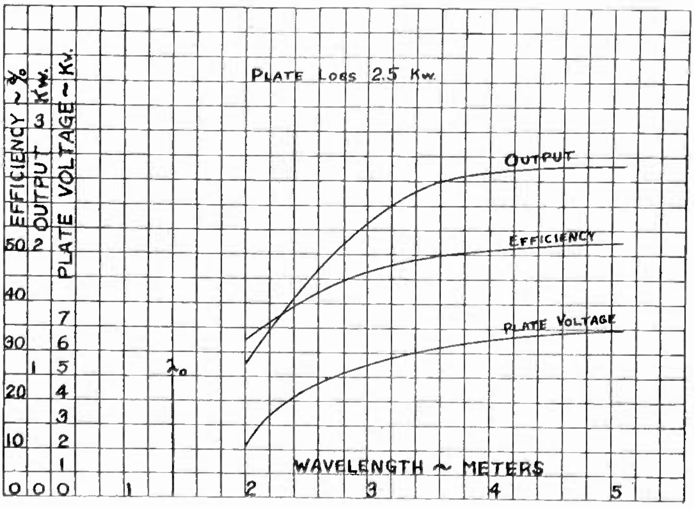
EFFICIENCY ~ %
OUTPUT ~ Kw.
PLATE VOLTAGE ~ Kv.
PLATE LOSS 2.5 Kw.
OUTPUT
EFFICIENCY
PLATE VOLTAGE
λ_0
WAVELENGTH ~ METERS
50
40
30
20
10
0
3
2
1
0
7
6
5
4
3
2
1
0
1
2
3
4
5

Fig. 6

cillating circuit by the tube becomes equivalent to the plate-to-screen and filament capacity in series with the grid-to-screen and filament capacity. This equivalent capacity is higher than the effective grid-to-plate capacity in the corresponding triode. For example, in the UX-860, which is identical with the UX-852 but with the addition of a screen grid, has a grid-to-filament and screen capacity of 8.5 $\mu\mu$f, and a plate-to-screen and filament capacity of 9.0 $\mu\mu$f. The effective grid-plate capacity in an oscillating circuit is therefore $(8.5\times 9)/17.5 = 4.37$ $\mu\mu$f. This is approximately 0.6 $\mu\mu$f higher than the effective grid-plate capacity of the UX-852, so that the UX-860 is inferior at very short wavelengths.

II. WAVELENGTHS BETWEEN 0.75 AND 1.5 METERS

Triodes can be constructed for operation in this wavelength range, but the necessity for low capacitances requires that the dimensions of the elements be reduced so that only a small output can be obtained. More power can be obtained in this wavelength range by the use of a split-anode magnetron. A split-anode magnetron in its usual form is a high-vacuum tube containing two semicylindrical anodes arranged symmetrically about an axial filament. It is used in conjunction with an axial magnetic field. Electrons flowing from filament to plate under the combined influence of the electric and magnetic fields give the tube a volt ampere characteristic which has a negative slope over a definite range. It is well known that such a "negative resistance" can be utilized to generate oscillations. Fig. 7 shows a typical volt ampere characteristic for such a tube. The tube performance when connected to suitable

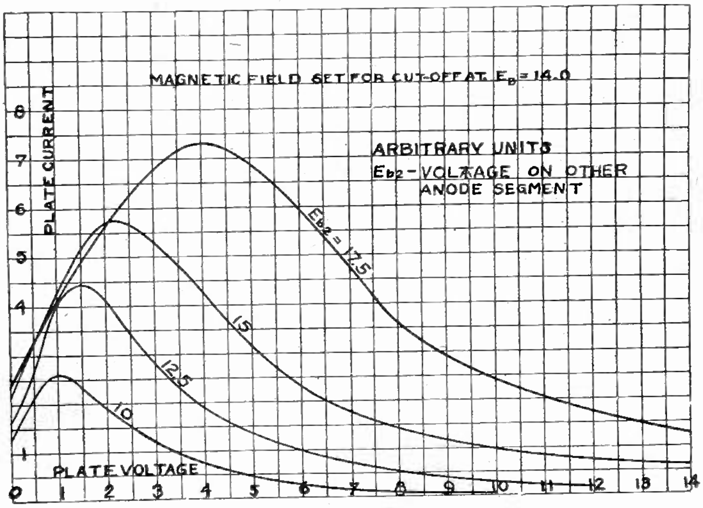

Fig. 7

oscillating circuits, such as shown in Fig. 8, can be predicted from the static characteristics.

The limitations on the operation of split-anode magnetrons at very high frequencies are in many respects similar to those applicable to triodes. The natural period of the tank circuit formed by the capacity of the two anode segments and inductance of their leads can be made extremely small. For this reason, the first requirement for a short-wave oscillator is more easily fulfilled by a split-anode magnetron that by a triode.

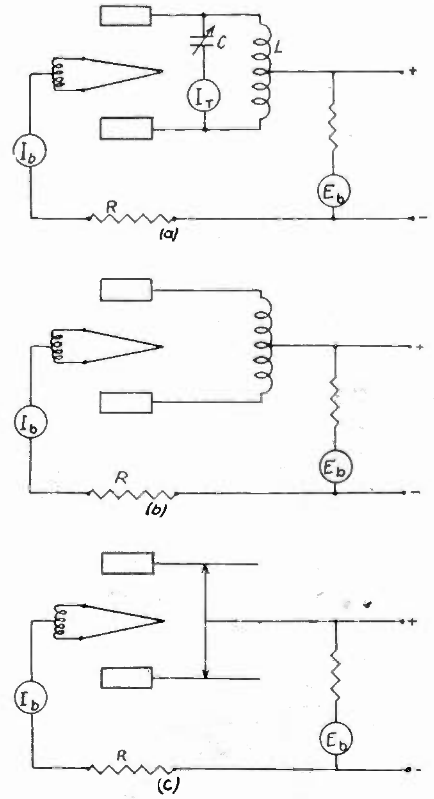

Fig. 8

In a split-anode magnetron, each anode delivers energy to the tank circuit during alternate half cycles, so that in effect the tube is equivalent to a push-pull oscillator. The tube is therefore delivering power to the tank circuit almost continuously and, for this reason, the decrement is of little importance.

However, the advantages of the split-anode magnetron outlined above are offset by two serious disadvantages. An analysis of the static characteristics shows that, for efficient operation, the effective resistance of the tank circuit at the fundamental frequency must be approximately ten times that required by a triode with the same anode dimensions. When the proper load resistance is used, efficiencies of the order of 80–90 percent may be obtained. In a typical case, the load resistance was 30,000–40,000 ohms. The load resistances that can be obtained below 1.5 meters are ordinarily only a small fraction of this, with the result that at these wavelengths, the efficiency of the tube becomes poor.

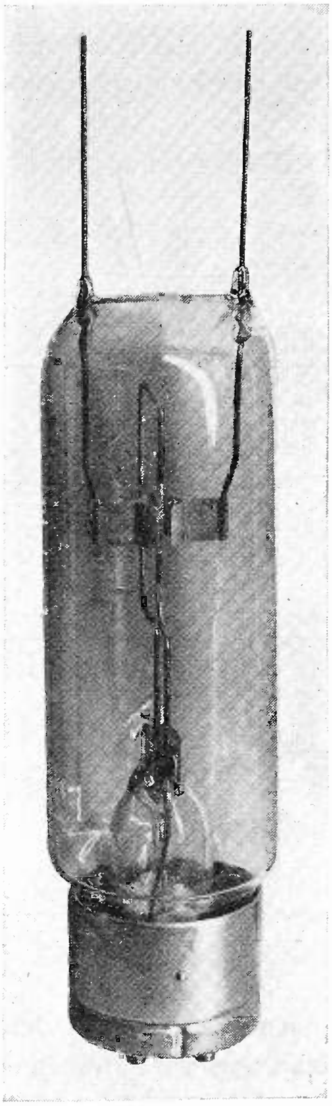

Fig. 9

The second disadvantage is that the electron current is concentrated on about one-quarter, or less, of the anode surface. This reduces the allowable anode dissipation and leads to anodes of special design. Consequently, the ratio of plate loss to interelectrode capacity may be only slightly more favorable than the same ratio for a triode of the same anode dimensions.

Fig. 9 shows a typical split-anode magnetron suitable for generation of power between 0.75 and 1.50 meters. The approximate interelectrode capacities are:

Anode to anode (filament grounded)	0.5 $\mu\mu f$
Anode to filament (other anode grounded) .	0.7 $\mu\mu f$

Fig. 10 shows the ouput obtainable from this tube as a function of wavelength.

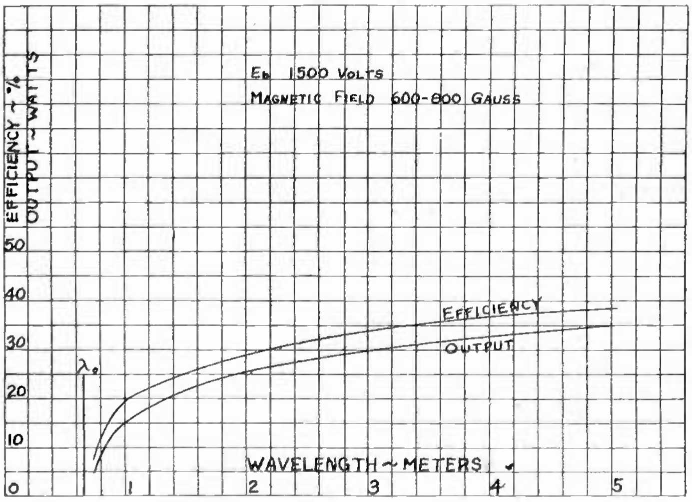

Fig. 10

III. Wavelengths Below 0.75 Meters

For generating continuous waves below 0.75 meters, there are two methods that have received considerable attention. The first is that described in considerable detail by Barkhausen and Kurz[2] using the triode, and the other is that described by Okabe[3] using the magnetron. Both of these methods are characterized by the fact that the wavelength depends primarily on the time of passage of the electrons from filament to anode. The efficiency of both these types of oscillators is very low and the maximum power output is limited. For example, two UX-852 tubes, operated in a push-pull circuit with a grid input of 100 watts per tube, will generate only enough power to light a small two-volt flash-light bulb. In view of the large amount of detailed information which has been published elsewhere on these types of oscillators, they will not be considered further here.

CONCLUSION

At the present time, the triode is the most useful electron tube for generating power at wavelengths down to approximately 1.5 meters. At wavelengths between 1.5 and 0.75 meters the split-anode magnetron is most satisfactory. Below about 0.75 meters it is necessary to resort to oscillators whose frequency is determined by the electron transit time. At the present time, the triode is the only type of tube which may be used as an amplifier.

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* Abbreviations are those used in Science Abstracts.

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FORMATION OF STANDING WAVES ON LECHER WIRES*

BY
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Summary—*With a short review of the work on the Lecher wire method of wavelength measurement, this paper describes in detail the wave form of current distribution along wires under a variety of terminal conditions of length and impedances.*

THE problem of precision determination of radio frequencies and keeping radio stations at their assigned places in the frequency spectrum is becoming more and more important owing to the increasing demand for channels both for domestic and international communications. In the case of long waves, several methods of direct comparison either by stroboscopic or spark photography systems are available. Higher frequencies are estimated by comparison with the harmonics obtainable from low-frequency sources such as the valve maintained tuning fork or the piezo-electric crystal oscillator in conjunction with multivibrator systems.

Several measurements of classical interest have been made based entirely on the principle of standing waves. In 1888 Lodge estimated frequencies of the order of several millions with a pair of wires. Lecher in 1890 and Blondlot in 1893 perfected the technique of this method, now well known as the Lecher wire method of wavelength determination. The speed of propagation of electromagnetic disturbances has also been estimated by this method. Its value is considered to be in the neighborhood of 2.998×10^{10} cm per second.

It was soon discovered that the decrement of the wires used tended to reduce the speed of propagation along wires as compared with propagation in free ether. The distributions of current and potential along the wires were also noticed to be not sinusoidal. This resulted in the observed length of wave being somewhat lower than the true wavelength in ether.

A correction factor of the form $\lambda_0 = 2L(1+\Delta)$ was worked out by A. Hund.[1]

Here λ_0 = true wavelength in ether,
L = distance between two consecutive antinodes,
Δ = correction factor depending on the decrement of wires.

Dunmore and Engel described "A method of measuring short radio

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* Decimal classification: R116. Original manuscript received by the Institute March 30, 1931.

[1] *Bureau of Standards Scientific Papers*, No. 491.

wavelengths and their use in frequency standardization[2]." Presumably the distribution of current observed was sinusoidal. However, Takagishi[3] while working on similar measurements, noticed the normal current antinode being split into a trough with a double hump. One of the present writers too while on 6-meter work, noticed similar double hump formation in place of a single resonance peak. It was then reported[4] as having been due to the presence of a strong third harmonic in the generated wave, rather than to close coupling as suggested by Dunmore and Engel. Takagishi[5] has just given a mathematical proof in explanation of this double hump formation under certain conditions of line and bridge impedances.

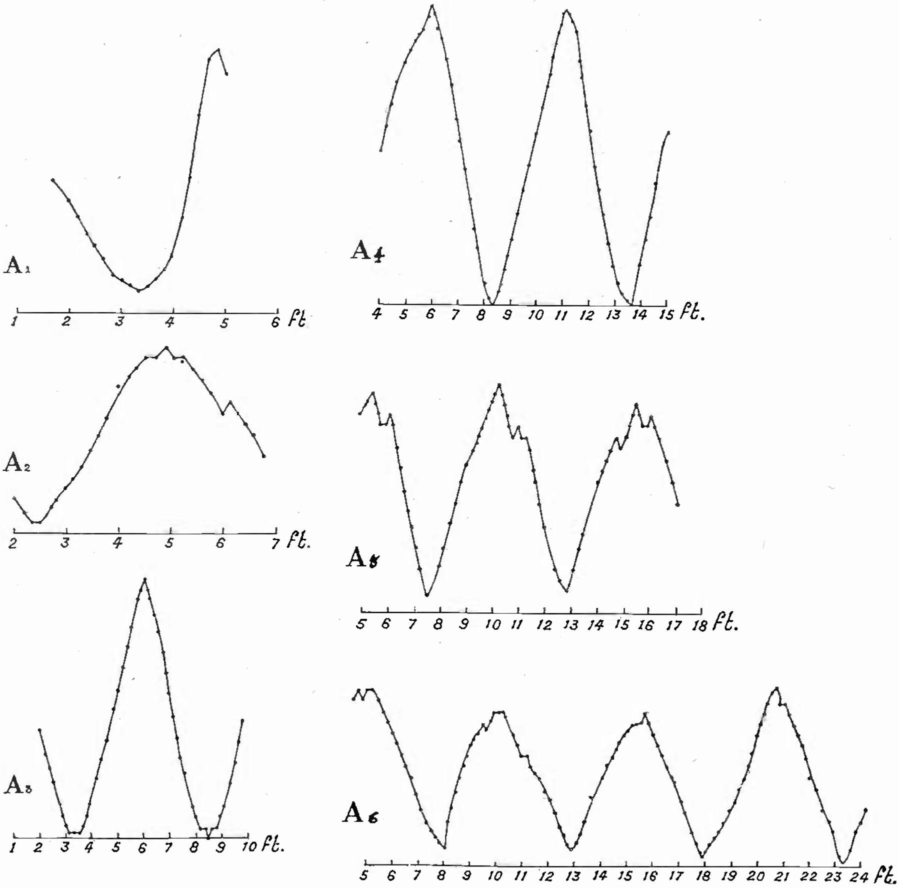

Fig. 1

The present investigation was undertaken in these laboratories to study the actual wave form of current distribution along wires under the following conditions:

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[2] Proc. I.R.E., **11**, 1923.
[3] Proc. I.R.E., **13**, 1925.
[4] Discussion between Kantebet and Dunmore, Proc. I.R.E., October, 1925.
[5] Proc. I.R.E., March, 1930.

(1) Constant generated frequency.

(2) Tight and loose coupled Lecher wires, both open- and short-circuited at far end.

(3) Length of wires varying from a fraction of a wavelength to 2 wavelengths.

The indicator used was a galvanometer having a range of 600 microamperes, with a crystal rectifier with contacts rigidly held in place. The assembly was hung up by a pair of short, stout copper rods, and shifted from place to place along the wires. Corresponding galvanometer deflections were noted.

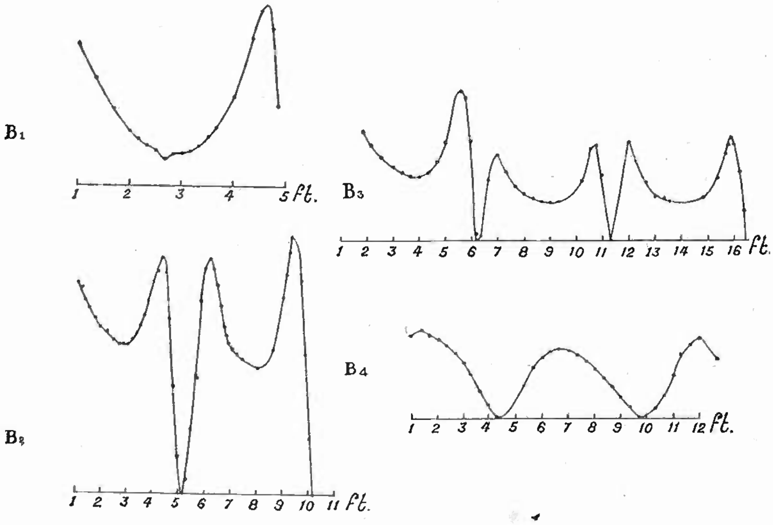

Fig. 2

The results are submitted in the shape of three groups of curves as follow:

Fig. 1, group A_1 to A_6—Length of wires 24 feet and coupling constant, the wires being bridged at various distances from far end, coupling loose, the distribution being mostly due to radiation field.

Fig. 2, group B_1 to B_4—Length of wire altered in steps of $\lambda/2$, the extra lengths being coiled up and wires bridged at bottom of coils.

Fig. 3, group *A* to 20—Constant coupling, line length decreased in steps from one wavelength to less than $\lambda/2$.

The *A* group of experiments would appear to show that so long as the far ends are open, the increase in the distance between the bridge and the far ends has little effect on the distribution, and with loose coupling current distribution is normal. Curve *A*1, however shows some peculiarities. The same has been plotted after repeated experiments. For this curve the distance between the node and the antinode is 15 inches corresponding to λ/8 rather than to λ/4. Experimental conditions were the same as with the other curves of the group.

The B group all show a double hump formation. It was suspected that the coupling might be the cause of the double humps. Observations corresponding to $B2$, with a length of 12 feet, were repeated with the short-circuiting bridge removed. The double hump disappeared giving the distribution of $B4$. From this set of experiments the peculiar distribution seems to be due to the low impedance bridge at the ends of the wires. Curve $B1$ corresponds to $A1$ giving a spacing of λ/8 and not λ/4 between the node and the antinode.

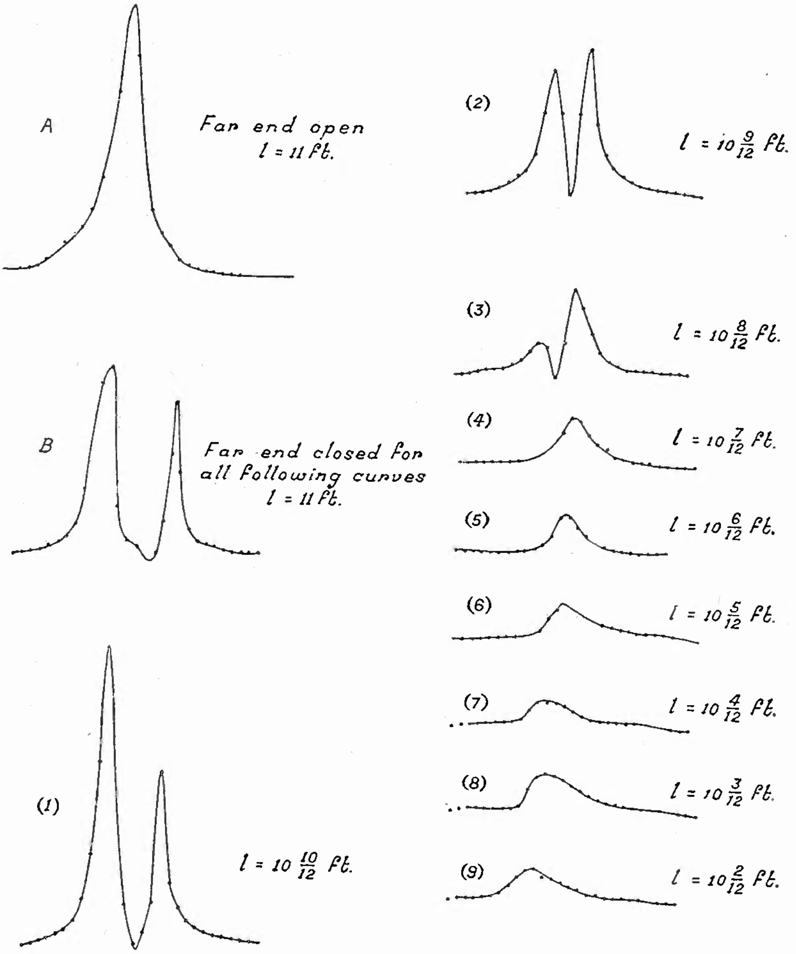

Fig. 3.—Group A to 9.

Finally the shape of a single resonance curve was studied in great detail. With the oscillator working stably at about 3.3 meters, a loose coupled Lecher system was used. The coupling was kept constant and the length of wires gradually reduced inch by inch and the current distribution in the neighborhood of a hump was observed. Curves 10 to 20 of Fig. 3 were thus obtained.

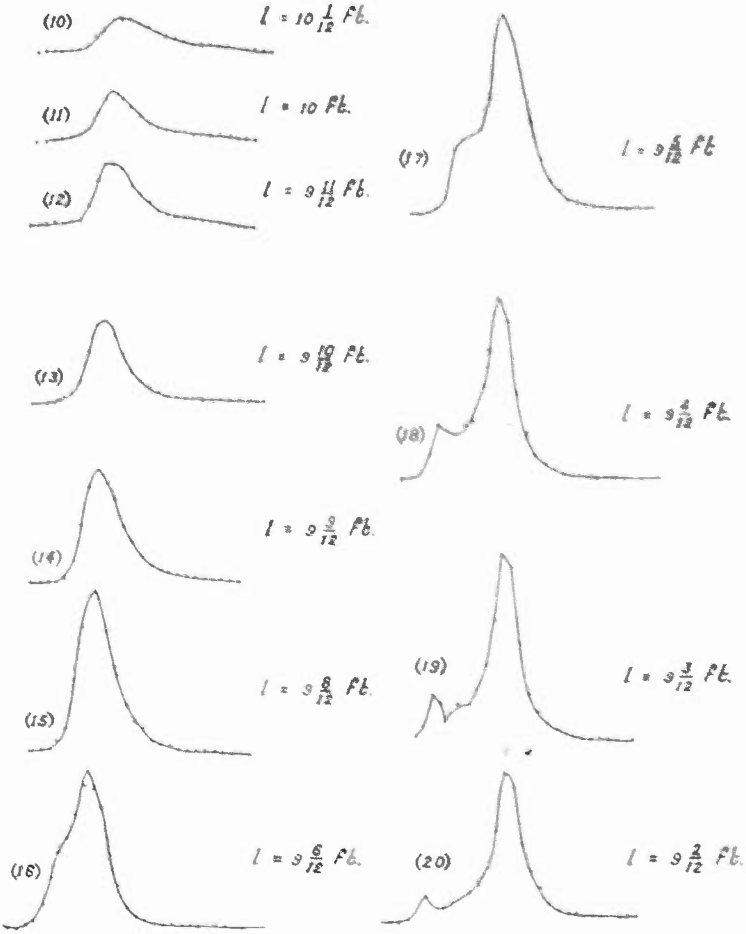

Fig. 3—Group 10 to 20.

In conclusion, the wave form in the Lecher wire method of short-wave measurements is liable to be complex if the lines are exactly a multiple of a half wavelength and the far ends are bridged. Under other conditions the distribution is controlled to a large extent by the dimensions of the system compared with the wavelength.

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POLARIZATION PHENOMENA OF LOW-FREQUENCY WAVES*

By
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Summary—*In this paper, the writer outlines the experiments of determining the state of polarization of a downcoming wave by using a cathode-ray oscillograph of Braun-tube type. Observations have been made at the Hiraiso Radio Laboratory near Tokyo for the transmissions of JAA and JND, both of which are the high power low-frequency transmitting stations located at a short distance (about 150 and 360 km respectively) away from the laboratory. The writer summarizes from the results of a series of observations that a downcoming wave is usually in a state of linear polarization during the daytime, and a sudden change occurs at sunset, the wave being changed into an elliptically polarized state, and that the wave transmitted from the station JAA located north of the laboratory is almost always in the state of left-handed polarization at night, while that transmitted from the station JND located west is nearly in the state of linear polarization during both day and night.*

1. Introduction

In RECENT years the investigations on wave propagation have been extended by many workers. Among them are Appleton[1] and Nichols and Schelleng[2] who have theoretically demonstrated that the earth's magnetic field influences the polarization of electric waves traveling through an ionized medium in the upper atmosphere. Nevertheless, little has been known about the actual state of polarization. The mathematical deducions of the workers mentioned above treat with simplified conditions, as we hardly know anything about the physics of the upper atmosphere, for example, about the distribution of its constituents, pressure, temperature, magnetic constants, etc., with respect to the height above the surface of the earth. Therefore, a further investigation on this subject should be carried out from both the theoretical and the experimental points of view.

On the other hand, although it has been determined by long experience that the direction finding with an ordinary closed-coil antenna is sometimes accompanied by serious errors, the importance of investigating the polarization phenomena has not been earnestly considered.

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* Decimal classification: R113.6. Paper originally received by the Institute, June 24, 1931. Abbreviated translation of the original paper in Japanese, *Jour. J.E.E.* (Japan), November, 1930. Presented before U.R.S.I., Copenhagen, July, 1931.

[1] E. V. Appleton, *Phys. Soc.*, November 28, 1924.
[2] H. W. Nichols, and J. C. Schelleng, *Bell Sys. Tech. Jour.*, May, 1925.

Considerable attention has recently been directed to the solution of questions as to changes in the stage of polarization of a wave radiated with the normal state of polarization when the wave is reflected or refracted by the upper atmosphere. The most important point in this connection is how to develop an experimental method of measuring the state of polarization of downcoming waves at a receiving station.The present paper outlines the method of determining the state of polarization by using a cathode-ray oscillograph of Braun-tube type and also gives a brief discussion of the results.

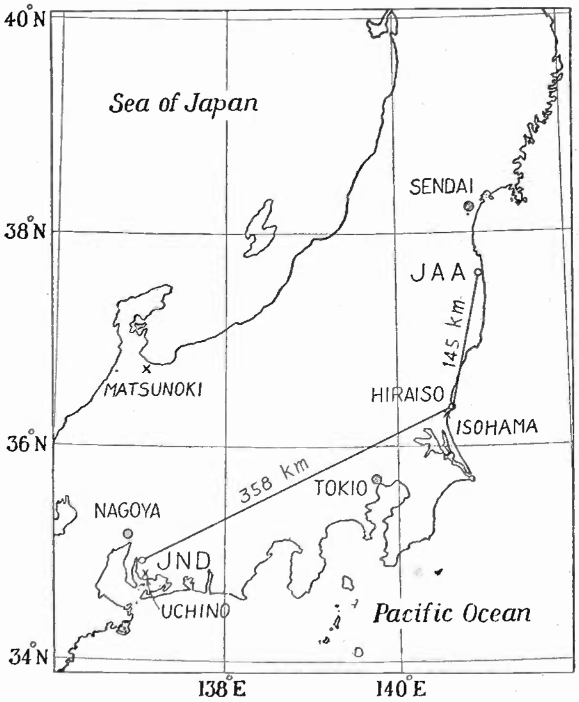

Fig. 1

2. Principle

The principle underlying the experiment is based upon the determination of the vertical and the horizontal components of a downcoming wave both in their magnitudes and phase relations. An elliptic figure which represents the state of elliptical polarization of the wave is first determined, and the sense of rotation of the ellipse is then decided by a special method. The state of polarization is thus completely known.

Observations were made at the Hiraiso Radio Laboratory (J1AG), nearly 100 km away from Tokyo, on the transmissions from JAA and JND, both of which are the high power low-frequency stations located at a short distance from the laboratory as seen in Fig. 1.

The important particulars of the stations are given in Table I.

TABLE I

Name of the Transmitting Stations	Station Call	Frequency (kc)	Geographical Position	Bearing	Distance (km)
Haranomachi	JAA	19.8	E. 140° 59′ 10″ N. 37° 37′ 59″	12° 44′	145
Yosami	JND	17.4	E. 137° 01′ 18″ N. 34° 58′ 15″	245° 35′	358

3. ASSUMPTIONS

The assumptions made in the present paper are as follow:

(1) The wave travels in the vertical plane of the great circle containing transmitter and receiver.

(2) The ground forms a perfect conductor for such low-frequency waves as treated here.

(3) All the reflected high-angle rays with exception of the lowest one are neglected due to the small amount of radiated energy at the transmitter.

(4) Throughout day and night the value of cos i (i = angle of incidence) is constant.

The validity of assumptions (1), (2), and (3) are generally recognized. Assumption (4) is made with special reference to this measurement only, and the error entering from it will be of the order of 10 per cent as roughly estimated in Table II. This assumption is valid only in the case of a short-distance transmission as in the present experiment, and it is not applicable to the case of a long-distance transmission. Fortunately, however, the question of polarization is very important in the former and not quite as much in the latter.

TABLE II
Value of cos i

Call of Transmitting Stations	Height of Conducting Layer (assumed)	
	80 km	100 km
JAA	0.74	0.81
JND	0.37	0.47

4. THEORY

The wave propagates in the $\xi\ \zeta$-plane to the positive direction of ξ-axis as shown in Fig. 2 and η-axis perpendicular to the plane of the paper is oriented in the direction away from the reader.

Let the downcoming wave be an elliptically polarized one with a vertical electric force $V \sin \omega t$ in the plane of incidence and a horizontal force $H\sin(\omega t+\theta)$ in the direction perpendicular to the plane of incidence, θ being the angle of elliptical polarization. The intensities of the component electric forces at a point P, at height h above the ground, may be written as follows:

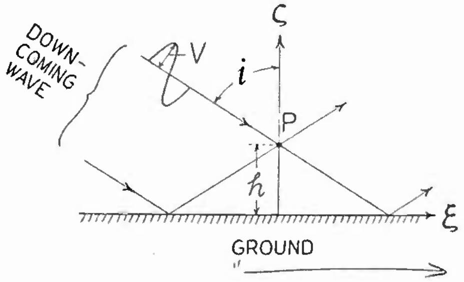

Fig. 2

$$\begin{aligned} e_x &= V\cos i\{\sin\omega t+\sin(\omega t+\Psi)\} \\ e_y &= H\{\sin(\omega t+\theta)+\sin(\omega t+\theta+\Psi)\} \end{aligned} \qquad (1)$$

or, what is the same,

$$\begin{aligned} e_x &= V'\sin\left(\omega t+\frac{\Psi}{2}\right) \\ e_y &= H'\sin\left(\omega t+\theta+\frac{\Psi}{2}\right) \end{aligned} \qquad (2)$$

where,

$$\begin{aligned} V' &= 2V\cos i\cos\frac{\Psi}{2} \\ H' &= 2H\cos\frac{\Psi}{2} \\ \Psi &= \frac{2h\omega\cos i}{v}-\pi \end{aligned} \qquad (3)$$

v and i being the wave velocity in free space and an angle of incidence respectively.

Two independent horizontal antennas are constructed and erected in such directions that one picks up e_x and the other e_y alone. The e.m.f.'s, after being amplified without causing relative change in phase and ratio of amplitude, are introduced to the pairs of deflecting plates of an oscillograph as shown in Fig. 3. An elliptic figure generally appears on the fluorescent screen. Then from Fig. 4,

$$\begin{aligned} \sin\theta &= \frac{x}{x_0} = \frac{y}{y_0} \\ V' &= K_1 x_0 \\ H' &= K_2 y_0 \end{aligned} \tag{4}$$

where K_1 and K_2 are over-all constants of a system of the Braun tube combined with the amplifier, which may be easily calibrated. From (3) and (4), θ, V, and H can be calculated.

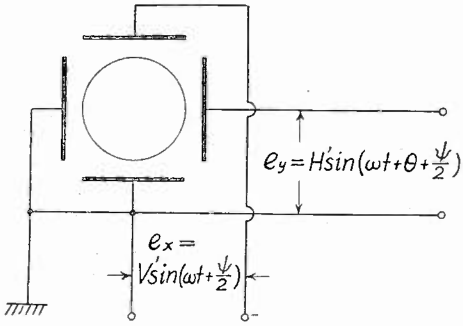

Fig. 3

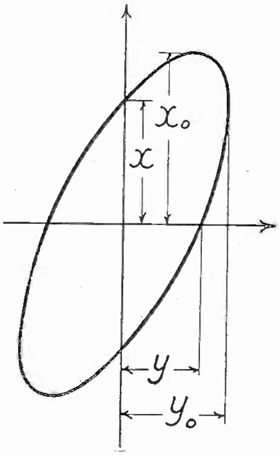

Fig. 4

Next inserting a phase shifting device composed of a tuning circuit (L and C in parallel) into a suitable part of the experimental set and changing the value of C, the sense of rotation of an ellipse which appears on the screen may easily be determined. For example, if an elliptic figure be changed to a straight-line figure of $\theta=0$ by increasing the value of C (as seen in Fig. 5), it shows that the terminal voltage of C, that is, of the pair of deflecting plates connected thereto, is leading with respect to that of the other pair. If the ellipse turns, however, to a straight-line figure of $\theta = 180$ degrees by increasing C, it will indicate that the phase relation is opposite.

Thus the four quantities of polarization, that is, $|\theta|$, V, H, and the sense of θ are definitely known.

5. Experimental Apparatus

The complete arrangement is schematically shown in Fig. 5. A and B antennas are both horizontal doublets, each measuring 50 meters long and 7 meters high above the ground with carefully transposed vertical parts. These are constructed in an open space free from local disturbances, A antenna having its orientation in the plane of incidence of the wave so that it picks up the electric force e_x alone and B antenna in the direction perpendicular to the former so that it picks up e_y alone. After making some preliminary experiments it was confirmed that no appreciable amount of the ground wave was induced in either of them.

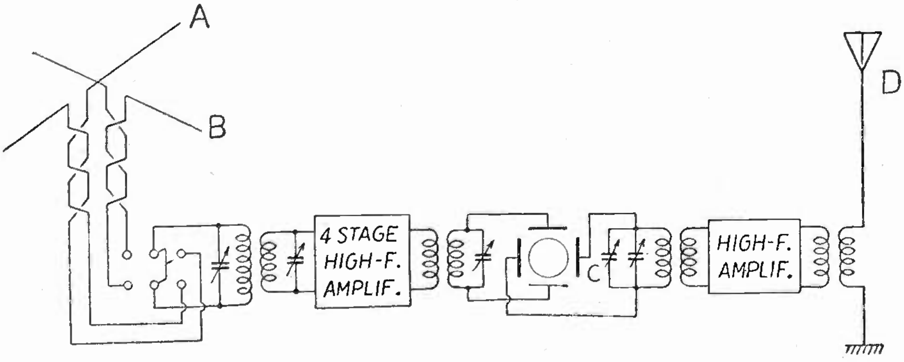

Fig. 5

Although the experimental system, in its principle, requires two independent amplifier sets having the same characteristics both in amplification ratio and phase relation, it is somewhat troublesome in practice to drive separate amplifier units under these strict conditions, and, in consequence, the inaccuracy of measurement will result. In our experiment only one amplifier unit has been provided for the principal measurement, another auxiliary receiving antenna and amplifier system called D (as shown in Fig. 5) being used. The phase of the e.m.f. induced in the auxiliary antenna D is chosen as a reference of phase at any instant, and the e.m.f.'s induced in A and B, i.e., e_x and e_y are successively introduced to the main amplifier, and magnitude and phase in each case were compared with the e.m.f. induced in D, For example, the e.m.f. induced in D and e_x are first introduced on each pair of deflecting plates of the cathode-ray tube. By adjusting the phase of the e.m.f. induced in D, the Lissajous figure may be just turned into a "straight-line figure of the same phase," and then the switch is quickly changed over from antenna A to antenna B, the phase difference between e_x and e_y being thus measured. The measurement of amplitudes of e_x and e_y is very easily made as shown in Fig. 4 and no particular difficulty arises. The whole procedure can be completed within about one minute, and for each measuring point this procedure is repeated.

Thus, for the measurement of polarization, only one amplifier is sufficient when the e.mf. induced in D is used as a reference of phase. This two-step method may look troublesome at a glance, but the accuracy of measurement thus obtained will be much higher than in the case of simultaneous driving of two similar amplifier units. It is, however, necessary that any sudden change in the state of things does not take place within an interval of a few seconds which is taken for changing over from A to B antenna. Fortunately in the case of low-frequency waves, the phenomenon generally seems to change so slowly that it can hardly be noticed during such a short interval of time.

The e.m.f.'s induced in the antennas were very small compared with the deflection voltage of cathode ray, and, therefore, an impedance-coupled 4-stage tetrode amplifier has been used. Outside the screen of the cathode-ray tube, a piece of transparent cross-sectional paper is pasted, so that easy and quick reading of the required quantities may be obtained.

6. EXPERIMENTAL RESULTS

A series of 24-hour continuous measurements were conducted for the stations JAA and JND over a period of six months since November, 1929, with the interval of once a month for each station. Although many data have been obtained, only some typical results will be shown here as all the others are similar in main characteristic features.

Example 1. Observations for JAA, March 10 to 11, 1930.

Results are shown in Figs. 6(A) and 6(B). Fig. 6(A) shows the phase difference θ between vertical and horizontal electric forces together with its plus-minus sign. Thus if θ is positive; i.e., H leads ahead of V, then the polarization must be left-handed, and, if negative, right-handed. Fig. 6(B) shows the relative magnitudes of V' and H' from which V and H may be easily calculated. As the abscissas are taken the time scale expressed in Japan Central Standard Time.

It will be seen from these results that during the daytime the value of V'/H' is large and θ is not far from 180 degrees. This means that the downcoming wave is nearly plane-polarized (i.e., an elliptically polarized wave with great eccentricity) with its electric force nearly in a vertical plane but slightly inclined in the counterclockwise direction. However, at sunset, remarkable change occurs and, during nighttime, the ratio V'/H' decreases and θ approaches 90 degrees. Thus the state of polarization of the wave changes from linear to elliptical, and very often to nearly circular polarization at midnight. The sense of rotation of the elliptical polarization is always left-handed. After sunrise it returns to the daylight state. In Fig. 7 are reproduced the changes of the state of polarization in the more familiar manner, which are constructed from V' and H' plotted in Fig. 6(B) by using the value of cos $i = 0.77$.

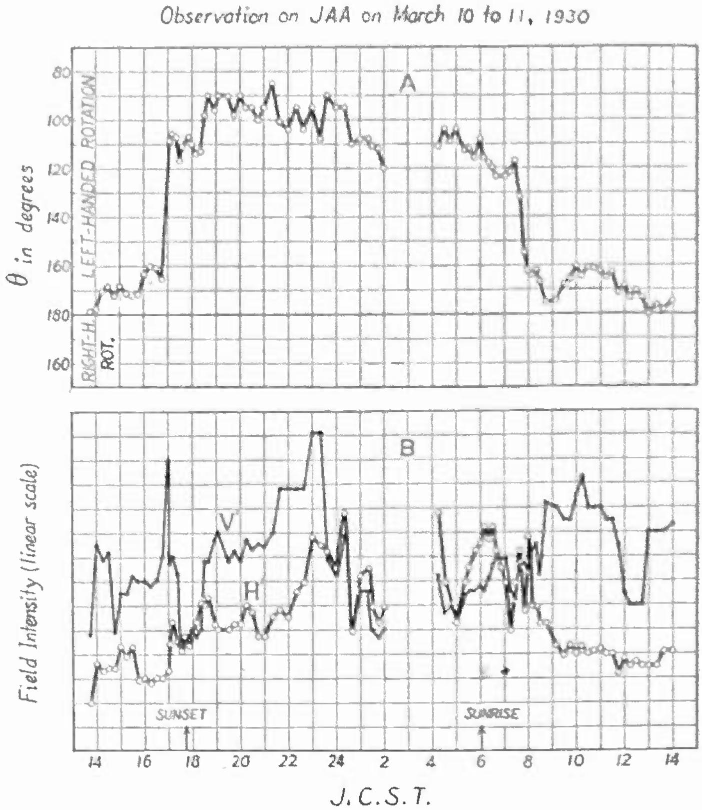
Observation on JAA on March 10 to 11, 1930

Fig. 6

Other results obtained for JAA are generally similar, but some data show that, at sunset, the polarization changes its state twice, and does not change only once. One example of this kind of variation is shown in Figs. 8(A) and 8(B), in which the polarization changes once quickly into the night state, then immediately returns to its daytime state, and again recovers the steady state at night. This phenomenon has been observed rather more frequently at sunset than at sunrise.

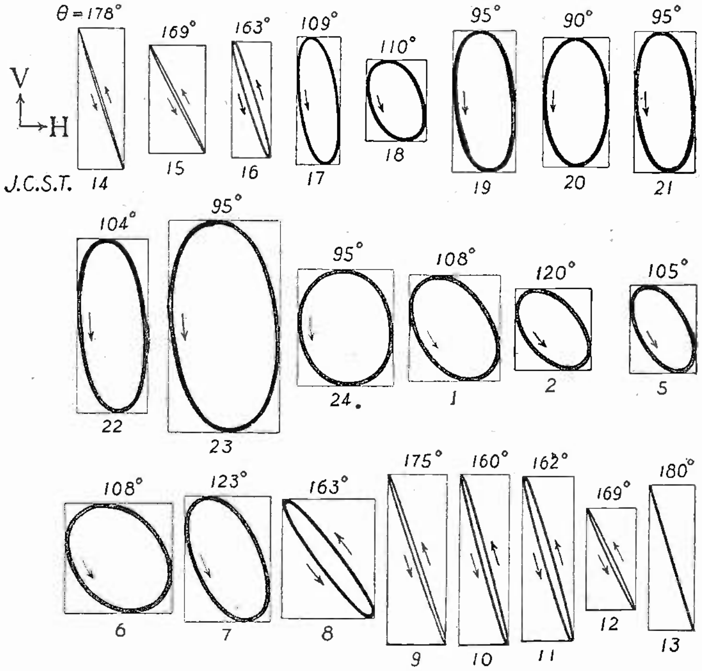

Fig. 7

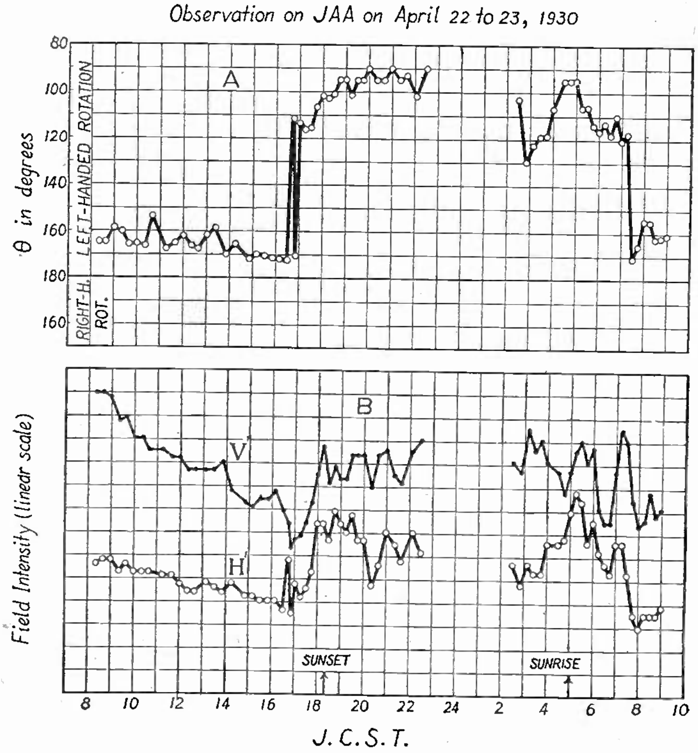

Fig. 8

Example 2. Observations for JND, February 24 to 25, 1930.

Figs. 9(A) and 9(B) show the similar results taken for JND, and the changes of the state of polarization are shown in Fig. 10, constructed from Fig. 9(B) by using the value of $\cos i = 0.4$. The characteristic feature concluded from these results is the fact that throughout day and night the ratio V'/H' was much larger than in the case of JAA. The state of polarization was, therefore, generally of an ellipse of very great eccentricity. Even at midnight the polarization ellipse was sharp. These sharp ellipses for JND were all nearly vertical and slightly inclined in the clockwise direction, which is quite a different state from the case of JAA. These characteristics were always common in many observed results, while, with regard to the sense of rotation of the elliptical polarization, it was quite at random, on one day a left-handed wave being observed while on the other a right-handed one.

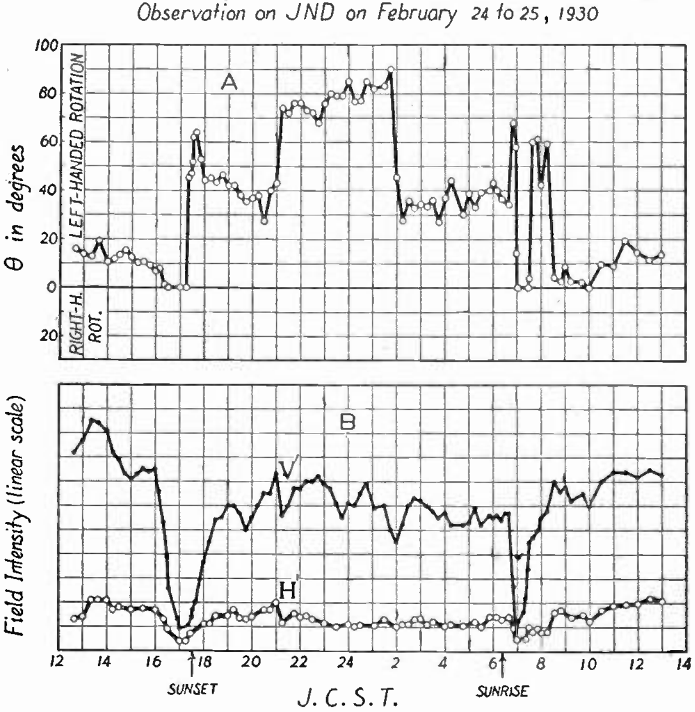

Fig. 9

7. Summary

The results may be summarized as follow:

(1) The downcoming wave is almost plane-polarized during daytime with its electric force nearly in a vertical plane. A quick change occurs at sunset, the wave being turned into an elliptically polarized state.

(2) The wave transmitted from the station JAA located north of the observing station is of the plane-polarized form slightly inclined in the counterclockwise direction during daytime, while, at night, it changes into the state of elliptical polarization of small eccentricity. The sense of rotation is always left-handed.

(3) The wave transmitted from the station JND located in the direction of west-south-west is, throughout day and night, nearly plane-polarized (i.e., elliptical polarization of very great eccentricity) and slightly inclined in the clockwise direction. The sense of rotation is irregular, sometimes right-handed and sometimes left-handed.

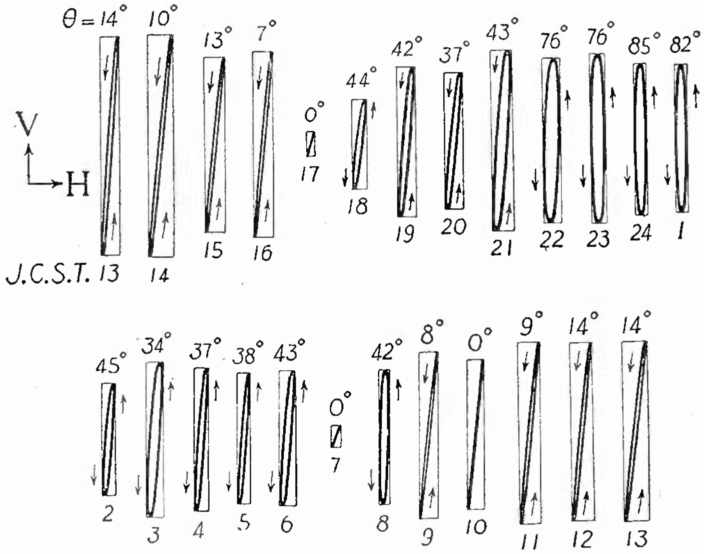

Fig. 10

(4) At sunset and sunrise, a quick change occurs. At sunset several results show a double transition phenomenon.

(5) Seasonal variations in polarization are not noticeable as far as the period of observations is concerned.

8. GENERAL CONCLUSIONS

How may the phenomena of elliptical polarization be produced? This is the vital point for discussion.

It may generally be admitted that the low-frequency waves as here treated are radiated from a transmitter with its electric force only in the vertical plane, if a long-wave transmitting antenna is used as in practice. The production of an elliptically polarized wave from a plane-polarized one whose electric force lies only in the plane of incidence would be possible when the medium into which the wave penetrates is not a perfect nonconductor. However the amount of the elliptical polarization thus obtained would not be so marked as to give a satisfactory explanation to the present results.

Next the existence of inclination or curvature in the ionized layer may be possible at sunset and sunrise, but, at night when the ionized state is considered to be quite steady for these low-frequency waves, it is rather difficult to imagine its existence for explaining the production of an elliptically polarized wave. The interfering action of reflected waves is also improbable, because the field strength of the downcoming ray shows no such remarkable change between day and night.

Another factor to be taken into account would be the action of the terrestrial magnetism. Yet the order of the effect which may be attributed to the earth's magnetic field is considered negligible as the wave frequency is so low. Thus it would scarcely be possible that the earth's magnetic field is so effective as to produce an elliptically, especially, a circularly polarized wave as observed in the present results.

However comparing the case of JAA with that of JND, there may be seen several distinct differences in their characteristics. First, the former displays predominant elliptical polarization during night while the latter shows it scarcely. The reason for this seems to be due to the shorter distance of transmission in the former. Second, in the former case the left-handed rotation is observed regularly while in the latter case certain irregularities are encountered, which may be fairly attributable to the difference in the direction of propagation with respect to the magnetic meridian. The transmission path of the former is nearly in opposite direction to the magnetic line, although that of the latter is almost perpendicular to (or slightly along) it.

In conclusion, the author is of opinion that it is yet uncertain whether the cause of the production of an elliptically polarized wave be attributed to the terrestrial magnetism or not. Further investigations are still necessary to give a satisfactory explanation to the present results.

ACKNOWLEDGMENT

The author is deeply indebted to Dr. H. Nagaoka who gave him valuable advice especially towards the theoretical considerations involved and to Mr. E. Yokoyama under whose direction the present study has been worked out. He would also like to acknowledge his thanks to Mr. S. Ueno by whom these measurements were carried out.

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POLARIZATION OF HIGH-FREQUENCY WAVES AND THEIR DIRECTION FINDING*

BY

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Summary—*This paper describes the results of experiments which were conducted during the past two years for the purpose of studying the high-frequency transmission phenomena, and some physical explanations deduced therefrom.*

The authors are of opinion that it is preferable to take up the questions of polarization and direction finding simultaneously. For the measurements of polarization, the authors used a single doublet which may be rotated in the directions of three coördinates, and measured the component electric forces by it. For direction measurements, they used an Adcock-type aerial which was specially designed by themselves so as to be suitable for the observations on high-frequency waves.

The conclusions thus obtained are briefly summarized as follows:

(1) The waves are, as a whole, elliptically polarized, and in general the state of polarization largely depends on the transmission distance. When the distance is short, the state of polarization will usually be horizontal, whereas it is generally vertical when the distance is long. In either case, the direction measurement is satisfactory.

(2) Within a certain distance, the direction measurement is impossible owing to the scattering of the waves.

(3) If transmitter and receiver are so situated as to be in nearly antipodal relation, the main waves do not always propagate along the great circle path, but take various routes according to the distribution of day and night.

INTRODUCTION

THOUGH the mechanism of short-wave transmission has been made considerably clearer in the light of the theory and practice recently advanced, new and unaccountable phenomena are still met with such as echo signals, rapid fading, scattering, etc. Investigations in wave transmission may start with the measurement of any one of the various quantities, such as field intensity, echoes, polarization, apparent direction, and so forth. The authors are of the opinion that it is preferable to study polarization and direction finding simultaneously in investigations of high-frequency transmission phenomena. With this object in view, a series of observations have been conducted by the authors during the past two years. In this paper a brief account is given of the experimental results obtained, together with some physical explanations deduced therefrom.

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* Decimal classification: R113.6×R125.31. Original manuscript received by the Institute June 24, 1931.

PART I. MEASUREMENTS ON POLARIZATION

1. GENERAL CONSIDERATIONS

For low-frequency waves, the electromagnetic energy per unit volume in space may be estimated by measuring its vertical electric force as is generally done. The method will, however, be of no meaning, when applied to high-frequency waves, on account of the presence of polarization phenomena similar to those of optical rays.

The authors observed last year the state of polarization of downcoming low-frequency waves by using a cathode-ray oscillograph under a few generally accepted assumptions.[1] This method is, however, hardly applicable to similar measurement for high-frequency waves, because the pattern on the fluorescent screen changes so rapidly (due to the fading) that no suitable method of recording it was found, and second, because the receiving set inserted between antenna and cathode-ray tube is much greater in dimensions, compared with the wavelength used, than that in the measurements for low-frequency waves. These facts explain why the measurements for high-frequency waves are much more erratic than those of low-frequency ones.

As a last resort, a simple method was used in which the three component electric forces are measured in magnitude alone. They are generally represented in the form of ellipsoid at a point in space due to the action of the ionized layer in the upper atmosphere and the earth. The determination of the complete form of the ellipsoid at any instant is almost impossible because of many unknown factors. The principle adopted by the authors is first to measure the component electric forces and then to estimate therefrom the probable state of polarization of the downcoming wave, using the knowledge of the property of the earth which is hitherto known, together with the results obtained from the direction finding experiment, which will be described later.

2. THEORY

The downcoming wave is assumed to propagate in the great circle plane containing transmitter and receiver, and it is generally assumed to be elliptically polarized with its electric force $V \sin \omega t$ in the plane of incidence and $H \sin(\omega t+\theta)$ in the direction perpendicular to it. The coördinates are chosen as shown in Fig. 1, in which the axis η is taken perpendicular to the plane of the paper away from the reader. Then the three component electric forces e_x, e_y, and e_z at a point with height h above the ground are:

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[1] S. Namba and S. Ueno, *Jour. I. E. E.* (Japan), November, 1930.

$$
\begin{aligned}
e_x &= V \cos i\{\sin \omega t + a \sin (\omega t + \psi_a)\} \\
e_y &= H\{\sin \omega t + b \sin (\omega t + \theta + \psi_b)\} \\
e_z &= V \sin i\{\sin \omega t - a \sin (\omega t + \psi_a)\}
\end{aligned} \tag{1}
$$

and,

$$
\begin{aligned}
\psi_a &= \frac{2h\omega \cos i}{v} - \Phi_a \\
\psi_b &= \frac{2h\omega \cos i}{v} - \Phi_b
\end{aligned} \tag{2}
$$

where v is the velocity of wave in free space, a and b are "reflection factors" which are introduced because the earth is considered to form an imperfect conductor; and Φ_a and Φ_b are the phase angles of wave changed at ground reflection which will give different values from 180 degrees because of the same reason above. Although downcoming rays are many in number, at any point it is assumed that these may be replaced by a single vector. It is, of course, not necessary to take into account the direct wave in studies of the transmission of high-frequency waves and it is hence omitted from the equation.

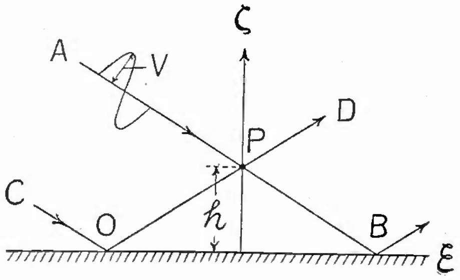

Fig. 1

From (1) a root-mean-square value of each component electric force will be found as follows:

$$
\begin{aligned}
X &= \left[\frac{1}{2\pi}\int_0^{2\pi} e_x^2 d(\omega t)\right]^{1/2} = \frac{V}{\sqrt{2}} \cos i \sqrt{1 + a^2 + 2a \cos \psi_a} \\
Y &= \left[\frac{1}{2\pi}\int_0^{2\pi} e_y^2 d(\omega t)\right]^{1/2} = \frac{H}{\sqrt{2}} \sqrt{1 + b^2 + 2b \cos \psi_b} \\
Z &= \left[\frac{1}{2\pi}\int_0^{2\pi} e_z^2 d(\omega t)\right]^{1/2} = \frac{V}{\sqrt{2}} \sin i \sqrt{1 + a^2 - 2a \cos \psi_a}.
\end{aligned} \tag{3}
$$

Quantities a, b, Φ_a, and Φ_b depend on the frequency and the angle of incidence of the wave, and also on the property of the earth. Unfortunately we have no exact knowledge of these quantities and, therefore, the authors used the data shown in Pedersen's book.[2] Calculating (3), the curves are obtained as shown in Figs. 2 to 4. They represent the relation of each component field strength at a point (at the height h above the ground) with the angle of incidence of the wave for various heights and frequencies, where the soil is assumed dry and also V equal to H. It is seen from Fig. 2 that the component Z predominates when the angle of incidence is large, whereas Y or X predominates when the angle is small; in other words, dry earth behaves as to make Y/Z or X/Z smaller or greater according to the angle of incidence. Figs. 3 and 4 are of similar nature to Fig. 2, in which different values of ω and h are used for calculation. Thus it will also be seen that, if X, Y, and Z be measured at a height of 7.5 meters as adopted in our experiment, Y will be the greatest for any angle of incidence, where it is assumed that $V = H$ in the downcoming ray.

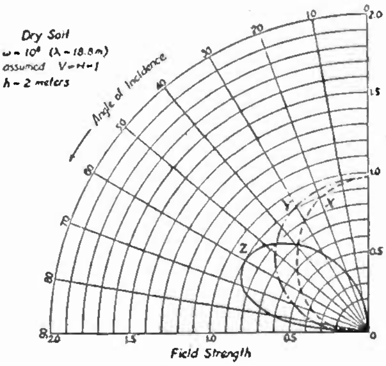

Fig. 2

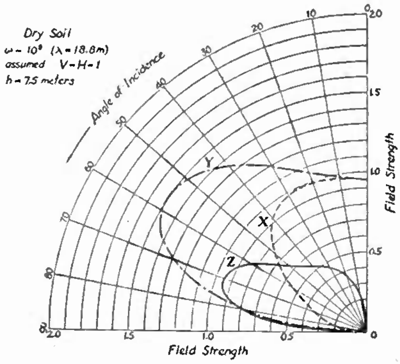

Fig. 3

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[2] P. O. Pedersen, Propagation of Radio Waves, pp. 122–135, 1928.

3. Experimental Apparatus

By rotating a single doublet in the directions of the x, y, and z axes successively, the electric forces X, Y, and Z are measured. The doublet, the center of which is 7.5 meters high above the ground, is constructed at the top of a wooden hut, so that the radiation height of the doublet may be varied by an amount as small as possible by its rotation.

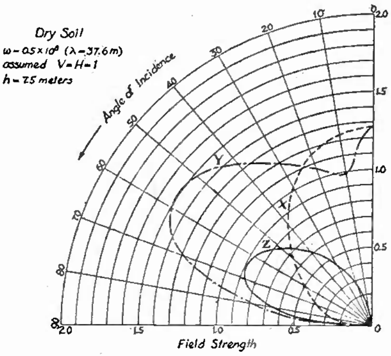

Fig. 4

Next, a valve voltmeter is constructed as shown in Fig. 5 for the indication of signal intensity. The voltmeter is connected to a receiving set composed of a two-stage high-frequency amplifier, a detector and a two-stage low-frequency amplifier. The complete arrangement is as shown in Fig. 6. As the voltmeter reading suffers fluctuation due to the fading of the wave, the mean values of X, Y, and Z are determined as shown in Fig. 7, the ratios X/Z and Y/Z being thus calculated. The procedure is repeated about ten times to calculate the geometrical mean values which are taken as final values of X/Z and Y/Z.

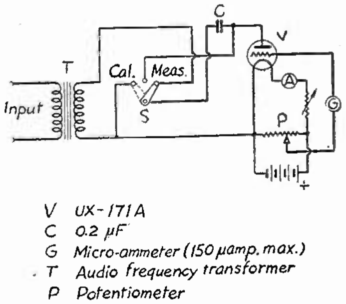

Fig. 5

4. Experimental Results

Many observations have been made at Hiraiso Radio Laboratory situated on the Pacific coast about 100 km northeast of Tokyo; only some typical results obtained will just be shown as the others were all similar in principal characteristics. The measurements on the stations whose distances are over 1000 km from the receiver generally show that Z is greater than Y, and X is much smaller than Y and Z as seen from

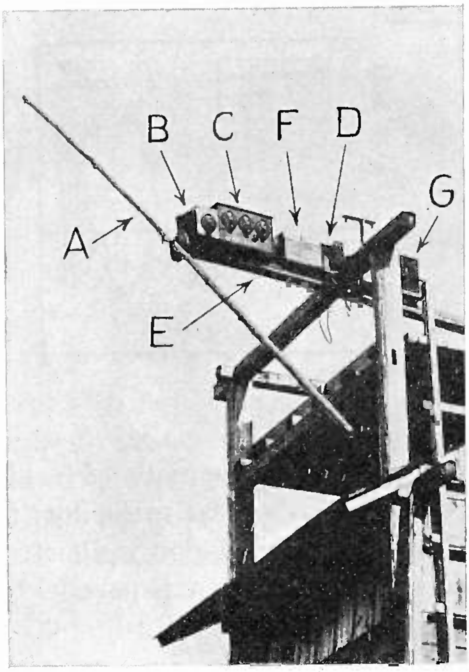

Fig. 6

A	Doublet (rotates in vertical plane)
B	Antenna coupling box
C	Receiving set
D	Valve voltmeter
E	Wooden arm (rotates in horizontal plane)
F	Anode battery
G	Filament battery

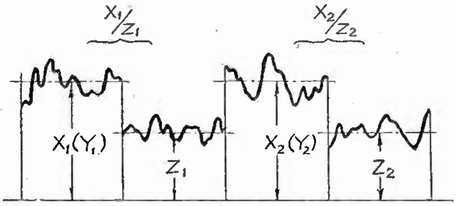

Fig. 7

Figs. 8 and 9. Although the earth behaves as to make Y/Z greater as described in the previous section, yet the result shows the predominance of Z. This reveals the fact that the wave from a distant station is mostly elliptically polarized, and the major axis is vertical to the ground as schematically shown in Fig. 10(a). From the result that the component X is much smaller than Z and Y, it is also seen that the wave of long-distance transmission comes into the receiver with a small angle of elevation as is thought to be.

On the other hand, for a nearer station such as JES (Osaka), very great values of Y/Z and X/Z are obtained as shown in Fig. 11, the ratio sometimes amounting to from 10 to 30. The earth behaves as to make Y/Z or X/Z greater when the angle of incidence of the wave is smaller, and yet we obtain such great ratios for these. It is thus seen that, when the distance of transmission is short, the wave is mostly elliptically polarized with the major axis parallel to the surface of the ground as schematically shown in Fig. 10(b).

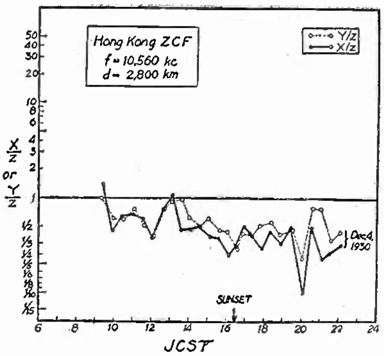

Fig. 8

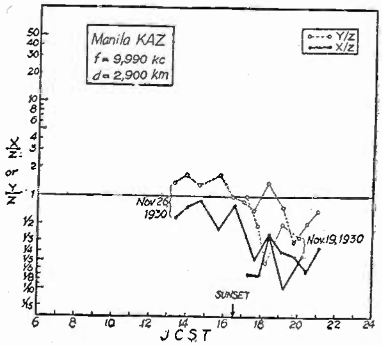

Fig. 9

The bearings of the stations above-mentioned can be determined accurately by means of an Adcock-type direction finder which will be described in Part II.

As previously mentioned, the electromagnetic field at a receiving point may be determined by the three factors; i.e., the polarization of a downcoming wave itself, the property of the earth, and the height of the point above the ground. Now the possible influences of the last two factors are taken into consideration and eliminated from the results of measurements. The probable state of polarization of a downcoming wave itself thus estimated varies mostly as the distance of transmission; at a short distance the ellipse is horizontal and at a great distance vertical. No reasonable explanation for the above can be found at present, as it may be imagined that the chances where H is larger or smaller than V occur with equal probability whatever may be the mechanism in the ionized part (earth's magnetic field, ionization, collision, etc.), as the length of the wave path in the ionized medium is of course considered to be very great, compared with the wavelength.

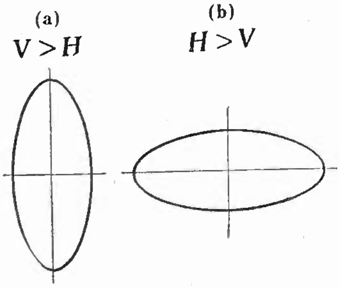

Fig. 10

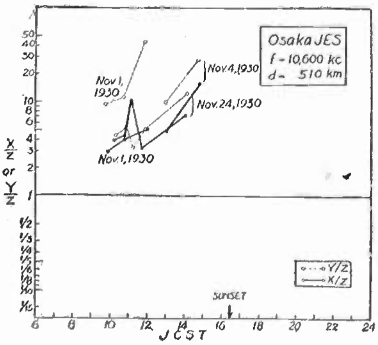

Fig. 11

On the other hand, Tokyo JAN (115 km away from the city of Tokyo) almost always had no bearing when tried with an Adcock-type direction finder. No adequate explanation of this is apparent to us. At first it was thought that the horizontal electric force might be very much greater than the vertical beyond the working limit of the direction finder, although the wave itself traveled along the great circle path. According to Smith-Rose,[3] lateral deviations of the broadcast wave can scarcely be observed by the Adcock-type direction finder and it is, therefore, interesting to study if high-frequency waves deviate laterally. Therefore, the authors tried the polarization measurement to

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[3] R. L. Smith-Rose, PROC. I. R. E., March, 1929.

confirm whether polarization or lateral deviation be true. Their results showed that the phenomena observed is not due to polarization effect but to the scattering effects as has recently been proposed by T. L. Eckersley.[4] As shown in Fig. 12, the electric forces X, Y, and Z measured were approximately equal; that is, the results turned out contrary to the author's expectation that Y/Z would be very great. It is, therefore, true that the rays arrive from various directions in this case. The state of polarization of each downcoming ray cannot be observed.

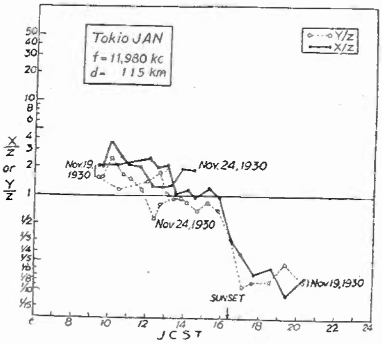

Fig. 12

PART II. DIRECTION FINDING

1. Construction of the Direction Finder

The Adcock-type aerial, patented in England far back in 1919, has been successfully used by Smith-Rose for direction finding at broadcast frequencies. The authors[5] have tried during the past two years to construct a portable direction finder for short waves based on the principle of the Adcock aerial.

After several seasons of experiments, a final apparatus has been constructed and it is shown in Fig. 13 and also schematically in Fig. 14. It is a symmetrical and balanced Adcock-type aerial which is rigidly mounted at the central part on a vertical rotating shaft 3.5 meters in length. The effective area of the aerial is 1.5×3 meters and a part of the receiving apparatus containing a high-frequency amplifier and a detector is set at the central part of the aerial, so that the whole structure can be rotated through the vertical shaft. The audio-frequency current detected runs down along a pair of lead wires and is introduced to an audio-frequency amplifier placed on the ground. The reason why the high-frequency part of the receiver is mounted up on the aerial is

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[4] T. L. Eckersley, *Jour. I. E. E. Wireless Proceedings*, September, 1929.

[5] A Japanese patent on the improved arrangement has been applied for and the outline was published in *Jour. I.T.T.E.* (Japan), December, 1929. A similar investigation was recently published by Barfield, (*Jour. I.E.E.*, September, 1930.)

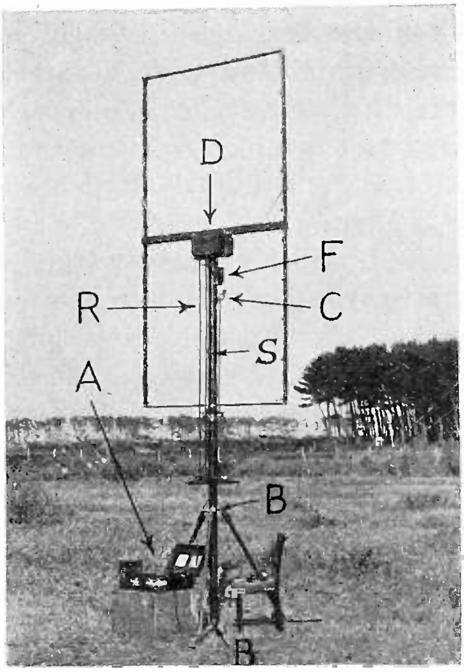

Fig. 13

D	H-F amplifier and detector
F	Filter box
C	Variable condenser for sense determination
R	Adjusting rods
A	A-F amplifier and d-c supplies
S	Main rotating shaft
B	Ball bearing

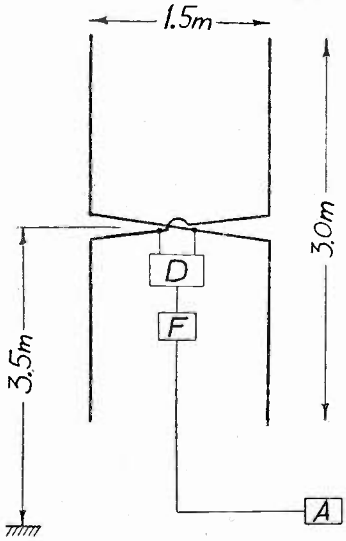

Fig. 14

D	One-stage h-f amplifier and autodyne detector
F	H-F filters
A	Two-stage a-f amplifier and d-c supplies

to make the lead wires carrying high-frequency current as short as possible. The condensers in the receiver on the aerial may be smoothly adjusted by means of long bakelite rods.

Another important part is a high-frequency filtering box which is seen in the photograph. In each of the d-c feeders and lead wires carrying detected current, a filtering unit composed of a choke coil and a bypass condenser is inserted, which will prevent the radio-frequency current induced in the vertical lead wires and feeders from flowing into the detector. Several choke coils with different values of inductance are provided, so that the most effective one may be selected according to the frequency of the wave.

The directional characteristic of the aerial in itself takes the form of the figure "8." However it may be transformed into that of a cardioid when the impedance of the filtering box is varied by adjusting an additional condenser which is connected across one of the choke coils, and thus the sense of the incoming wave may be known.

The main shaft supporting the aerial can be rotated so smoothly, being all provided with ball bearings at its lower end, that the operator need not pay special attention in operating this apparatus against the change of beat note which may be caused while the aerial is in motion; otherwise, the beat frequency will fluctuate because of the mechanical vibrations of the moving body.

2. ACCURACY AND SOURCES OF ERROR

The errors for direction finding are considered to be due to the following causes:

(a) Orientation and leveling of the apparatus,
(b) Polarization of wave,
(c) Near-by conductors.

It has been ascertained by numerous experiments hitherto conducted that a maximum error due to (a) may be estimated approximately at ±2 degrees, and that due to (b) ±4 degrees under the condition that the horizontal electric force of the wave has a value less than 30 times as large as the vertical. The latter figure has been obtained from a series of careful experiments carried out with the aerial by receiving direct waves which were generated near by and whose plane of polarization could be turned at will to various inclinations. The apparatus works satisfactorily, of course, in practical cases, in which the state of polarization of incoming waves is generally of such an order that Y/Z is less than 20 as explained in Part I.

The elimination of error due to (c) is very important in the case of practical use of the apparatus. Some experiments were carried out to know roughly the minimum distances at which no appreciable error is caused by near-by conductors. The results of the tests are summarized in Table I.

TABLE I

Kind of Near-by Conductors	Minimum Distance in Meters
Metallic Structure; Power and Telephone Line	50
Antenna Guy-Wire Sectionalized by Insulators	50
Assemblage of Buildings in City Area	100
Assemblage of Aerials of Various Kinds such as Radio Receiving Station	200

The method of direction finding by the apparatus is to rotate the aerial and to find the point of minimum response as in the case of a frame aerial for low-frequency waves. However the practical application of this method is somewhat difficult compared with the case of low-frequency waves due to the fact that first the wave suffers from fading and second the direction of incoming wave seems to be wandering about, though the amount is not so great. It is also generally required to find both positions of minimum response and to average them to get the true bearing, as a slight amount of the vertical antenna effect is often existing in the apparatus. Figs. 15 to 17 show the typical results in which ϕ_1 and ϕ_2 are not equal, due to the cause above-mentioned. A complete polar curve may be obtained within ten minutes while the observation on a single bearing involving the measurements of both positions of minimum response can be made within two minutes. The deformations and discontinuities in the polar curves indicate the effects due to fading.

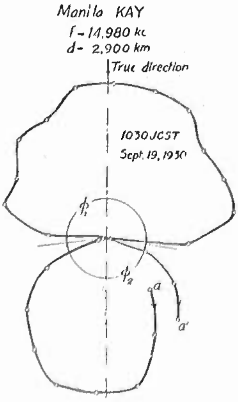

Fig. 15

3. RESULTS OBTAINED FOR LONG-DISTANCE STATIONS

According to the results obtained during the past two years for short-wave stations whose frequencies are from 5000 to 25,000 kc, the bearing of any station can be measured with good accuracy except in two cases, (1) when the transmitter is situated very near to the antipode of the globe with respect to the receiver, and (2) when it is located within a few hundred kilometers from the receiver.

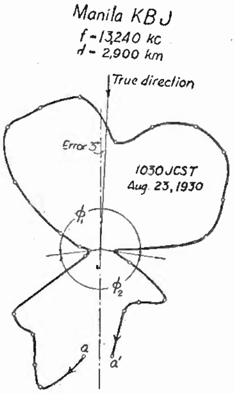

Fig. 16

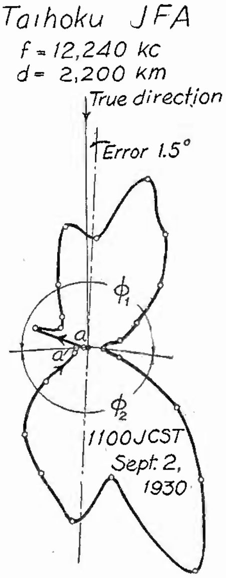

Fig. 17

The diurnal variation of bearings of stations located at moderately long distances is not so great even at sunset and sunrise, but for some of these stations, there occur certain distinct variations with the altitude of the sun, although their amplitude is not so great. A report on this kind of irregularity in direction finding will be published shortly in a separate paper.

In Figs. 18 and 19 are shown some typical results for moderately long-distance stations. As all long-distance stations in various continents gave correct bearings with no exception, the results are omitted here.

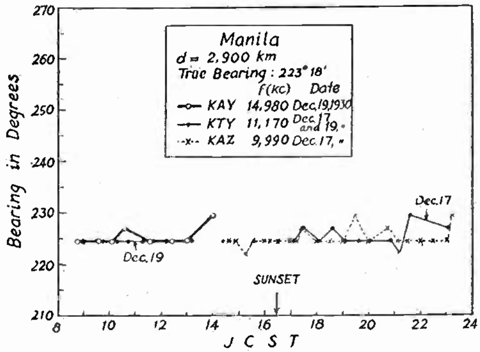

Fig. 18

4. No-Bearing Phenomena at Short Distances

Though the direction finding is an easy matter for distant stations, it is generally difficult for those stations located within the distances of from about 50 to a few hundred kilometers.

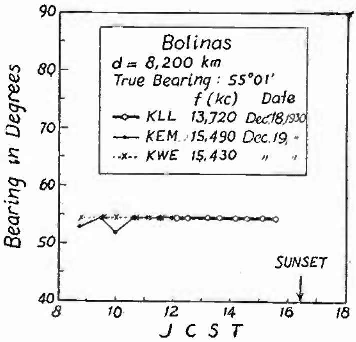

Fig. 19

In order to get a more exact knowledge on the latter cases, a direction finder was carried to places at various distances from the transmitter and measurements on bearings were made there on various frequencies. The results are summarized in Fig. 20. The zigzag portions in the signal intensity-distance curves indicate no-bearing regions, while the full-line portions show the regions where true bearings were obtained. Thus the no-bearing phenomenon seems to be closely associated with the so-called skip distance, for it is only at the edge of the skip distance that this phenomenon is observed.

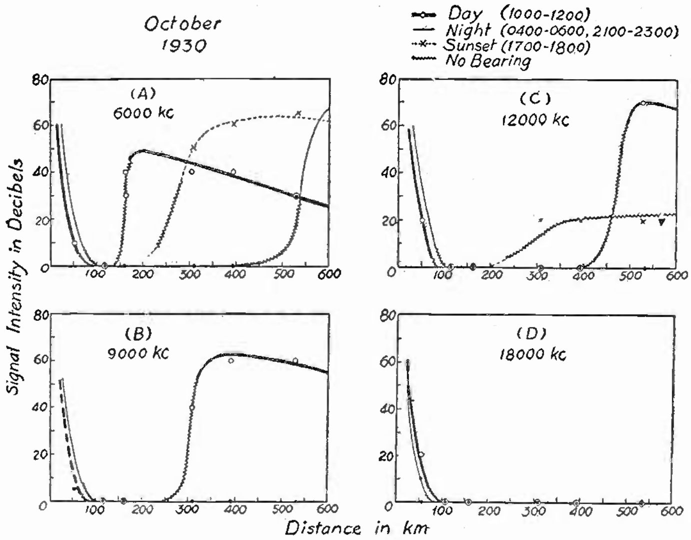

Fig. 20

Other examples of no-bearing phenomena, which were observed on JAN, are shown in Fig. 21. Bearings could not be measured at sunset and sunrise, although at the remaining hours fairly good results were obtained.

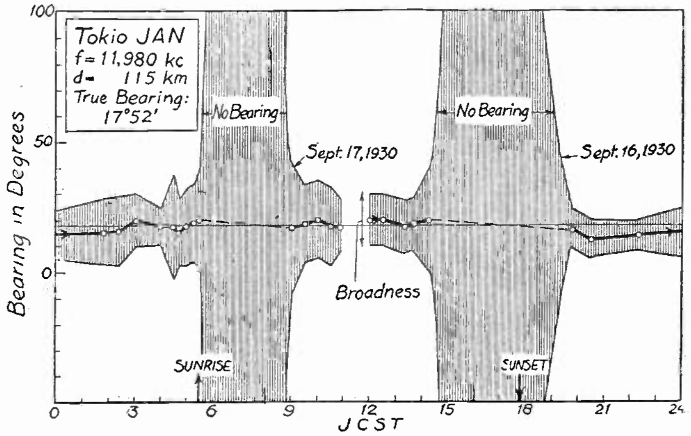

Fig. 21

This phenomenon depends not only on frequency, transmission distance, time of day and season, but also sometimes on the form of transmitting aerial. As examples Figs. 22 and 23 are given, in which two transmitters, JNA and JNG, of Nagoya station were observed at Yokkaichi, 37 km away. These transmitters are provided with beam aerials for the same direction, the former being an RCA-type broadside projector composed of vertical elements while the latter is a Telefunken-type horizontal beam projector. Though the former showed no bearings at sunset and sunrise, the latter gave a good reading on bearing even at sunset.

5. Antipodal Effect

If a transmitter be situated at the exact antipode of the receiver, there is no definite geometrical great circle path, that is, the wave may arrive from any direction. However, if the station be slightly apart from the exact antipode, what will be the direction of wave propagation? Does the path of the wave deviate laterally?

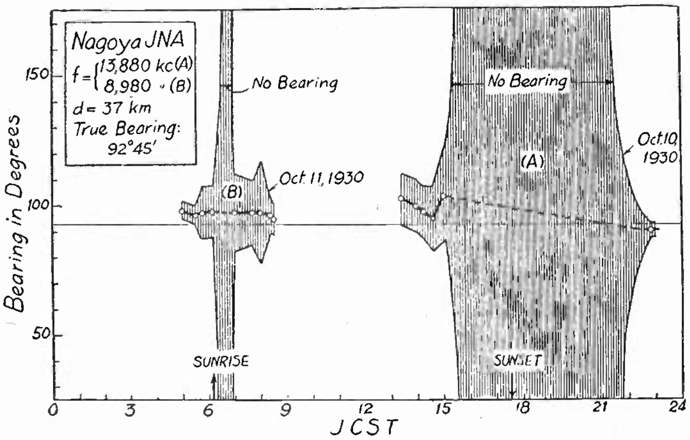

Fig. 22

Now the Monte Grande station is situated about 1700 km from the antipode of Tokyo and its true bearing in Tokyo is 90 degrees; i.e., due east. The bearings of Stations LSI, LSX, LQA were observed during the period extending from November to December, 1930, and the results of these observations are as shown in Fig. 24, in which (A)

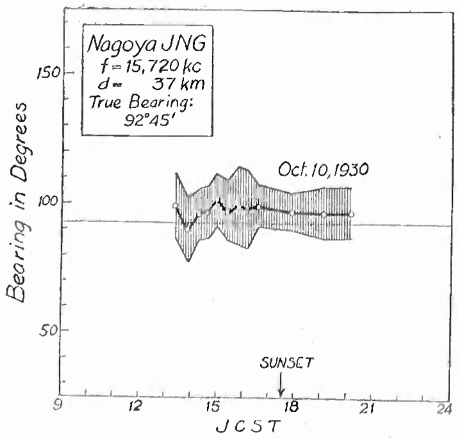

Fig. 23

shows the variation of bearings observed, (B) the average variation, and (C) the corresponding signal strength of the stations.

Referring to Japan Central Standard Time (which is ahead of G.M.T. by 9 hours), in the morning the wave was coming from the west, and at about 10:00 A.M. it gave no bearing; after a while it began to arrive from the northeast, and then the bearing gradually varied towards east until it passed over the true bearing of 90 degrees, and at sunset it reached about 150 degrees; i.e., south-south-east, after which it gradually returned to the true bearing.

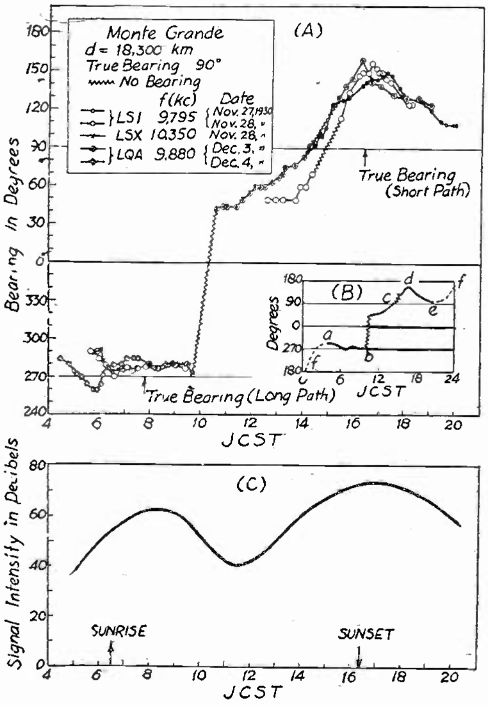

Fig. 24

The interesting phenomenon in directional observations on these stations is explained below. It is obvious that these lower-frequency waves under discussion mainly propagate through the darkened hemisphere. Therefore, in order to give fairly strong signals at the receiver, the wave will be required to propagate along its transmission path containing as short a daylight portion as possible. As for the above-mentioned stations situated slightly apart from the antipode, it may be easily imagined that the wave propagates along a small circle path on which the daylight portion is minimum, rather than along the great circle path on which the sunlit part is a little longer. In Fig. 25 it is shown how the minimum daylight path varies as the hours of the day and how it is in agreement with the actual variation of observed direction.

In Fig. 24(B) the curved portion *cde* is raised high up until it reaches almost 150 degrees. The reason will be that at this time of the day the sunset twilight zone lies in the direction of 153 degrees as viewed from the receiving point as seen in Fig. 25. On account of the intense rays coming through this zone the observed bearing of the wave is so shifted. It is a well-known fact that short waves may travel with a wonderfully small attenuation through a twilight zone as frequently observed in echo phenomena.

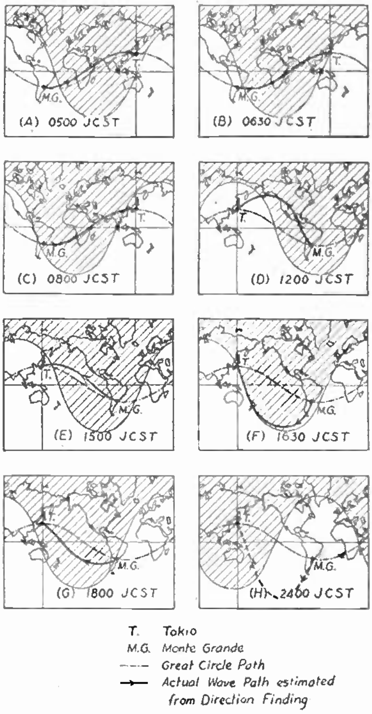

Fig. 25

At sunrise no remarkable lateral deviation in the direction of the incoming wave is observable, while at sunset the marked deviation is noticeable. The reason for this dissimilarity lies in the fact that in November and December the transmitter is yet in a dark region at the time of sunset at the receiver, while it is still in a sunlit region when sunrise approaches at the receiver. The wave, in the latter case, travels along the minimum daylight path independent of twilight zone at the receiver, no remarkable deviation of bearing being thus observed at the sunset period.

CONCLUSIONS

(1) Measurements on polarization of a downcoming high-frequency wave present great difficulties as our knowledge of the electrical properties of the earth is very much limited. However, if hitherto known electrical constants are adopted, it is possible to eliminate the influence of the ground and to estimate the probable state of polarization from the results of measurements. The waves are, in general, elliptically polarized, the state of polarization being

(a) mostly horizontal, that is, an ellipse with its major axis parallel to the ground as shown in Fig. 26, when the distance of transmission is short,

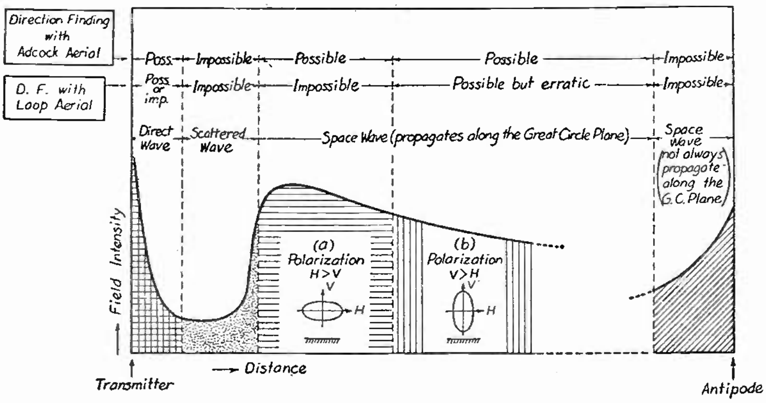

Fig. 26

(b) mostly vertical, that is, an ellipse with its major axis perpendicular to the ground as seen in Fig. 26, when the distance is long, and

(c) within a certain distance, the measurement is impossible as the scattering phenomena are predominant.

(2) Electric force measured at a receiving point which is at a small height above the ground as in common practice, is in general somewhat greater in the Y component than in Z, the reason being due to the dielectric properties of the earth for the high-frequency waves Thus a horizontal doublet is generally preferable as a receiving aerial although the downcoming wave itself is not so predominant in horizontal force. The most suitable height of the horizontal aerial to be mounted above the ground depends on the properties of the earth, frequency of the wave, and its angle of incidence. If attention be directed to this point, the receiving sensitivity which is several times greater than that in a usual case might be obtained. As for a vertical aerial it must be placed as close to the ground as possible to obtain its maximum sensitivity.

(3) From item (1), it will easily be seen that the use of a loop aerial for short-wave direction finding is sometimes meaningless. Although the results measured by a loop may be approximately correct for a distant station where the vertical electric force fortunately predominates, the results will not turn out true for a nearer station where the horizontal force predominates. An Adcock-type aerial works satisfactorily in either of the above two cases. However, at a certain distance where the scattering phenomena are predominant, the bearing can hardly be obtained even with the Adcock-type aerial as the waves actually come in from many directions.

The possible range of direction finding both by Adcock and by the usual loop aerials with reference to the probable state of polarization of the wave is as shown in Fig. 26.

(4) If a transmitter be situated slightly apart from the exact antipode of the receiver, a fair amount of lateral deviation of the wave may be observed. In the case of a 30-meter wave transmission, the wave does not always propagate along the great circle plane, but chooses a path on which the sunlit portion is minimum. The bearing thus shows marked diurnal variations as shown in Fig. 24.

The present work has been carried out under the direction of Mr. E. Yokoyama to whom the authors are deeply indebted and also they would like to thank Mr. M. Yoshikawa and Mr. S. Shirane for their painstaking assistance throughout the measurements.

* * *

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THE USE OF ROCHELLE SALT CRYSTALS FOR ELECTRICAL REPRODUCERS AND MICROPHONES*

By

C. Baldwin Sawyer
(Brush Laboratories, Cleveland, Ohio)

Summary—*The paper begins with a brief historical résumé of the development of piezo activity for acoustic uses. References are given.*

Methods developed by the author and his associates permit the cheap commercial production of Rochelle salt crystals and sections thereof, but the saturation and variation with temperature of Rochelle salt (shown in diagrams) must be compensated for by special assemblies of the Rochelle salt sections. The underlying principle of the special assemblies is that of mutual opposition with resultant magnification of motion. This principle of opposition may be utilized to produce bending or twisting elements of Rochelle salt of great simplicity. Such elements may then be combined with appropriate acoustic members to operate with great sensitivity and efficiency in either an input or output circuit. Rochelle salt requires no exciting field of any sort, which property results in the elimination of the necessity for any external excitation.

Microphones, pick-ups, and especially speakers are described, with some discussion of limiting conditions of load, temperature, and other operating conditions.

The article concludes with a tabulated summary of advantages offered by the use of Rochelle salt sections.

OVER a century ago it was noticed that certain substances exhibited an electric charge when subjected to pressure. Electricity so generated was called piezo-electricity. A. C. Becquerel[1] from 1820 to 1833 made many experiments and tested a large number of substances, crystalline and otherwise, for this effect.

In 1880 J. and P. Curie,[2] the same who later worked with radium, published the results of their experiments with quartz, and determined the amount of electricity generated by unit pressure along various axes of this substance.

Lippman[3] in 1881 predicted from mathematical considerations that if quartz were subjected to an electric field, deformation of the quartz would result. The Curies tested this experimentally and confirmed his conclusions.[4] They also pointed out that according to the principle of the conservation of energy any piezo-electric substance which acts as a

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* Decimal classification: R191. Original manuscript received by the Institute, March 31, 1931. Presented before Sixth Annual Convention of the Institute, June 5, 1931, Chicago, Illinois. Presented before Cleveland Section of the Institute, February 27, 1931.

[1] *Bulletins des Science de la Societe Philomathematiques de Paris,* p. 149. 1820; *Annales de Chemie et de Physique,* **36,** 265, 1827; *Memories de la Classe des Sciences Mathematiques et Physiques de l'Institute Paris,* **12,** 551, 1833.

[2] *Compte Rendu,* **91,** 294, 383, 387, 1880.

[3] *Ann. Chim. Phys.,* **5,** 45, 1881; *Jour. de Phys.* **1,** 10, 381, 1881.

[4] *Compte, Rendu,* **92,** 186, 352, 1881; **93,** 1137, 1881.

generator of electricity in response to mechanical motion, will act conversely thereto. They made the first practical applications of this converse property in the construction of an electrostatic voltmeter. Moreover, they determined the piezo-electric constants of very many crystalline substances among which that of Rochelle salt was by far the greatest.

To Roentgen[5] of X-ray fame belongs the honor of having foreseen in 1890 the acoustic application of piezo-electric substances. This followed as the result of his study of the torque produced in a plurality of quartz cylinders when subjected to appropriate electrical charges.

Under the impetus of the great war, many investigators engaged themselves in the application of piezo-electric properties to the detection and location of submarines by supersonic water vibrations. The brilliant French investigator, Langevin,[6] first combined piezo-electric devices with vacuum tube amplifiers, at both input and output ends. He was primarily interested in superaudible frequencies, but also demonstrated the applicability to the audible range of acoustics.

A series of investigations and experiments at the Western Electric Company[7] had branched off into a development based on the composite Rochelle salt crystal, such crystals being distinguished by lack of homogeneity and the inclusion of aqueous mother liquor. Apparently this development was never brought to a commercial stage, and our own experience with the deterioration and lack of uniform properties of such crystals convinced us that only the clear and homogeneous crystal could be used.

At the time when the Brush Laboratories Company initiated its investigation of Rochelle salt, the most comprehensive work on the piezo-electric properties of clear and homogeneous Rochelle salt existed in the various publications by Valasek and his associates.[8] He had shown a marked variation in the piezo-electric constant of Rochelle salt with temperature—a great decrease in the value of the constant taking place at 20 degrees C and above. He also showed the existence of saturation effects in the piezo-electric properties of this substance—a quality which seems to be lacking in quartz.

It was evident that a Rochelle salt device, to have commercial opportunity in the acoustic field, would have to be so constructed that in conditions of service at various temperatures and sound volumes,

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[5] *Wiedemann's Annalen d. Phys.*, 39, 16, 1890.

[6] *Interallied Conf. Report Nat. Research Council*, 1918; see also *Bureau Hydrograph. Internat. Publ.*, Special No. 3, Monaco, 1924.

[7] *Proc. A.I.E.E.*, 38, 1315–1333, 1919.

[8] *Science*, LXV, 1679, 235, 1927; *Phys. Rev.*, 17, 475, 1921; 19, 478, 1922; 20, 639, 1922; 24, 560, 1924; 21, 348, 1923; 24, 569, 1924.

the saturation effect would never interfere with performance. The most promising devices tested were those employing two or more sections of Rochelle salt acting in opposition upon each other, just as in the familiar bimetallic thermostat. In such thermostats two metals having different linear coefficients of thermal expansion are welded together. On warming, one of the metals expands more than the other and forces the welded assembly to assume a different curvature. The relative motion of the ends of a strip of such bimetallic metal is very much greater than the actual difference of expansion of the two metals. Similarly good loud speaker units of Rochelle salt may be constructed by cementing together two sections of Rochelle salt crystal so that on application of an electric field one of them tends to expand while the other contracts, resulting in a bending motion of the whole. The mechanical magnification of such an assembly is so great that for ordinary temperatures the saturation limit of Rochelle salt is never encountered, nor does any other lack of proportionality appear and the reproduction remains pure over a sufficient range of temperature and volume.

It was evident that the use of the principle of opposition would be advantageous for other reasons—among which may be mentioned simplicity, exact reproducibility, and great flexibility of design. But, in order to realize such possibilities to the greatest extent it was primarily necessary to have a cheap and adequate source of perfect crystals of Rochelle salt, and then to have means for shaping and machining such crystals. After much arduous endeavor, both of these problems were very satisfactorily solved. Perfect crystals of Rochelle salt can be produced very cheaply, quickly, and in large quantities by a process requiring very little labor. At the same time methods were developed for handling and sectioning such crystals by shop methods, such as might be applied in woodworking.

With the solution of the problems of crystal production, and of crystal shaping, it became at once possible to employ the principle of opposition in many different ways, and a variety of designs for speakers, phonograph pick-ups, microphones, record cutters, etc., was produced utilizing chiefly this principle. Before proceeding to the special features of these designs, it is probably best to note some of the electrical and mechanical features of Rochelle salt.

In the first place it is well known that the properties of Rochelle salt vary with reference to the crystalline axes. For purposes of illustration in this paper it will suffice to restrict consideration to plates cut from the crystal so that their major surfaces are perpendicular to the electric or *a*-axis. Such plates will then lie in the plane of the *b*-*c* axes with sides parallel to the *b*- or *c*-axis as in the drawing.

If a plate, so cut, be coated with tin foil on the surfaces perpendicular to the *a*-axis and be then electrified with say a 60-cycle alternating potential difference, while the corners *x* and *y* (see Fig. 1) are mechanically prevented from moving, all points in edge *q–r* will move back and forth synchronously with the potential difference and in a straight line parallel with the *b*-axis. While such a plate is thus seen to be sensitive to shear, it is apparent that this shear sensitivity must of necessity result in compression or extension sensitivity when a bar is cut from the plate at 45 degrees to the *b*- and *c*-axes as indicated by the dotted lines in the drawing.

Evidently, then, depending on their orientation, it is possible to produce single piezo-electric active Rochelle salt bars or plates which will expand and contract, or which will vibrate in shear in response to an alternating potential difference.

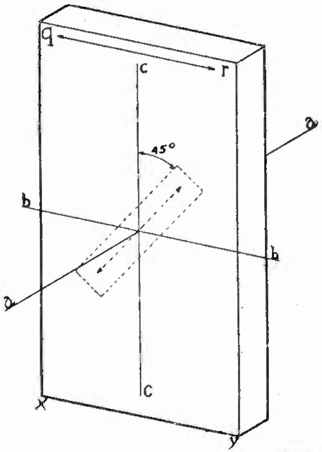

Fig. 1—Orientation and resultant deformation of Rochelle salt plate.

Such elementary sections of Rochelle salt may obviously be combined as single units with a sound reproducing diaphragm, and so function immediately as the simplest electrical sound-reproducing device which it is possible to devise. Similarly they can be used for microphones, etc.

It is very interesting to consider the current——voltage diagram obtained when such a simple Rochelle salt plate is connected with an alternating potential difference. In Fig. 2, obtained from a cathode-ray oscillograph, the abscissas are proportional to voltage and the ordinates to quantity or charge. The traces show both saturation and hysteresis, reminding one of the permeability of iron. As with the permeability of iron, the specific inductive capacity of such Rochelle salt, (with properly applied electrodes)[9] is a thousand times as great as that of any

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[9] Sawyer and Tower, *Phys. Rev.*, 35, 269, 1930.

other crystalline substance. Thus at 18 degrees C the apparent specific inductive capacity is 18,000 with 60-cycle alternating current. The type of diagram obtained from the plate varies greatly with the temperature.

If all four corners of the plate in Fig. 1 are mechanically prevented from moving, the traces from the cathode-ray oscillograph alter from those at the top of Fig. 2 to those at the bottom of Fig. 2, and all evidences of saturation disappear. The same holds true when two such plates are cemented together in mechanical opposition for great magnification. Thus, simultaneously, disproportion such as of saturation is overcome and great mechanical magnification obtained. Other methods for producing great magnification may overcome the difficulties of disproportion existing in Rochelle salt, but, so far, opposed sections give the best results.

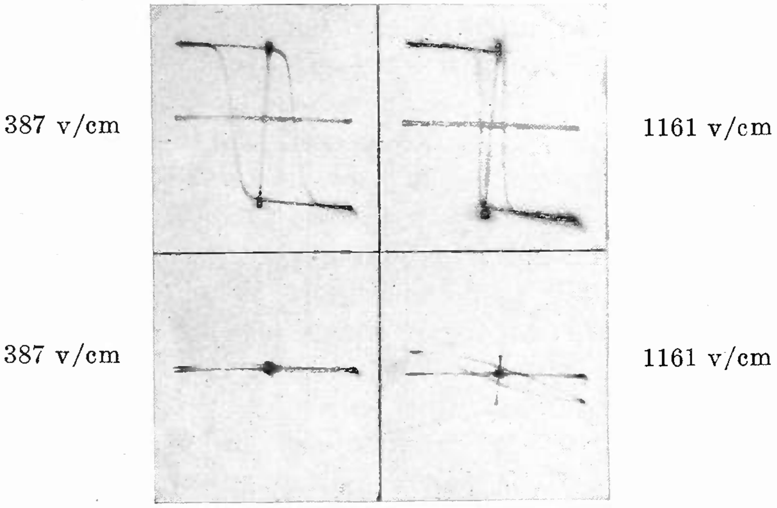

Fig. 2—Crystal plate, free and restrained. 15 degree C, 60 cycles per second. Free above, restrained below.

Crystal elements employing the principle of opposition may be constructed either to bend or to twist on the application of electric potential. Two Rochelle salt bars cut at 45 degrees to the *b*- and *c*-axes, so that they expand and contract respectively when in the electric field, may be cemented together to form a crystal element, bending as does the familiar bimetallic strip of thermostatic metal. Similarly two plates of Rochelle salt with edges parallel to the *b*- and *c*-axes (see Fig. 3) so that they are responsive to an electric field in shear, may be cemented together in opposition to respond by twisting, or torque. Either of such elements, namely the flection or torsion, may act as receivers or emitters of acoustic impulses.

In passing, it is well to note that cementing of the plates is not strictly necessary. They may, for instance, be held together simply by mechanical pressure with reliance placed on the frictional contact.

Should a crystal element of lower impedance be desired it is possible to multiply the number of bars or plates entering into the construction of such an element, simultaneously reducing their thickness. Since the electric field changes direction through each adjacent plate, as in an ordinary condenser, the orientation of adjacent plates must be properly chosen.

Of the many applications possible for Rochelle salt, the most interesting to the I.R.E. are probably the microphone, the phonograph pick-up, and the radio speaker. All of these applications may take any of several forms, but some specific designs are shown by way of illustration. All of them are remarkable for extreme simplicity. This characteristic is largely due to the lack of necessity for anything analagous to permanent magnets, magnetizing coil, or polarizing field. In a sense, Rochelle salt creates its own electrostatic field.

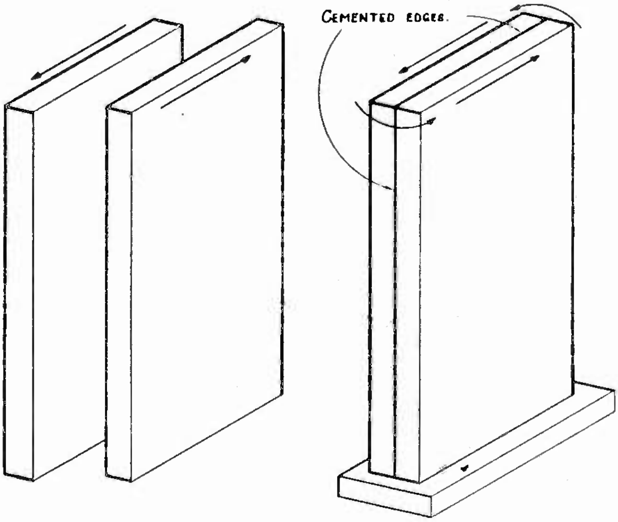

Fig. 3—Generation of torque from shear plates.

Nothing can illustrate the simplicity attainable better than does the cube microphone. A Rochelle salt cube measuring about an inch on the side, is foiled on the surfaces perpendicular to the *a*-axis and suspended from rubber bands. When the foiled surfaces are directly connected to a vacuum tube, the Rochelle salt cube functions as a microphone of highest quality. The natural period is above the audible range, while the sensitive cube itself is of such small dimensions as to approach the ideal more closely than has hitherto been possible with any type of device. The sensitivity is less than that of the condenser microphone, but can be increased by cementing the cube to a disk of wood or metal.

Other types of Rochelle salt microphones combining the principle of opposition with larger acoustic surfaces for picking up more sound energy, have a sensitivity in excess of the carbon microphone and, of course, require no battery whatever. Moreover, they are still compact and of extreme simplicity, and of course, are entirely free from carbon hiss and packing.

The phonograph pick-up which is chosen for this illustration, is designed for the greatest cheapness. Two Rochelle salt bars having a 1/8 in. thick cross section are cut for shear sensitivity and cemented together in opposition with a thin aluminum vane between them. One end of the vane is fastened to a lead slug serving as a mechanical reactance, while the other end is pivoted and carries a short extension for picking up the transverse vibrations of the phonograph groove.

The possibilities of these pick-up devices are best appreciated when it is realized that deformation of Rochelle salt can easily produce voltages sufficient to discharge through a 90-volt neon tube and may even produce a very small jump spark in air. The consequences of such voltage sensitivity, when it is applied to the grid of a tube, need no comment here.

When Rochelle salt sections are to be used for a radio speaker, it may be desirable to increase their size over those used for pick-up devices. For instance, the plates used in one of the drivers such as is here exhibited measure about $2\frac{3}{4}$ in. × $3\frac{1}{2}$ in. Such plates are cut for shear sensitivity, as in the pick-up already described. But unlike the pick-up, no central aluminum vane is employed, the two tin-foiled plates being cemented directly together and in opposition. A lead-in wire or foil makes contact with the two inner foiled surfaces and a gauze strip serves to contact the two outer foiled surfaces with the other lead. The crystal element assembly may be varnished if desired.

Such crystal element acts in torque. To connect it with the sound radiating diaphragm, one end of the element may be anchored, as by the frame of a speaker, while the other end is connected through a lever arm to the apex of a sound radiator. In the laboratory model here set out for illustration, a cast-iron frame carries a stamped channel into which the end of the crystal element is slipped. A similar stamped channel at the opposite end of the element is attached to a hickory arm leading to the apex of the cone. That there may be no lost motion, the acoustic axis of the hickory arm is anchored with a piano wire. A spring pushes the hickory arm, the channels and the element together, but serves no other function. The sensitivity of the element is not perceptibly influenced by the degree of compression. Various forms of cases for the crystal element have been tried, and one of the most satisfactory completely encloses it between sponge rubber pads.

Such units, at ordinary temperatures, equal or excel the dynamic in sensitivity and tone quality. However, as the temperature is raised, the sensitivity and tone quality at first somewhat increase and then begin to decrease with serious falling off at temperatures above 100 degrees F. They are still somewhat operative at 120 degrees F. The crystal element itself is not permanently damaged except by heating to temperatures in excess of 130 degrees F. When heated to temperatures less than 130 degrees F it regains all its good properties on cooling. Whenever heating experiments are conducted on the naked crystal, care must be taken to avoid the production of any considerable temperature differences, as by rapid and uneven heating or cooling of the crystal. With its low thermal conductivity and high coefficient of expansion, cracking is apt to ensue. Naturally such cracking never occurs when the crystal is surrounded and protected by a metal case.

The ordinary two-plate crystal speaker acting in torque has a load characteristic which may be represented by a somewhat leaky capacity of about 0.02 μf. The leakage, however, is rather small. Consequently the impedance of such a speaker will vary with frequency about as would that of a condenser. The impedance may be about 130,000 ohms at 60 cycles, but will decrease to about 20,000 ohms at 500 cycles. The impedance behaviour is, therefore, exactly opposite to the various electromagnetic speakers, whose impedance decreases at low frequencies but becomes very high at high frequencies. A light crystal speaker with small cone may, therefore, be operated effectively in parallel with a dynamic to improve both the power factor and high-frequency production.

Crystal speakers may be operated directly from the choke of a high impedance tube, and the new pentodes seem especially adapted to this purpose. When it is desired to operate the crystal speaker from 245 tubes in a push-pull, resort must be had, as in the case of the dynamic, to a transformer. In the case of the crystal such transformer is, however, used to step up the voltage, and a three-to-one ratio is satisfactory.

Direct impedance match can also be obtained by doubling the number of plates in the crystal element.

Frequency——response curves of a crystal speaker and a dynamic speaker are shown herewith. (Fig. 4). As these curves were obtained about a year ago, they do not represent the latest improvements for either type of speaker, though both curves represented maximum advance at the time.

Commenting on the curves it is apparent that the crystal speaker has, on the whole, a greater sensitivity than the dynamic, but that it has a more peaked response. It is believed that considerable advance has since been made in smoothing out the peaks with accompanying heightening of the center part of the curve. Since the characteristics of the three-to-one step-up transformer will affect the curve, these characteristics must be taken into consideration. For instance, the transformer has a tendency to cut off response in the bass. In reality the crystal speaker has a good response even at frequencies as low as 40 cycles. In this connection it is apparent that a crystal once charged will hold its resultant deformation until the charge leaks off. It is, therefore, possible to design a crystal speaker which will, in response to a steady e.m.f., maintain a displaced position of the cone without accompanying flow of current.

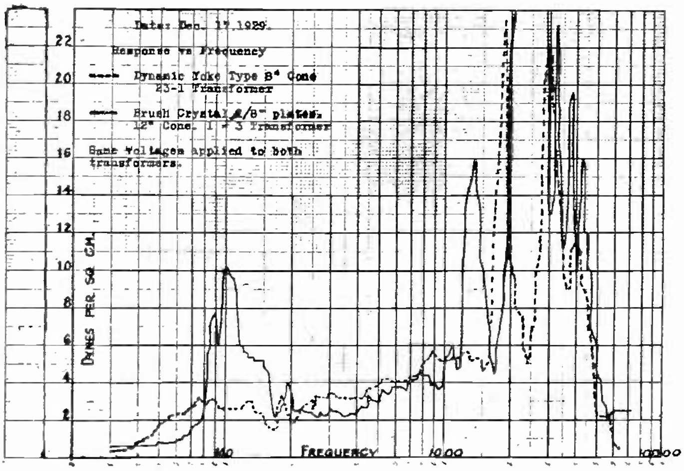

Fig. 4

At the extreme high-frequency end of the curve the crystal speaker even with transformer connection, exhibits an output superior to the dynamic. Moreover, in other work it has been shown that the crystal itself responds far into the superaudible range, so there seems to be no definite limit to high-frequency response, should such become desirable.

The maximum displacement of the cone of this laboratory model of a crystal speaker is something over 1/8 in. and occurs at low frequencies. Displacements of the cone are in general, at any given frequency, strictly proportional to the voltage applied. The force of the displacement is very large and so permits the use of heavy cones and heavy connecting levers which would be impossible for other types of speakers. For certain purposes it may even be desirable to increase by as much as 30 grams the weight of an ordinary small cone. Such large force of displacement may be especially useful for such purposes as the cutting of records and the movement of very large diaphragms.

Over the musical range the maximum output of the crystal torque element is the same as that of the average dynamic for radio sets. All crystal elements will stand the full undistorted output of two 245 tubes in push-pull with 250 volts on the plate, but when such elements must also stand the maximum output of the above tubes under any circumstances, some sacrifice of quality in the bass must so far be made to gain the necessary strength.

The crystal is not hygroscopic.[10] On the contrary, at elevated temperatures and with very dry air the naked crystal may be dehydrated at its surface, but such action has not been observed when the crystal is protected with varnish. The life of the crystal is indefinite, and it will not fail from atmospheric variations, or from fatigue. Crystal elements have been continuously subjected to 220-volt 60-cycle alternating current for over two years and show no evidence of deterioration. The tests were made in a loosely constructed steam-heated building so that the extremes of dry air in the winter and moist air in the summer surrounded the crystal.

The Rochelle salt development offers the following outstanding advantages to radio and telephone engineers:

1. Inherent cheapness and simplicity.
2. Long life and freedom from fatigue failures.
3. Flexibility of design.
4. In an input circuit, the generation of high voltages for tube grids.
5. In an output circuit, directly matched with high impedance and pentode tubes. Also directly matched with low impedance tubes in multiple speaker installations for hotels and apartment houses.
6. In an output circuit, gives a large force for vibrational displacement, permitting the use of heavy cones and diaphragms.
7. Freedom from necessity of exciting currents, permanent magnets, or polarizing bias. Rochelle salt carries its own field excitation.

The work here described was begun under the very able leadership of the late Charles F. Brush, Jr. Its continuation has been a privilege to the staff of the Brush Laboratories Co.

[10] International Critical Tables, I, 67, Curve 18, 1926.

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DISCUSSION "ON THE AMPLITUDE OF DRIVEN LOUD SPEAKER CONES"[*]

M. J. O. STRUTT

N. W. McLachlan:[1] A number of interesting issues arise in connection with M. J. O. Strutt's paper "On the amplitude of driven loud speaker cones." The same paper appeared in *Experimental Wireless and The Wireless Engineer*,[2] and in the June issue of that journal I contributed a letter[3] dealing with certain features thereof. In the present communication the salient points of the letter are stated, but new material is added which may be of general interest.

The occurrence of circular nodes on a conical diaphragm, which is said to be novel, was anticipated in my book "Wireless Loud Speakers"[4] written in 1925 and published in March, 1927. In *The Wireless World and Radio Review* two years ago[5] I described experiments on a conical diaphragm illustrating radial and circular nodes, the latter commencing at a frequency of about 300 cycles per second. The general "break-up" effect and the acoustic short-circuit effect are also treated in these publications. From the data obtained during the experiments on circular nodes, the radial velocity of sound in the diaphragm was calculated. A paper was submitted to *The Wireless World* in December, 1928, but publication did not ensue till June 4th, 1930. It seems clear, therefore, that these problems lost their novelty some years ago.

The linearity of output from loud speakers with varying input was treated in a recent publication.[6] The results were obtained early in 1928 and a paper submitted to a certain English journal during that year. It was returned eighteen months later with the comment that the subject was too academic! Fortunately the *Philosophical Magazine* thought otherwise. The method described in the *Philosophical Magazine* tests the linearity of the whole diaphragm structure (surround, cone, and drive), and is more rapid and direct than that used by Strutt. Tests of diaphragm amplitude should be made at a number of radii to ensure that the paper is elastic in all directions. This is discussed in detail in the letter to *Experimental Wireless*.

The statement in section 2 that the efficiency of a loud speaker can be determined from M_e, the effective mass of the diaphragm, deserves further comment. For a free edge centrally driven disk of uniform thickness with one nodal circle $M_e=0$,[7] but the sound output during vibration in air is a *maximum*. Hence in this case the value of M_e is no criterion of the acoustic efficiency except *in vacuo!* Here the total linear momentum of the disk is zero. Thus $m\omega\int pds=0$, and therefore $\int pds=0$, where m = mass of disk per unit area, $\omega=2\pi\times$frequency, p = axial amplitude and ds is an element of area. The motion at resonance is assumed to be sinusoidal, giving an axial velocity ωp. Thus $\int pds$ and M_e both being zero, the relationship $\eta=\int pds/ps=M_e/M$ is valid (in this particular case) *in vacuo*, but not in a fluid. If the edge of the disk is *clamped*, the shape during

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[*] PROC. I.R.E., 19, 839; May, 1931.
[1] Radio engineering consultant, London, England.
[2] Vol. 8, 238, May, 1931.
[3] *Ibid.*, p. 312, June, 1931.
[4] Iliffe & Sons, Ltd., London, 1927.
[5] P. 33, July 10th, and p. 62, July 17th, 1929.
[6] *Phil. Mag.*, II, 1–54; January, 1931.
[7] A. G. Warren, *Phil. Mag.*, 9, 881; May, 1930. In practice nodes are actually places of minimum amplitude. See letter to *Experimental Wireless*, September, 1931.

vibration is alternately concave and convex, there being no nodal circle at the first symmetrical mode. Nevertheless $M_e=0$, since the sum of the elastic and inertia forces over the disk is zero. $\int pds$ over the disk is *not* zero, but attains a maximum value—in air or *in vacuo*. It is obvious, therefore, that even *in vacuo*, $\int pds$ depends upon external conditions, and is not necessarily related to M_e.

Measurement of the effective mass of a conical diaphragm vibrating in air is of considerable interest. Using a different method from Dr. Strutt, I obtained the results given in Table I. The data refer to a coil-driven conical diaphragm with an annular rubber surround and a baffle 6 feet square.[8] The value of M_ϵ at any frequency is the *apparent* mass of the complete diaphragm structure M_a, plus the accession to inertia, the latter being due to divergence of sound waves from the diaphragm as source.[9] In the case of a rigid disk, say 10 cm radius, operating with a baffle of customary dimensions, M_ϵ is the sum of the *natural* mass M plus the accession to inertia. If the value of the latter in the middle register, where it is constant, is M_1, its value near zero frequency[10] is $\frac{1}{2}M_1$ and at 2500 cycles it is almost zero. Thus M_e changes from $(M+\frac{1}{2}M_1)$ to $(M+M_1)$, thence to M with increase in frequency, so that it is never less than the natural mass of the disk.

TABLE I

SHOWING EFFECTIVE MASS OF VIBRATING CONICAL DIAPHRAGM AT VARIOUS FREQUENCIES

F Cycles per second	$M_\epsilon=M_a+M_1$ Effective mass (gm)	Remarks
50	+26	
100	+38	
150	+48	Increase in M_ϵ due to elasticity of surround.
200	+77	
215	− 9.2	Resonance of rubber surround as an auxiliary diaphragm.
250	+ 5.1	
280	+18	
400	+26	Approach to first center stationary mode.
740	+ 4.8	Near first center moving symmetrical mode: reduction in M_ϵ due to elasticity of diaphragm.
1200	+12.7	
1800	+ 0.2	
2000	− 1.1	Near second center moving symmetrical mode, M_ϵ very small
3000	+ 2.2	

The case of an actual diaphragm is quite different, owing to elasticity of (1) the surround, (2) the diaphragm. The surround resonates by itself[8] and causes M_ϵ to attain a negative minimum thus being zero twice. In the neighbourhood of the first center moving symmetrical mode M_ϵ is a minimum, whilst for the second it is substantially zero. The sequence of values can be readily followed from Table I. The minimum and the zero values of M_ϵ correspond closely to the *maximum* values of sound output. If M_ϵ were a criterion of acoustic efficiency, it follows that the diaphragm will absorb sound when M_ϵ is negative, which is obviously absurd. Also since M_ϵ exceeds the natural mass M at low frequencies, owing to accession to inertia, Dr. Strutt's efficiency $\eta=M_\epsilon/M$ exceeds unity. Negative values of M_ϵ have also been found for a coil-driven free edge aluminium disk. Starting from zero frequency, M_ϵ rises from $(M+\frac{1}{2}M_1)$ to a positive maximum far exceeding this. When the *center stationary* mode,[6,7] occurs, M_e suddenly falls to a large negative value, thereafter gradually increasing and passing through

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[8] *Phil. Mag.*, II, 27; January, 1931. See *Wireless World*, p. 166, August 12, 1931, Fig. H for curves of M_ϵ, also *Phil. Mag.*, October, 1931, for methods and formulas.

[9] *Wireless World and Radio Review*, p. 372, March 30th, 1927, also *Phil. Mag.*, p. 1011, June, 1929, and p. 1137, June, 1931.

[10] *Jour. I.E.E.* (London), 69, 612, 613, 1931.

zero at the first symmetrical mode. In the hypothetical case where the loss is zero, M_ϵ would be infinite *in vacuo*, since the disk would continue to vibrate with stationary center without replenishment of wasted energy. Owing to radiation and internal losses, energy is required to sustain the so-called vibration with stationary center, so that M_ϵ never becomes infinite. These cases are comparable with the impedance of one or more parallel coil and condenser combinations in series (1) without, (2) with resistive loss.

Thus the relationship $\eta = \int pds/PS = M_\epsilon/M$ is quite invalid as an indication of the acoustic efficiency of a vibrating diaphragm.

The statement in section 6 that radial nodes do not enhance the sound output is not borne out in practice. I have shown elsewhere[11] that a radial node on a practical diaphragm is accompanied by appreciable increase in output. Resonance is quite sharp and lasts only a few cycles—about 6.

In measuring sound output by the decay method mentioned in section 8, presumably the diaphragm loss is included. E. D. Cook[12] has shown that the diaphragm loss above 1500 cycles is appreciable. Consequently, to arrive at the sound output alone, the diaphragm loss must be measured. For this purpose a vacuum is used, but, owing to removal of the acoustic load, the shape of the diaphragm when it has broken up is the same in air and *in vacuo*. Cook's method consists in taking impedance measurements of the moving coil in air and *in vacuo*, free and fixed. Computation of sound output depends upon impedance differences, and serious errors can occur at high frequencies when the difference is small compared with one or other of the major quantities. Errors arise in two ways, (1) temperature variation in the three test conditions due to the large heating effect of the magnetizing winding,[13] (2) difference in effective iron loss during the fixed and free measurements. No. 1 can be avoided by checking constancy of resistance by a d-c bridge, but No. 2 is difficult to evade. I discovered the effective alteration in iron loss early in 1928 during tests on a permanent magnet type of moving-coil loud speaker. Above 4000 cycles the sound output plus diaphragm loss, as found by the difference between the fixed and free resistances, was *negative*. This has also been experienced with various forms of speaker having electromagnets. The conditions of magnetization of the iron and in the air gap are different in the two cases. In the free state the current not only drives the coil, but it causes an alternating magnetic field in the air gap, which induces an e.m.f. in the coil, thereby creating harmonics. In the fixed state the latter effect is absent. In effect the net result is a variation in iron loss for the free and fixed conditions.

In calculating the sound output, differences as low as 3 per cent of one of the major quantities are encountered. Thus an error of 1 per cent in both of the latter entails an error of 67 or zero per cent in the difference, according as both errors are positive or one positive and the other negative. For the sound output to be negative, errors of considerable magnitude must occur at the higher frequencies due to variations in the magnetic conditions when the coil is fixed and free. Doubtless, the same effect occurs in the testing of telephones of the diaphragm and reed type. On the whole, therefore, it appears that accurate determination of the acoustic output from a system of low efficiency is a difficult matter.

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[11] *Wireless World*, p. 479, May 6th, 1931.

[12] *Gen. El. Rev.*, 33, 505; September, 1930.

[13] *Wireless World*, p. 479, May 6th, 1931; *Jour. I.E.E.* (London), 69, 613, 1931.

M. J. O. Strutt:[14] In reply to the above remarks by N. W. McLachlan, I should like to bring forward the following points.

My paper contains the sentence: "the evidence, here given, that ordinary driven paper cones have circular nodes already at 500 cycles seems to be somewhat unexpected, as most constructors of loud speakers assume that cones are nodeless up to much higher frequencies." As an example of this assumption I quote: H. Stenzel, *Ann. der Phys.*, 7, 947, 1930. I am sorry not to have mentioned Dr. McLachlan's previous publications in this place. As to the "novelty" of these problems, I think the reader can best make out for himself.

Dr. McLachlan treated the linearity of loud speakers in a paper, published January, 1931. My paper was submitted to these PROCEEDINGS November 18, 1930. Hence I could not have any knowledge of his work. As to Dr. McLachlan's statement, that his method is more direct and rapid than mine, I wonder that no reason or argument in favour of this statement is put forward by him. In fact his method makes use of a microphone, an amplifier, and a voltmeter. These three instruments have to be tested on their linearity *separately* before reliable results of measurements with this combination can be obtained. How this method can be called more direct than mine escapes my comprehension. Answering Dr. McLachlan's last remark on this point, in fact we *did* measure the amplitude at different radii of cones. I did not, however, think it necessary to publish all of the curves thus obtained.

Coming to the central point in this discussion, I first consider in some detail the statements, made in my paper. Only the case, that "the wavelength of sound in air is large compared with the dimensions of the cone," was contemplated in my paper. I explicitly stated: "if this condition is no longer fulfilled, the emission of sound depends on the motion of the cone in a more complicated way, which will not be discussed in this paper." I refer to a paper in the *Ann. der Physik*, 11, 129, 1931, for this latter case. Under the condition just mentioned, the sound output of a cone, whether with free or with clamped edge, set in an infinite baffle, is proportional to the volume of air put aside by the cone's motion. P being the amplitude of the center and S the total surface, this volume is $P \times S$ for a perfectly rigid cone. In other cases, this volume is $p \times ds$, p denoting the amplitude of the surface element ds. Hence the efficiency of a cone as a sound emitter, compared with the perfectly rigid case, is $\int p \times ds / P \times S$. In what respect the sound output of a cone with one nodal circle is a *maximum*, as stated above by Dr. McLachlan, is not clear, if we follow the foregoing considerations. Unfortunately, he gives no single argument in support of his view. As regards the definition of the effective mass of a centrally driven cone, some care is needed. In fact, several definitions have been proposed and used in literature, as shown in the paper "Ueber die Admittanz linearer Schwingungssysteme," (*Ann. der Phys.* 10, 244, 1931). I fear that Dr. McLachlan's definition does not agree with mine. It also does not agree with the late Dr. Crandal's, for in the latter's book, "Theory of Vibrating Systems and Sound," p. 27, I find that the mass of a membrane oscillating in its first natural frequency, if driven at the center, is 0.28 of its total mass and not zero, as stated by Dr. McLachlan in his discussion. Similar data are found in the work of Prof. Kennelly, "Electric Vibration Instruments," p. 32. I stress the statement, made in my paper, that no frictional effects and hence no gradual phase displacements along the cone are taken into account in the considerations there given. Summing up, no argument, given by Dr. McLachlan,

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invalidates the statements of my paper, concerning the equivalent mass and the acoustic efficiency of cones.

The fact, mentioned by Dr. McLachlan, that radial nodes in practice really have influence on the sound output says nothing against the statement of my paper, that they would not, if the cone is *truly centrally driven.* I agree that the influence exists in practice, but only as an outcome of the departure from a truly central driving arrangement. This latter point does influence the effective mass also to a large extent, as will be shown in a future paper describing some recent measurements.

In his last paragraph Dr. McLachlan questions the accuracy of our decay measurements. As no details of these measurements were mentioned in my published paper, his argument seems doubtful. I refer to a future paper for this particular point.

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BOOK REVIEWS

Principles of Electricity, by Leigh Page and N. I. Adams. D. Van Nostrand Company, New York City, 1931. XII+620 pages, 319 figures. Price $4.25.

This book, as its name implies, gives the fundamental principles of electricity. It can be recommended very highly to anyone wishing to obtain a knowledge of the origin of the concepts which are used in electrical engineering. It is very modern in that the relativity principle, although not mentioned explicitly, is adhered to throughout while the electron theory of matter is used from the beginning. The derivations of equations are concise and are designed to give an insight to the theory; the book is well balanced, carrying most topics to a satisfactory conclusion and others, such as vacuum tubes, to the point where the specialist must step in. In order to show how comprehensive the book is, we may mention a few topics of particular interest to the radio engineer: Electrostatic and electromagnetic shielding, the application of complex quantities to a-c circuits, a chapter on "Coupled Circuits, Filters and Lines," and a chapter on "Electromagnetic Waves." All of the above topics were treated fully enough to provide an excellent introduction to them. This thorough and accurate analysis was made possible by the authors' facility of expression and their use of the best approved methods for expressing the equations of the theory. Thus, in circuit theory, complex numbers were used throughout, in the theory of electromagnetic waves, vector expressions made possible a considerable simplification of reflection and refraction phenomena. Furthermore, the theory is well illustrated with various problems at the end of each section.

K. A. Norton*

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* Bureau of Standards, Washington, D. C.

Short Waves, by Charles R. Leutz and Robert B. Gable. 384 pages, 185 figures Price $3.00. Published by C. R. Leutz, Inc., Altoona, Pa.

This is a descriptive book surveying short-wave achievements throughout the world. It contains a historical review, a discussion of short-wave propagation, commercial transoceanic, and ship-to-shore radiotelephony and -telegraphy, both American and foreign, directional antennas, television, aircraft radio equipment, short-wave broadcast receivers, medical and surgical applications of ultra short waves and amateur short-wave equipment. This book describes what is being accomplished and how it is being done, gives circuit diagrams of much equipment, minimizes the discussion of theory and principles, and contains no mathematical discussions.

S. S. Kirby*

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* Bureau of Standards, Washington, D. C.

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Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

Copies of the publications listed on this page may be obtained gratis by addressing a request to the manufacturer or publisher.

A thirty-two page booklet entitled "Super-Seasoned Fiber" gives the properties of fiber manufactured by the National Fiber & Insulation Co. of Yorklyn, Del., and contains a list of suggestions for uses of fiber in various industries. Stock fibers include tubes, sheets, and rods of various sizes.

"A Vest-Pocket Manual of Phenolite Laminated Bakelite" gives the physical, electrical, and mechanical characteristics of various grades of phenolite laminated bakelite and contains information on punching, tapping, threading, sawing, and drilling the various grades of bakelite manufactured by the National Vulcanized Fiber Co. of Wilmington, Del.

A colored folder describing fixed resistors from 15 ohms to 10 meghoms and in power ratings from 1/5 watt to 5 watts has been issued by the Erie Resistor Corporation of Erie, Pa., to describe their line of molded resistors. These resistors may be obtained with the R.M.A. color code markings.

A line of vacuum tube sockets designed primarily for manufacturers is illustrated in a three-page folder issued by the Central Radio Corporation, 156 Roosevelt Ave., Beloit, Wis.

The National Electric Products Corporation of Fort Wayne, Ind., has issued a table of data on copper wire in a convenient cardboard folder.

A sixteen-page brochure published by the Sangamo Electric Co. of Springfield, Ill., describes the Sangamo line of audio transformers and interstage coupling devices for radio receivers and audio amplifiers. The mica dielectric molded bakelite fixed condensers manufactured by this concern are also listed.

Bulletins 41 and 41-A issued by the Crowe Name Plate & Manufacturing Co., 1749 Grace St., Chicago, illustrate dials and driving units for ganged tuning condensers as well as embossed escutcheons. The data are of primary interest to manufacturers of broadcast receivers.

The proper use of solder as well as a description of the various types of solders available for particular purposes is given in a forty-page booklet issued by the Kester Solder Co., 4201 Wrightwood Ave., Chicago. The title of this instructive booklet is "Facts on Soldering" by P. C. Ripley.

A series of bulletins issued by the Webster Electric Co. of Racine, Wis., lists their complete line of audio-frequency equipment. This line includes phonograph pick-ups, audio-frequency interstage coupling units, audio-frequency power amplifiers, and a line of centralized radio and sound distributing equipment for relay rack mounting.

A "General Reference Sheet for Shakeproof Lock Washers and Locking Terminals" illustrating detailed dimensions of stock types of these washers is available from the Shakeproof Lock Washer Co., 2501 N. Keeler Ave., Chicago, Ill.

"The Micabond Manual," a 72-page booklet describing various types of built-up mica plates, is published by the Chicago Division of the Continental Diamond Fibre Co., Newark, N. J. The electrical characteristics of micabond, together with recommended mica testing standards are given. Although intended primarily for electrical insulating purposes, other applications of micabond are also given.

Heat resistant insulators which may be made available in a variety of shapes are described in a 24-page booklet entitled "Lava and Magnesia" issued by the American Lava Corp., Chattanooga, Tenn. Among the radio applications illustrated are notched insulating tubes used in the cathode construction of quick heating vacuum tubes.

Condensers for transmitting equipment are illustrated in a booklet issued by the Dubilier Condenser Corp. of New York entitled "Dubilier Capacitors—Transmitting Types."

A loose-leaf folder of the Rawson Electrical Instrument Co., Cambridge, Mass., describes direct-current and alternating-current microammeters, milliammeters, ammeters, millivoltmeters, and voltmeters. The alternating-current meters are of the thermocouple type. Various models are available in single and double pivot mountings. Electrostatic voltmeters and fluxmeters are also described.

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Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

RADIO ABSTRACTS AND REFERENCES

THIS is prepared monthly by the Bureau of Standards,* and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of radio subjects: An extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, which appeared in full on pp. 1433–56 of the August, 1930, issue of the PROCEEDINGS of the Institute of Radio Engineers.

The articles listed are not obtainable from the Government or the Institute of Radio Engineers, except when publications thereof. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R000. RADIO

R007.9 R. Homburg. The next world conference at Madrid and the international regulation of electric and radio-electric transmissions. *Jour. Radio Law*, **1**, 220–241; July, 1931.

The advisability of the fusion of the two conventions, telegraphy and radiotelegraphy discussed.

R051 ×R361 J. F. Rider. Perpetual radio reference data (book). Noted in *Radio Engineering*, **11**, 60; July, 1931. Published by Radio Treatise Co., New York City; 1931; price $5.00.

A loose-leaf library of radio receiver circuits encompassing practically all commercial broadcast receivers manufactured since the popularization of radio.

R055 A bibliography of bibliographies in electrical engineering 1918–1929. Published by the Special Libraries Association, 345 Hudson Street, New York City; price $1.50 per copy.

R100. RADIO PRINCIPLES

R113 C. R. Burrows. The propagation of short radio waves over the North Atlantic. PROC. I.R.E., **19**, 1634–1659; September, 1931.

Transmission conditions over the Atlantic on frequencies from 6 mc to 18 mc are discussed. Graphs are given which show the best frequencies for the transmission at different times of day. Seasonal variations are also given.

R113 N. H. Edes. The relation connecting skip distance, wavelength, and the constants of the ionized layers. PROC. I.R.E., **19**, 1663–1674; September, 1931.

For single reflection at a single layer an equation is developed giving the wavelength in terms of the skip distance, the height of the layer, and the degree of ionization of the layer. The curve represented by this equation is discussed. The equation, in conjunction with experimental data, shows the height of the layer which governs the skip distance in daylight to be about 230 km, and its ionization about 7.0 x 10^5 electrons per cu. cm. The data lead to a value of 10.4 meters for the shortest, useful wavelength for daylight work. The case of two or more layers is also discussed.

R113 ×R114 S. W. Dean. Long-distance transmission of static impulses. PROC. I.R.E., **19**, 1660–1662; September, 1931.

An explanation of accompanying oscillograms showing atmospherics received simultaneously at Houlton, Me.; Cupar, Scotland: and New Southgate, England, is given.

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* This list compiled by Mr. W. H. Orton and Miss E. M. Zandonini.

R113.2 L. W. Austin. A method of representing radio wave propagation conditions. Proc. I.R.E., **19**, 1615–1617; September, 1931.

The daylight radio transmission conditions across the North Atlantic Ocean in 1930 for wavelengths of 10,000 to 20,000 m (15–30 kc) are shown in a table based on the daily observations of the signal strength of seven European high power stations taken in Washington.

R113.5
×R113.61 A study in radio transmission. *Radio Engineering*, **11**, 19–20; July, 1931.

The effects of the moon on the Kennelly-Heaviside layer and on radio wave transmission are discussed.

R113.5 I. J. Wymore-Shiel. A correlation of long-wave radio field intensity with the passage of storms. Proc. I.R.E., **19**, 1675–1683; September, 1931.

Variation in received field intensity of long radio waves is compared with variation of temperature, pressure, and rainfall during the passing of general storms at Washington. The results show a falling off in signal intensity in front of a low; and an increased intensity following a low.

R113.62 How many ionized layers? *Wireless Engineer and the Experimental Wireless* (London), **8**, 463–464; September, 1931.

A brief summary of a preliminary article which appeared in the June number of the *Zeitschrift für Hochfrequenztechnik* is given. It is pointed out that many indications of more than one layer may be accounted for by multiple reflection. A brief description of the methods used is also given.

R113.62 G. Goubau. Echomessungen in der drahtlosen Telegraphie. (Echo measurements in radiotelegraphy). *Ann. der Physik*, **10**, 329–372, 1931.

The evaluation and results of echo measurements made during the period September, 1929, to July, 1930, are given. The wavelength used was 530 meters and the method employed was a modified form of that due to Breit and Tuve.

R116 T. Walmsley. Distribution of radiation resistance in open wire radio transmission lines. *Phil. Mag.*, **12**, 392–396; August, 1931.

The purpose of this article is to show how the radiation component of resistance varies along a transmission line, and to indicate the numerical value of this component.

R116 K. Baumann and H. O. Roosenstein. Über neue Dämpfungsmessungen an Hochfrequenz-Energieleitungen. (On new damping measurements of high-frequency transmission lines). *Zeit. für Hochfrequenz.*, **38**, 73–77; August, 1931.

It is pointed out that the time decrement of a standing wave is the same as the space decrement of a traveling wave. A method of Lecher wire damping measurement, using this principle, is described.

R120 B. van der Pol and K. F. Niesson. Über die Raumwellen von einem vertikaler Dipolsender auf ebener Erde. (Space waves from a vertical half-wave antenna located on a plane earth). *Ann. der Physik*, **10**, 485–510, 1931.

Operational methods are used to derive a formula for the Hertz potential function of a vertical dipole radiator located above a flat conducting earth.

R121 W. H. Wise. The grounded condenser antenna radiation formula. Proc. I.R.E., **19**, 1684–1689; September, 1931.

Exact formulas for the wave function and vertical electric field at the surface of the ground are derived for a vertical dipole of zero height.

R125 F. Kiebitz. Versuche über die Abstimmung von Richtantennen bei kurzen Wellen. (Experiments on the tuning of short-wave directional antennas). *Telegraphen und Fernsprech Technik*, **20** 239–242; August, 1931.

Experiments were carried out with a two-wire antenna system, similar to Lecher wires. Such an antenna, with ½-meter separation, and 180 meters long, permitted world-wide reception and possessed an advantage over the normal array in that it was easily tuned to any desired frequency.

R131 ×R339 J. C. Warner. Some characteristics of thyratrons. Proc. I.R.E., **19**, 1561–1568; September, 1931.

The fundamental characteristics of thyratrons are discussed. Comparisons are made with characteristics of high-vacuum tubes to show the outstanding advantages and limitations of the thyratron. Starting characteristics are discussed and typical examples are given. Several types and sizes of thyratrons are described briefly.

R132 A. Forstmann. Über die Wirkungs und Betriebsweise der Gegentaktschaltung in Niederfrequenzverstärken (The theory and operation of the push-pull circuit arrangement in low-frequency amplifiers).

A theoretical analysis of the push-pull amplifier is made and its peculiar advantages are discussed.

R133 J. Sahanek. Einige Bemerkungen zum Probleme der Erzeugung sehr kurzer elektromagnetischer Wellen. (Some remarks concerning the problem of generating very short electromagnetic waves). *Zeits. für Hochfrequenz.*, **38**, 78–80; August, 1931.

A summary is given of the author's theoretical work in connection with Barkhausen-Kurz oscillations.

R139 T. v. Nemes. Kunstlicher Lichtbogen mit Doppelgitterröhrer (Artificial arc from the screen-grid vacuum tube). *Zeits. für Hochfrequenz.*, **26**, 77; August, 1931.

It is shown that the four-element vacuum-tube when connected in space-charge fashion exhibits many of the properties of the electric arc.

R140 W. A. Barclay. Coil resistance shunts. *Wireless Engineer and Experimental Wireless*, **8**, 482–484; September, 1931.

A graphical construction for an inductance coil shunted by a pure resistance is given. The author shows how it is possible to use the construction to meet the practical requirements of frequency variation.

R140 T. S. E. Thomas. Transients and telephony. *Wireless Engineer and Experimental Wireless*, **8**, 485–488; September, 1931.

This article gives a mathematical treatment of the methods of amplifying telephone transients, and the response of cone loud speakers to transients.

R144 R. Peierls. Zur Theorie der magnetischen Widerstandsänderung (On the theory of resistance variation due to magnetic effects.) *Ann. der Physik*, **10**, 97–100; 1931.

In this theoretical treatise, equations expressing the resistance of a conductor in a magnetic field are derived.

R146 B. F. Asseef. Note sur le calcul d'un doubleur de Frequence (Note on on the calculation of a frequency doubler.) *L'Onde Electrique*, **10**, 36–47; January, 1931.

This article contains equations for the calculations involved in designing a frequency doubler.

R148 N. F. S. Hecht. Modulation and side bands—Relation between amplitude and frequency modulation. *Wireless Engineer and Experimental Wireless* (London), **8**, 471–481; September, 1931.

This article contains a mathematical and graphical discussion of modulation, amplitude modulation, frequency modulation, conversion of frequency modulation into amplitude modulation and the suppression of one side band.

R149. C. Wagner. Zur Theorie der Gleichrichterwirkung (On the theory of rectifier action.) *Phys. Zeits.*, **32**, 641–645; August 15, 1931.

A generalized theory of rectifier action is developed with special attention given to copper-oxide and similar rectifiers.

R152 K. Haupt. Untersuchungen über funkenerregte Schwingungen sehr hoher Frequenz (Spark-excited oscillations of very high frequency). *Zeits. für Hochfrequenz.*, **38**, 57–66; August, 1931.

The production of spark-excited frequencies up to $\lambda = 14$ cm is described, and various aspects of the method used are analyzed.

R165 M. J. O. Strutt. Über die Admittanz linearer Schwingungssysteme (The admittance of linear oscillating systems.) *Ann. der Physik*, **10**, 244–256, 1931.

In connection with an experimental study of equivalent mass and damping of loud speaker diaphragms, several simple relations were discovered which generally allow the admittance of the diaphragm to be calculated as a function of frequency. These relations are shown to apply to any linear oscillating system.

R170 ×R550 C. B. Aiken. Interference from shared-frequency broadcasting. *Electronics*, **3**, 100–101; September, 1931.

A discussion of the cause and types of interference produced by shared-frequency broadcast systems is given.

R200. Radio Measurements and Standardization

R210 C. H. Becker. Der Stahloszillator mit phasenreiner Rückkopplung. (The steel oscillator with proper-phased regeneration.) *Ann. der Physik*, **10**, 533–557, 1931.

A 5000-sec^{-1} frequency standard consisting of a vacuum-tube controlled, vibrating steel rod is described. A very high order of stability is claimed.

R213 W. Fehr, and G. Leithäuser. Über ein Präzisionsverfahren zur Messung kurzer Wellen (A precise method for measuring short waves.) *Elek. Nach.-Tech.*, **8**, 337–339; August, 1931.

A harmonic method of frequency measurement is described. The method has been used to measure frequencies up to 30 megacycles per second and is adaptable to even higher frequencies.

R240 L. Pungs and H. Vogler. Ein neues elektro-optisches Messverfahren für Spannungen und Ströme sehr hoher Frequenz (A new electro-optical method for measuring current and voltage at very high frequencies.) *Elek. Tech. Zeits.*, **52**, 1053–1056; August 13, 1931.

An electro-optical method of measuring current and voltage at frequencies of the order of three megacycles per second is based on the Kerr-effect and is shown to give more reliable results than the usual thermo-methods.

R243 ×R116 L. Rohde and F. Bahnemann. Eine neue Methode zur Spannungsmessung an Paralleldrahtsystemen. (A new method of voltage measurement in parallel wire systems.) *Elek. Nachr. Technik*, **8**, 335–336; August, 1931.

A method of making direct voltage measurements at any point along a Lecher wire system is described. A specially constructed vacuum tube is used.

R243.1 H. J. Reich, G. S. Marvin and K. A. Stoll. Vacuum-tube voltmeter of high sensitivity. *Electronics*, **3**, 109–111; September, 1931.

Constructional details of a high sensitivity vacuum-tube voltmeter are given.

R256 H. F. Olson and S. Goldman. The calibration of microphones. *Electronics*, **3**, 106–108; September, 1931.

Methods are presented for calibrating various types of microphones including a Rayleigh disk method, an attenuator method and the thermophone method. Comparative curves are given for different microphones.

R262 J. R. Barnhart. A new method of measuring vacuum-tube characteristics. *Radio Engineering*, **11**, 30–31; July, 1931.

A simple method of determining the dynamic mutual conductance, amplification factor, and plate resistance is given.

R270 ×R210 H. Mögel. Feldstarkemessungen deutscher Kurzwellensender in England. (English field intensity measurements on German high-frequency radio transmitters.) *Elek. Nach. Technik*, **8**, 321–330; August, 1931.

The results of frequency and field intensity measurements made in London on several high-frequency radio-transmitters located at Nauen are reported. Also, frequency measurements made simultaneously in New York, London and Berlin are compared.

R300. RADIO APPARATUS AND EQUIPMENT

R325.31 J. Marique. Ut nouveau radiogoniometre a lecture directe. (A new direct-reading radiogoniometer.) *L'Onde Electrique*, **10**, 355–362; August, 1931.

The article describes a direct reading goniometer. Some experimental curves are shown.

R339 C. E. Wynn-Williams. The use of thyratrons for high speed automatic counting of physical phenomena. *Proc. Royal Soc. A*, **132**, 295–310; July 2, 1931.

Several circuits are described whereby thyratron valves can be used for very high speed automatic counting of voltage impulses. Two impulses separated by only 1/1500 second could be recorded. A note on the method of operation of a thyratron tube is included.

R355.9 A. T. Starr. A single-valve multi-frequency generator. *Wireless Engineer and Experimental Wireless* (London), **8**, 465–470; September, 1931.

A single-valve multi-frequency generator can be constructed which will produce frequencies of arbitrarily chosen values with amplitudes of desired ratios. It would be possible to construct a beat-frequency oscillator with one valve producing two frequencies, one of which could be varied by means of a variable condenser and a rectifying valve.

R365.3 ×R270 P. A. de Mars, G. W. Kenrick, and G. W. Pickard. Use of automatic recording equipment in radio transmission research. PROC. I.R.E., **19**, 1618–1633; September, 1931.

This is an apparatus paper describing equipment recently developed for low-frequency (17.8 kc): intermediate-frequency (770 kc); and high-frequency (6942.5 kc) field intensity recording.

R383 G. Hauffe. Über lineare Stromregelung. (On linear regulation of current.) *Elek. Zeit.*, **52**, 1065–1066; August 13, 1931.

Resistance combinations, which permit the linear regulation of current are described.

R385.5 P. Massaut. Recherche de la force electromotrice fictive d'un transmetteur microphonique. (Investigation of the effective electromotive force of a transmitting microphone.) *L'Onde Electrique*, **10**, 303–316; July, 1931.

The author investigates the conditions under which a microphone can be considered a generator of constant impedance. An expression is derived for the electromotive force generated by a microphone. A simple application is discussed.

R388 ×R365.3 K. Buss and A. Pernick. Kathodenoszillographische Aussen-Aufnahmen mit Linse und Kamera bei extrem rasch verlaufenden Vorgängen. (External photography, with lens and camera, of rapidly moving phenomena in a cathode-ray oscillograph.) *Archiv für Elektrotechnik*, **25**, 545–550; August 14, 1931.

It is shown that non-recurring, rapidly moving, transient phenomena may be photographed.

R390 K. Hoffman. Lautstärkeregulierung durch Regeldrosseln. (Volume control by means of variable choke coil.) *Elek. Nach.-Technik*, **8**, 331–335; August, 1931.

It is shown that a variable inductor offers several advantages over the usual attenuation network of the resistance type.

R390 ×R190 L. B. Hallman. An analysis of the series-type mixing control. *Radio Engineering*, 11, 17–18; September, 1931.

This paper analyzes the series system of mixing control; establishes definite rules for the design of mixing control unit; and shows how nearly such an arrangement may be made to approach the standards already established.

R400. RADIO COMMUNICATION SYSTEMS

R410 A. H. Reeves. The single side-band system applied to short wavelengths. *Electrical Communication*, 10, 3–19; July, 1931.

The object of this article is to describe one of the possible single side-band systems for use on short-wavelengths, and to describe experiments carried out by the International Telephone and Telegraph Laboratories in conjunction with the Laboratories of Le Materiel Telephonique, Paris, during the past year with this system between the International Telephone and Telegraph commercial transmitting station at Pozuelo del Rey near Madrid and an experimental receiving station at Trappes, near Paris.

R430 A. Larson. Über Rundfunkstörungen. (Static interference with broadcasting.) *Elek. und Maschinenbau*, 49, 641–648; September 23, 1931.

Methods of eliminating radio interference due to electrical apparatus and machinery are described.

R430 ×R170 Short wave interference with broadcast reception. *Radio Engineering*, 11, 25–26; July, 1931.

Types of interference produced by short-wave transmitters and methods of eliminating such interference are discussed.

R500. APPLICATIONS OF RADIO

R520 R. Hermann and P. Grenier. Les ondes courtes dans l'aviation. (Short waves in aviation.) *L'Onde Electrique*, 10, 325–337; August, 1931.

This article contains discussions of the following subjects: Advantages and inconveniences of short waves, the transmission of two wavelengths from an airplane, and the characteristics of aerodrome transmitters.

R522.1 A. P. Bock. Twenty-watt aircraft transmitter. PROC. I.R.E., 19, 1569–1578; September, 1931.

This article describes an aircraft transmitter which may be used either for continuous wave or telephone transmission. The transmitter is flexible in operation and light in weight.

R550 A. W. Scharfeld. The Mexican broadcasting situation. *Jour. Radio Law*, 1, 193–219; July, 1931.

This article describes the general broadcasting situation in Mexico. The control of stations, number of stations, power, and programs are discussed.

R550 S. D. Gregory. Synchronization of Westinghouse radio stations WBZ and WBZA. *Radio Engineering*, 11, 29–33; September, 1931.

This article tells of the Westinghouse Company's attack upon the problem of synchronizing two broadcast transmitters situated in separate localities. Further simplification of amount of equipment and tubes used is in prospect.

R583 R. Barthelemy. La reception en television. (Reception in television.) *L'Onde Electrique*, 10, 281–302; July, 1931; 338–354; August, 1931.

A development of the principal questions touching reception in television is given. Wire circuits and circuit constants are discussed. A comprehensive discussion of the methods used in synchronizing television transmitters and receivers is also given.

R590 W. R. Blair and H. M. Lewis. Radio tracking of meteorological balloons. PROC. I.R.E., 19, 1531–1560; September, 1931.

This paper deals with a radio method of determining successive balloon positions. A light transmitter, weighing about a pound, is carried up by the balloon at a known ascensional rate. Loop receivers are employed in ranging for this transmitter.

R800. Nonradio Subjects

535.38 ×R339 Simplicity extends light-control possibilities. *Radio Engineering*, **11**, 21–22; September, 1931.

New light sensitive cell, together with simplified associated apparatus is described.

537.65 E. G. Watts. Quartz oscillator wave constants. *Radio Engineering*, **11**, 23–26; September, 1931.

An attempt is made to coördinate the results of the prominent investigators in the field, presenting in summarized form the data on the constants of longitudinally and transversely vibrating modes.

621.374.33 ×535.38 R. P. Lejay. L'amplification de courants photoelectriques faibles au moyen de la lampe electrometre Philips (Amplification of weak photo-electric currents by means of the Philips electrometer lamp.) *L'Onde Electrique*, 10, 363–368; August, 1931.

A decription is given of a method which uses a lamp electrometer in amplifying photoelectric currents.

621.382.8 W. Doebke. Die Hysteresedämpfung von Pupinleitungen. (The hysteresis loss in Pupinized cables.) *Elek. Nach.-Technik*, **8**, 340–343; August, 1931.

The losses in a Pupinized cable due to hysteresis in the Pupin coils are calculated.

621.385.96 W. A. MacNair. Some acoustical problems of sound picture engineering. Proc. I.R.E., **19**, 1606–1614; September, 1931.

Sound pictures have made necessary rapid changes in the formulas and apparatus used in sound recording. Acoustical problems are discussed.

Proceedings of the Institute of Radio Engineers
Volume 19, Number 11 *November, 1931*

CONTRIBUTORS TO THIS ISSUE

Andrew, Victor, J.: Born August 31, 1902 in Medina County, Ohio. Received B.S. degree, Wooster College, 1926; M.S. degree, University of Chicago, 1928. Amateur, experimenter and operator, 1919 to date. Junior radio engineer, Signal Corps radio laboratories, Fort Monmouth, New Jersey, 1926–1927; radio engineer, Westinghouse Electric and Manufacturing Company, 1928–1930; graduate student and assistant, physics department, University of Chicago, 1930 to date. Associate member, Institute of Radio Engineers, 1925; Member, 1929.

Bemis, Isabel S.: Born September 26, 1897 at Bayport, New York. Received A.B. degree, Columbia University, 1919. Engineering assistant, department of development and research, American Telephone and Telegraph Company, 1919 to date. Associate member, Institute of Radio Engineers, 1931.

Conklin, J. W.:

Dingley, Edward N., Jr.: Born July 18, 1902 at Kalamazoo, Michigan. Radio operator, ship and shore stations. Received degree, Massachusetts Institute of Technology, 1926. Laboratorian in photoradio development and facsimile transmission, RCA Laboratories, 1926; marine inspector, RCA Marine Department, 1926; radio inspector, Navy Yard, Washington, D. C., 1926–1928; associate radio engineer, Bureau of Engineering, Navy Department, 1928–1929; radio engineer, Mackay Radio and Telegraph Company, 1929–1930; radio engineer in charge, construction of Marine station WMR, 1930; engineer, RCA Radiotron Company, Inc., 1930 to date. Associate member, Institute of Radio Engineers, 1928.

Espenschied, Lloyd: See PROCEEDINGS for July, 1931.

Finch, James Leslie: Born February 18, 1893 at Grand Island, Nebraska. Received B.S. degree in Mechanical Engineering, University of Washington, 1915. Testing department, General Electric Company, 1916–1917; with U. S. Navy, stationed at New Brunswick transoceanic radio station, 1917–1918; radio engineering department, General Electric Company, 1918–1920; engineering department, Radio Corporation of America, 1920 to date. Associate member, Institute of Radio Engineers, 1919; Member, 1928.

Hansell, C. W.: See PROCEEDINGS for August, 1931.

Hoffmann, K.: Born January 3, 1900 at Berlin, Germany. Received degree, University of Berlin, 1923. Siemens and Halske, 1922–1925; Reichs department for telegraph technique, Reichs Central Post Office, 1925–1928; collaborator of Eugen Reisz, 1928–1929; Reichs Broadcasting Company, 1930 to date. Nonmember, Institute of Radio Engineers.

Iso, Eiji: Born October 3, 1905 at Tokushima City, Japan. Studied electrical engineering, Tokyo Higher Technical School, 1923–1926. Radio section, Electrotechnical Laboratory, Ministry of Communications, Tokyo, Japan, 1926 to date. Associate member, Institute of Radio Engineers, 1930.

Kantebet, S. R.: Born in 1900. Graduated, Bombay University, 1921. Studied electrical technology course, Indian Institute of Science, Bangalore, 1921–1924; assistant engineer, Bombay Telephone Company, Ltd.; studied radio communication, Marconi's Wireless College, Chemlsford, England; assistant engineer, Marconi's Wireless Telegraph Company, Ltd., on erection and testing of the Wireless Beam Station at Poona for England-India service, 1924–1928; assistant professor, electrical communication engineering, Indian Institute of Science, 1928 to date. Member, A.M.I.E.E. Associate member, Institute of Radio Engineers, 1925; Member, 1931.

Lubszynski, Günther: See Proceedings for July, 1931.

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Mohammed, Aijaz: Born in 1904 at Jaipur, India. Graduated, Aligarh University, 1926. Studied electron theory, X-rays, and wireless telegraphy at Lucknow. Received M.S. degree, 1929; research work, communication engineering department, Indian Institute of Science, Bangalore, 1930 to date. Associate member, Institute of Radio Engineers, 1931.

Namba, S.:

Sawyer, C. Baldwin: Born July 15, 1894 at Cleveland, Ohio. Received B.A. degree, Yale University, 1915; graduate student, Massachusetts Institute of Technology, 1915–1917; instructor, heat treatment of metals and naval aviation inspection, 1917–1919; postgraduate student, 1919–1921; received Ph.D. degree, 1921. Associated with Brush Laboratories Company, 1921 to date, president since 1927. Nonmember, Institute of Radio Engineers.

Spitzer, Edwin E.: Born February 22, 1905 at Fitchburg, Massachusetts. Received B.S. degree and M.S. degree in E.E., Massachusetts Institute of Technology, 1927. Research laboratory, vacuum tube engineering section, General Electric Company, Schenectady, New York, 1927 to date. Associate member, Institute of Radio Engineers, 1928.

Ueno, Shigetoshi: Born January 2, 1908 at Wakayama Prefecture, Japan. Educated at the Training Institute of the Communications Department; entered Electrotechnical Laboratory, Ministry of Communications, 1927. Nonmember, Institute of Radio Engineers.

◆

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- —LOOSE CONNECTIONS
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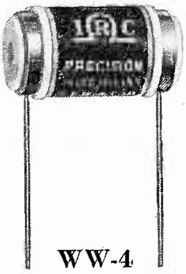
PRECISION *WIRE WOUND* RESISTOR


WW-4

This improved unit has stepped into the lead among wire wound resistors because it has hurdled obstacles which previously blocked the path to accuracy.

The elimination of open contacts by the use of moulded ends; the elimination of shorted turns by the use of a special impregnating compound which *hardens* with high temperatures instead of softening; the exclusive use of the highest grade and largest alloy wire consistent with resistance value—these and other features have proved of highest importance to the vacuum tube industry.

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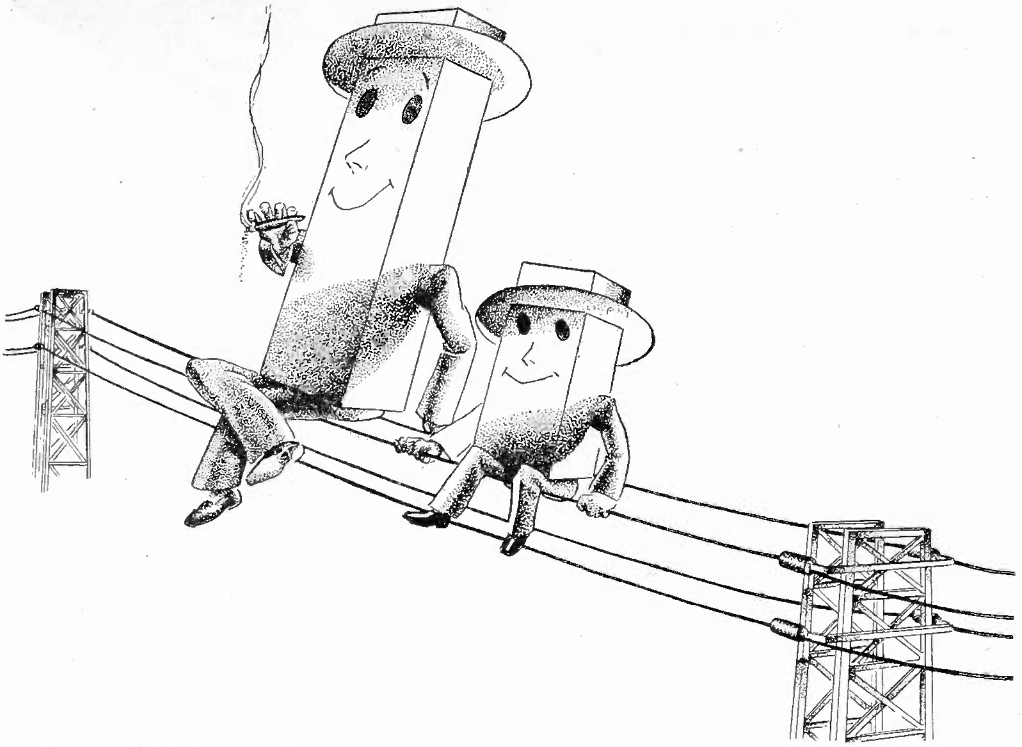

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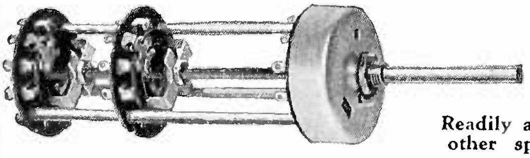

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3 gang, 4 positions
single circuit

Readily adaptable to
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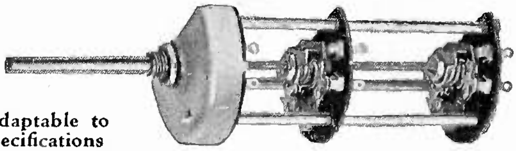

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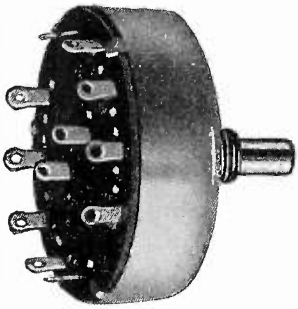
2 circuits



No. 7150A
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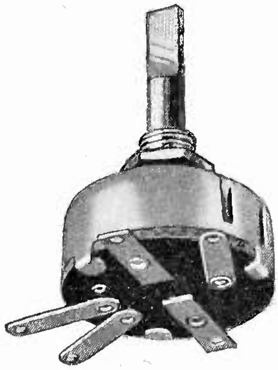
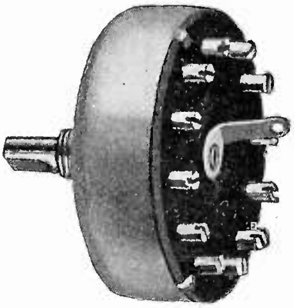
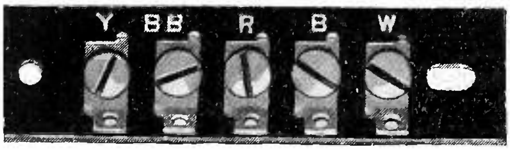


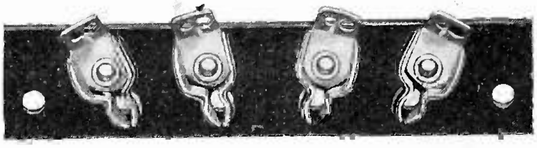
No. 7120A
Combined Acoustic and muting switch 2 or 3 positions



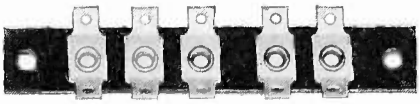
No. 7220A
12 positions, single circuit



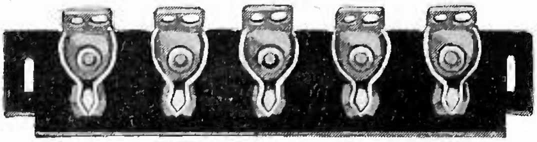
Terminal Strip
5 Lugs No. 6880A, 4 lugs No. 6990A



Terminal Strip
4 Clips, No. 6830A



Terminal Strip
5 Lugs, No. 6950A



Terminal Strip
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OF MERIT AND
FAIR PRICES

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DUAL "CUB" CONDENSER

This latest development of Cornell engineers—the result of three years' experience in the manufacturing of our now famous "Cub" condensers—has met with an enthusiastic reception throughout the radio industry because of the following features—

> Single mounting strap—can be attached to panel—initial cost is less—most flexible and easiest mounting—no loss in efficiency—reduces costs by cutting assembly operations — high insulation resistance — extraordinary dielectric strength.

BIGGEST SEASON IN OUR HISTORY. The tremendous popularity of Cornell "Cub" condensers has resulted in a 300% increase in sales.

Write for samples and let us know your requirements. We shall be glad to send you full particulars.

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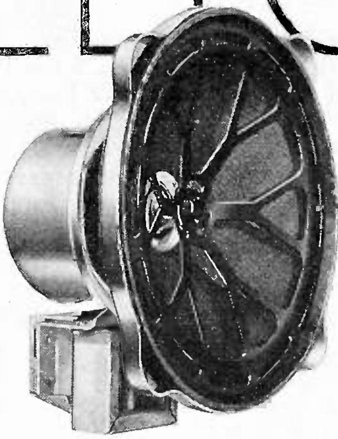
MILLIONS

FOR BETTER BROADCASTING



why not a few cents more for

BETTER RECEPTION?

Radio authorities are agreed:—Radio transmission is making tremendous forward strides. Radio *reception* is lagging behind. Look at the constant improvements in transmission. The use of acoustic panels, of condenser and reflector microphones. The clarification of tone; the reduction of interference, over-lapping, fuzzing, and fading . . . It all sounds fine to the radio listener—until his speaker says to him: "Try and get it!"

What radio needs

The far-sighted maker of radio sets won't take a chance. He realizes that the industry cannot remain deaf to this challenging demand by better broadcasting for better reception. He knows what the radio public wants—what radio needs.

He knows what Magnavox has done in the past to meet this need. And, being "up" on the latest developments, he knows that the new Magnavox 40 Series Symphonic Speaker represents a great advance, reproducing the full range of voice and music—clear and true—from low G to high C. . . .

A few cents more for better reception—and some wise radio manufacturer is going to solve some mighty troublous problems of "price" competition!

Make no commitments without investigating the New Magnavox 40 Series Symphonic Speaker. A model, with engineering data, will be furnished without obligation.

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Magnavox SPEAKERS

THE PRODUCT OF TWENTY YEARS' PIONEER RESEARCH

Piezo Electric Crystals

New Price List Effective Immediately

We are extremely pleased to announce NEW REDUCED PRICES for HIGH GRADE CRYSTALS for POWER use. Due to our NEW and MORE EFFICIENT METHOD of preparing these crystals, we are allowing you to share in the LOWER COSTS of producing these crystals.

We are proud of the confidence our customers have shown toward us, we extend to them our sincere thanks for their patronage thus making this reduction possible.

New prices for grinding POWER crystals in the various frequency bands, together with the old prices are as follows:

FREQUENCY RANGE	**NEW LIST**
100 to 1500 Kc	**$40.00**
1501 to 3000 Kc	**$45.00**
3001 to 4000 Kc	**$50.00**
4001 to 6000 Kc	**$60.00**

The above prices include holder of our Standard design, and the crystals will be ground to within .03% of your specified frequency. If crystal is wanted unmounted deduct $5.00 from the above prices. Delivery two days after receipt of your order. In ordering please specify type tube, plate voltage and operating temperature.

Special Prices Will Be Quoted in Quantities of Ten or More

POWER CRYSTALS FOR AMATEUR USE

The prices below are for grinding a crystal to a frequency selected by us unmounted, (if wanted mounted in our Standard Holder add $5.00 to the prices below) said crystal to be ground for POWER use and we will state the frequency accurate to better than a tenth of one per-cent. IMMEDIATE SHIPMENT CAN BE MADE.

1715 to 2000 Kc band	$12.00 each
3500 to 4000 Kc band	$15.00 each

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We have stock available to grind crystals as low as 13 Kilo-cycles. Prices quoted upon receipt of your specifications.

CONSTANT TEMPERATURE HEATER UNITS

We can supply a high grade heater unit which maintains a constant temperature BETTER than a tenth of one degree centigrade. These units have provision for two of our Standard Holders, (one used as a spare) and operate from the 110 V 60 cycle supply mains, entirely automatic and of excellent design. Price and description sent upon request.

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Continental Resistors

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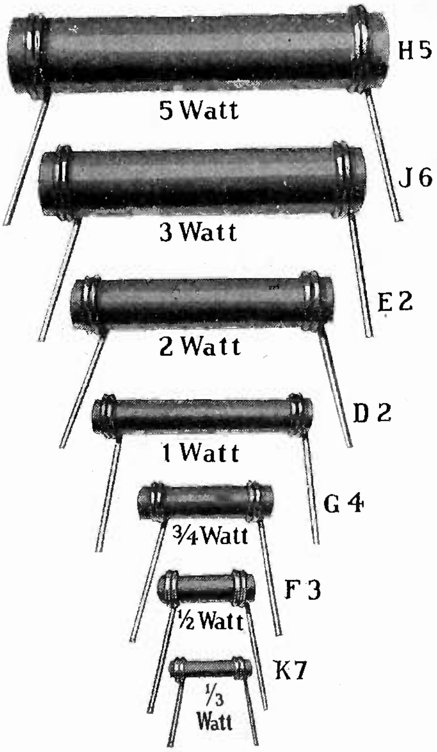

RESISTOR CHARACTERISTICS:

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RESISTANCE CONSTANT
SMALL TEMPERATURE COEFFICIENT
RUGGED
FIRMLY SOLDERED TERMINALS
DEPENDABLE
COLOR CODED

UNITS SHOWN HALF SIZE

CONTINENTAL SUPPRESSORS

For Radio-Equipped Cars

Stop ignition noise in the automobile radio set when used with suitable by-pass condensers. The distributed capacity is extremely small. The resistors are enclosed in a tough ceramic tube of high crushing and tensile strength, of low coefficient of expansion and of high dielectric strength. They are hermetically sealed in the tube and this renders the suppressors moisture proof.

Suppressors shown full size

SPARK PLUG SUPPRESSOR

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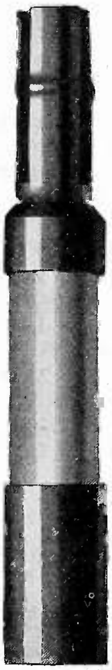

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Curtis Electro Chemical *Condenser*

Essential Characteristics

Full capacity at all voltages

Uniform capacity at all frequencies

Low freezing point

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Low leakage

Made in shape and size to suit the customer, in round, square or rectangular, metal or cardboard containers. Working voltage from 6 Volts to 450 Volts.

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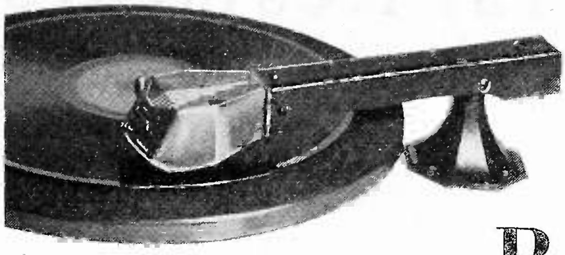

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ideal for new long playing records

Due to its low center of gravity, the Phonovox plays the new long playing phonograph records without jumping, although the record grooves are much narrower than ordinary records. A full swingback head means easy needle changing. All the parts in the Pacent Master Phonovox are adjusted to so accurate a degree of precision that you are insured a constantly correct needle pressure with a minimum wear on the record. You can install the Pacent Phonovox on your radio and phonograph in two minutes. Write to us for full particulars or see and hear the Pacent Phonovox at your radio dealer's.

Pioneers in Radio and Electric Reproduction for more than 20 years

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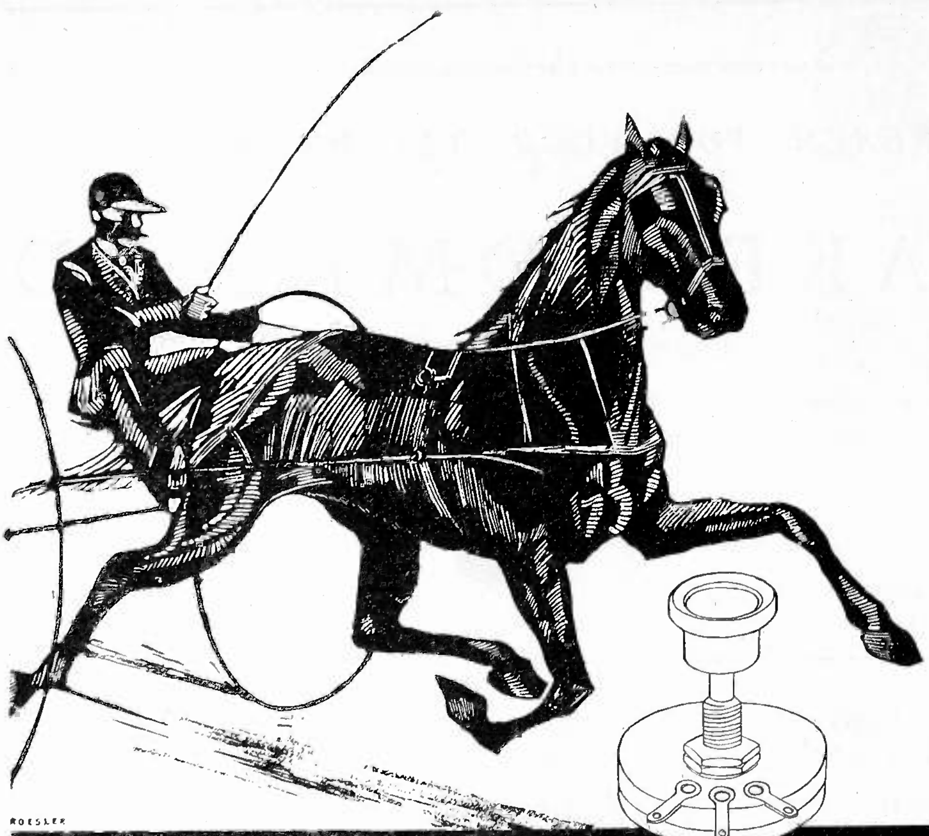
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You need only pick up your telephone to control millions of dollars' worth of property . . . a thousand yards or a thousand miles of wire . . . five thousand or five million dollars' worth of equipment . . . a few or many of the Bell System's hundreds of thousands of trained workers.

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higher emission
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than Nickel with the same filament input, voltage, and temperature and is *one-third as microphonic*

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stronger filament
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Typical of original and unrelenting DeForest research and engineering is the foregoing filament. Such efforts mean a DeForest version of every standard and special type receiving or transmitting tube, always incorporating obvious refinements and improvements to make it a worthy successor of the Audion or original radio tube.

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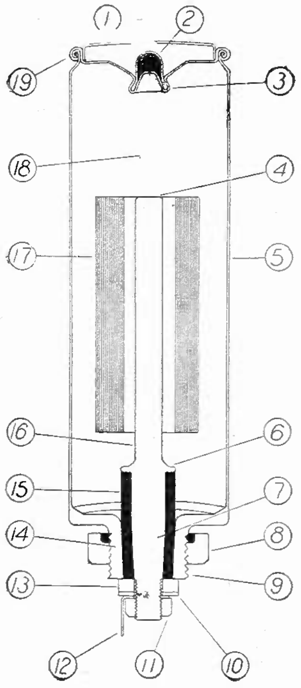
ACRACON

Electrolytic Condensers



Alone Offer All These Features In Electrical Design and Mechanical Construction

1. Metal cover for protection and appearance.
2. Live, rubber nipple.
3. Nipple spun into aluminum shell. Absolutely leak-proof.
4. Anode spiral cold welded into anode, giving rigid construction.
5. One piece extruded aluminum container.
6. Retaining flange for rubber gasket.
7. Tapered anode stem for snug fit.
8. Large cadmium plated steel mounting nut, concave to insure tight connection.
9. ¾"-16 thread neck for mounting.
10. Metal washer.
11. Anode nut.
12. Anode soldering tab.
13. Large size insulating washer.
14. Tapered hole to take tapered anode.
15. Special live, rubber insulating gasket free from impurities.
16. Heavy, rigid, anode stem of high purity aluminum.
17. High purity anode, spiral, so wound as to eliminate the necessity of insulating liner between anode and container.
18. Special, high, critical voltage electrolyte, well over anode to insure long life.
19. Leak-proof rolled seam as used in canning industry.

Follow the leaders of the industry. Specify Acracon Electrolytic Condensers. Also By-Pass, Wax Impregnated, Oil Impregnated, Power and Transmitting types. Write today, enclosing specifications.

The Acracon unit is now available in capacities up to 16 microfarads at either 440 or 475 volt peak in the single anode type.

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And Other Principal Cities

11-31

The Institute of Radio Engineers

Incorporated

33 West 39th Street, New York, N. Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

To the Board of Direction
Gentlemen:

I hereby make application for Associate membership in the Institute.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

....
(Sign with pen)

....
(Address for mail)

....
(Date) (City and State)

References:

(Signature of references not required here)

Mr. .... Mr. ....

Address .... Address ....

Mr. .... Mr. ....

Address .... Address ....

Mr. ....

Address ....

The following extracts from the Constitution govern applications for admission to the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

(Typewriting preferred in filling in this form) No.........

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

1 Name ....
(Give full name, last name first)

2 Present Occupation ....
(Title and name of concern)

3 Permanent Home Address ....

4 Business Address ....

5 Place of Birth........................... Date of Birth.............Age......

6 Education ....

7 Degree ....
(college) (Date received)

8 Training and Professional experience to date..............................

NOTE: 1. Give location and dates. 2. In applying for admission to the grade of Associate, give briefly record of radio experience and present employment.

DATES HERE	

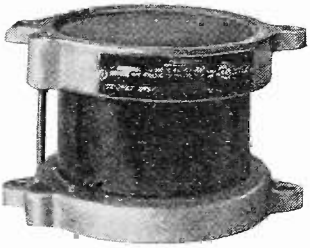
9 Specialty, if any..

Receipt Acknowledged............ Elected............ Deferred............
Grade............ Advised of Election........... This Record Filed...........


SPRAGUE
Electrolytic
CONDENSER
Capacity
8 MFD
Peak Voltage
430 DC
Can Negative
SPRAGUE SPECIALTIES CO.
QUINCY-MASS.

FARADON
Capacitors
for
Dependability

"FARADON" quality and dependability have been proven by many years of continuous service in all parts of the world. "Faradon" Capacitors have been employed as standard equipment for years in radio apparatus used by the U. S. Army, Navy, Coast Guard and Dept. of Commerce; also in the leading broadcasting stations, marine and commercial transmitters, direction finders, aircraft apparatus, etc.



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Our Capacitor engineering facilities are available to all users of both Mica and Paper Capacitors, and we are admirably equipped to assist in the development of special capacitors to your specifications.

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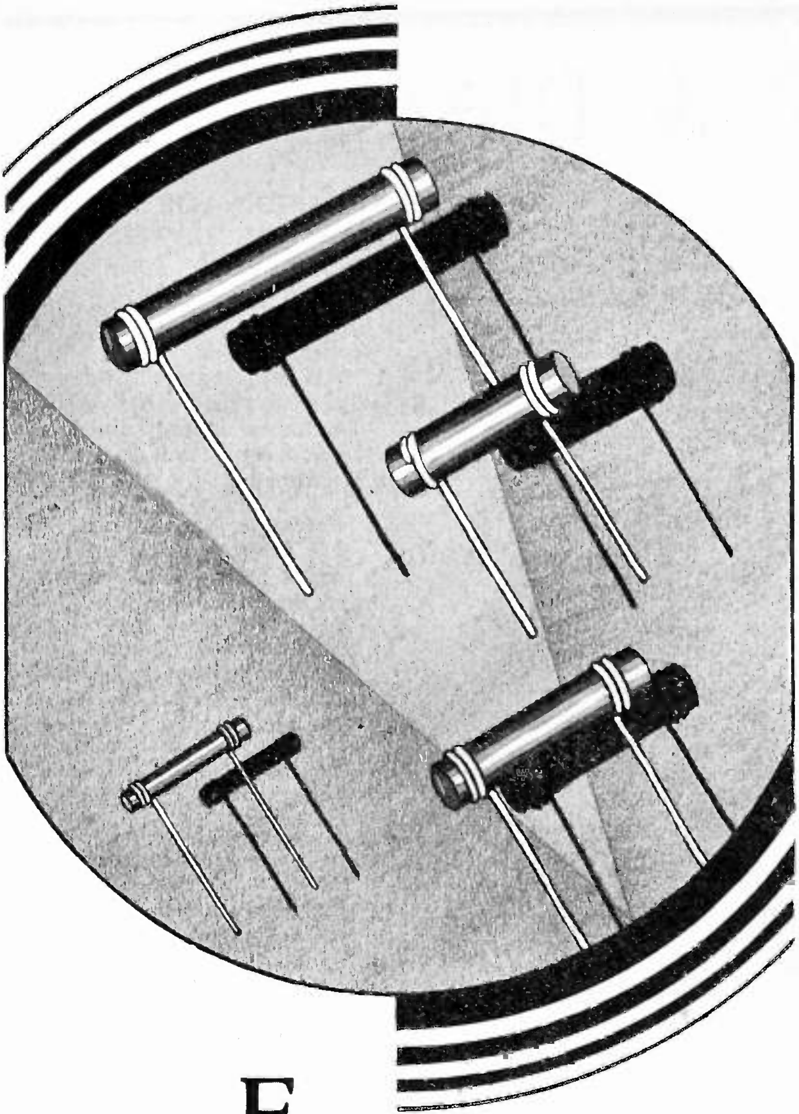

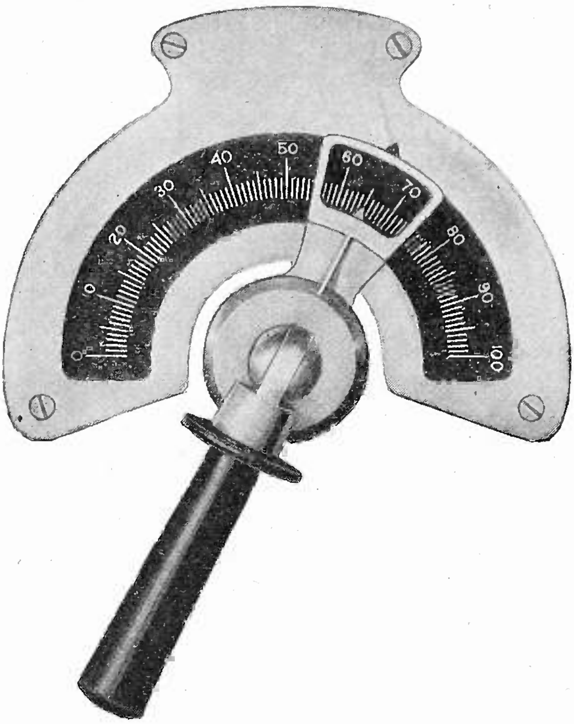
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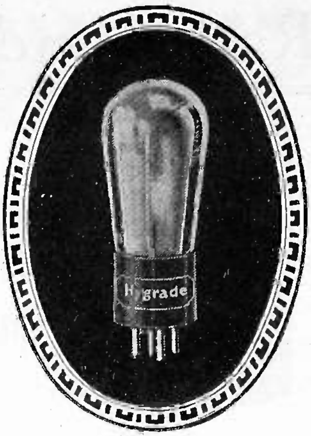
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The New

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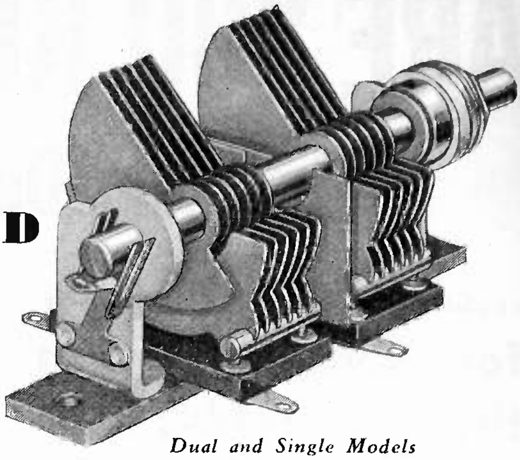

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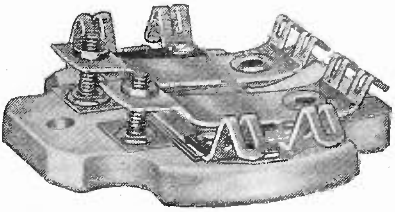

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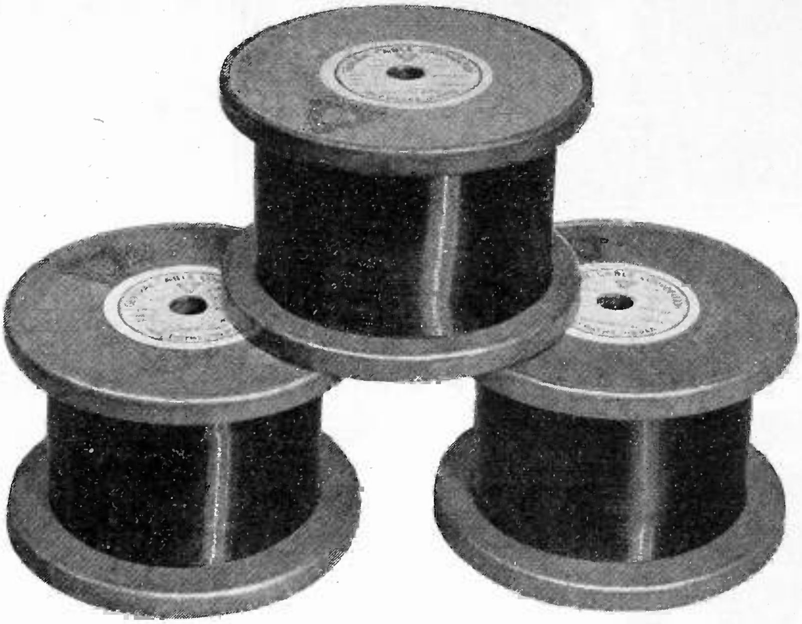

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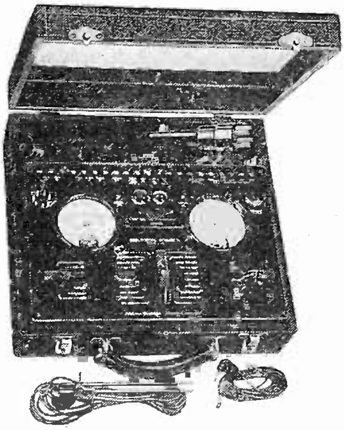
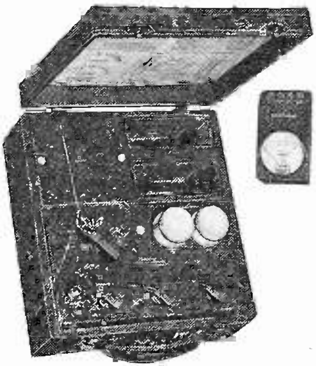


The Pattern 444 Set Analyzer—Performs every necessary test on all receivers, quickly and accurately.



The Pattern 560 Test Oscillator—An absolute necessity for the proper adjustment of any set.

The ease and rapidity with which thorough-going checks and accurate adjustments can be made with the Pattern 444 Set Analyzer and the Pattern 560 Test Oscillator allow servicemen to repair many sets that an inadequately equipped serviceman would return to the factory.

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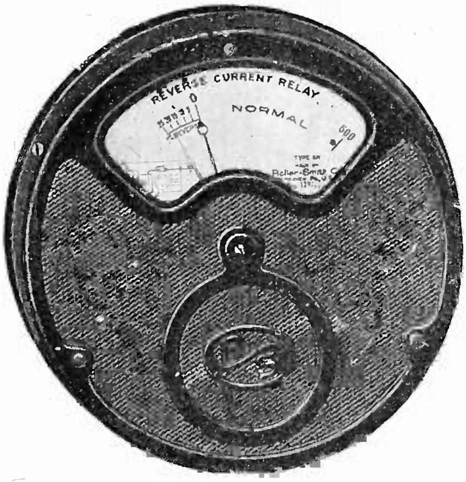

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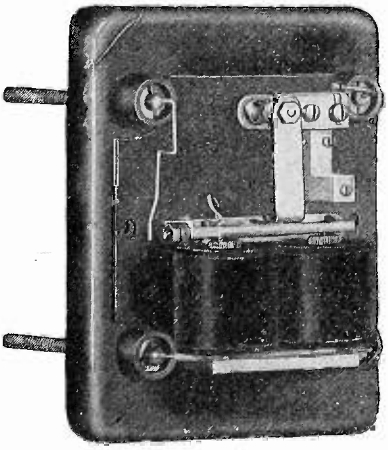

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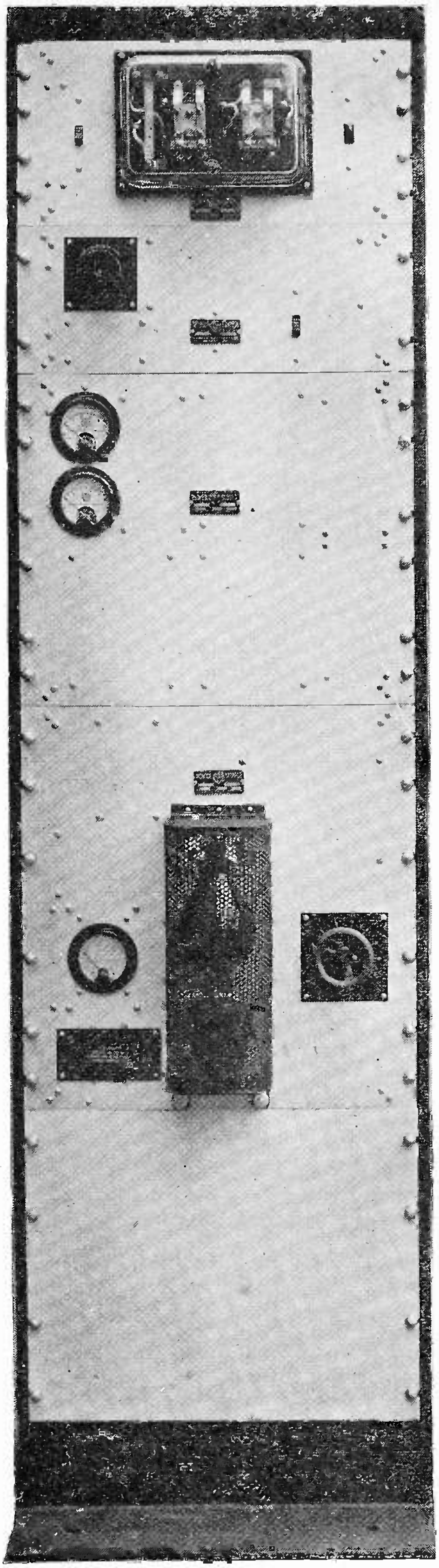

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- Vol. 7 (1919) February, April, August, and December
- Vol. 15 (1927) January, April, May, June, July, October, November, and December
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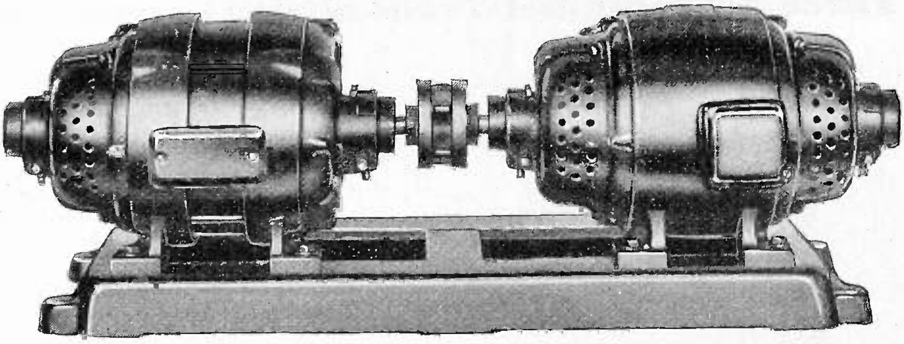

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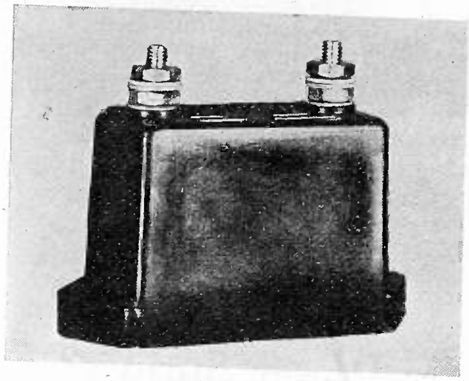

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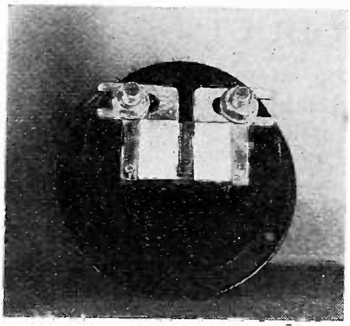

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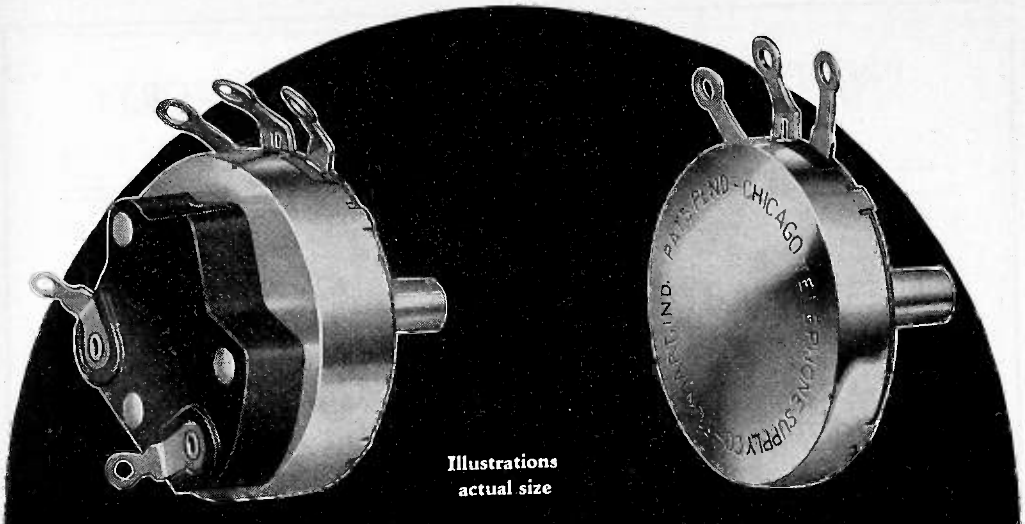

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Our new "70" Series is dominant among Volume and Tone Controls because of superior quality and value

Leadership in any industry usually is founded upon several factors, not the least of which are that the product itself must be of superior quality and of unquestioned value.

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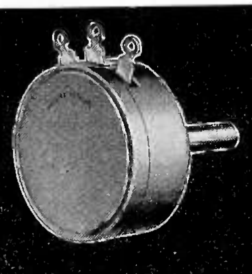

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Alphabetical Index to Advertisements

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Advertisements on this page are available to members of the Institute of Radio Engineers and to manufacturing concerns who wish to secure trained men for positions. All material for publication on this page is subject to editing from the Institute office and must be sent in by the 15th of the month previous to the month of publication. (November 15th for December PROCEEDINGS IRE, etc). Employment blanks and rates will be supplied by the Institute office. Address requests for such forms to the Institute of Radio Engineers, 33 West 39th Street, New York City, N.Y.

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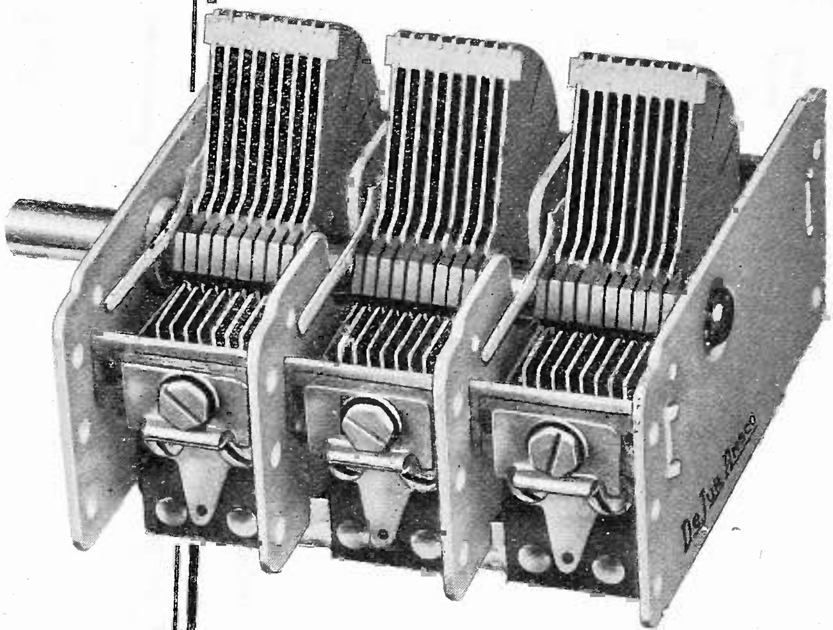
ENGINEERS ASSISTANT desires position in radio laboratory. Pratt Institute electrical engineering graduate, 1928. One year laboratory experience in all phases of radio receiver design and development including power supply, hum, audio systems, radio systems and general measurements. Age 25. Single. Box 88.

MANUFACTURING FOREMAN with experience in servicing broadcast receivers as well as several years as foreman desires position as manufacturing foreman or mechanical designer, preferably of radio equipment. Has had one and one-half years broadcast experience in Germany. Received diploma from German agricultural college in 1922. Married. Age 30. Box 89.

GRADUATE of Westinghouse technical night school in 1927, and of reputable radio school. Holds Commercial Operators' License. Experience includes one year engineering information service, three years in complete charge of stock for research laboratory, and one year service work. Desires work with broadcast station, laboratory or jobber. Single. Will travel. Age 23. Box 91.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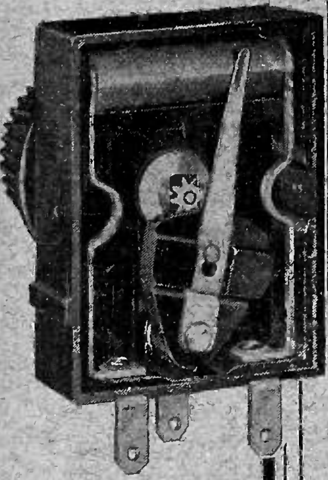
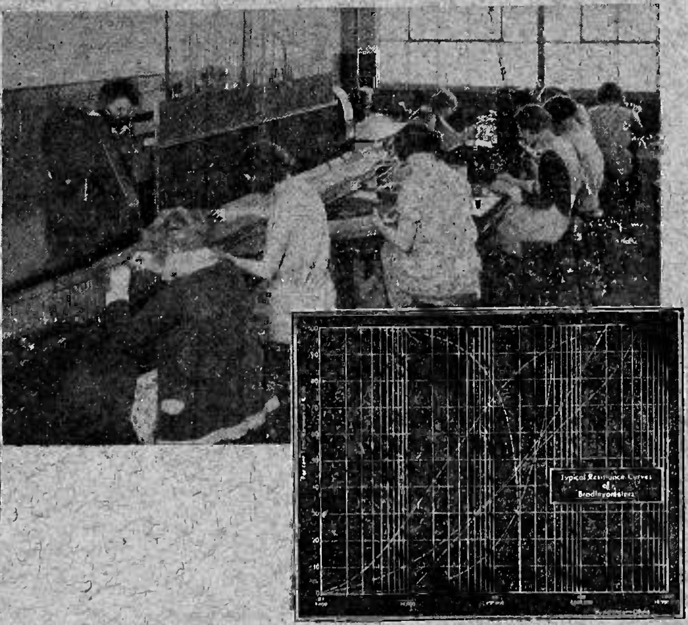
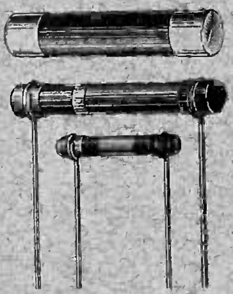




Other Allen-Bradley Radio Products



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Type A Single Bradleyometer

Type AA, Double Bradleyometer

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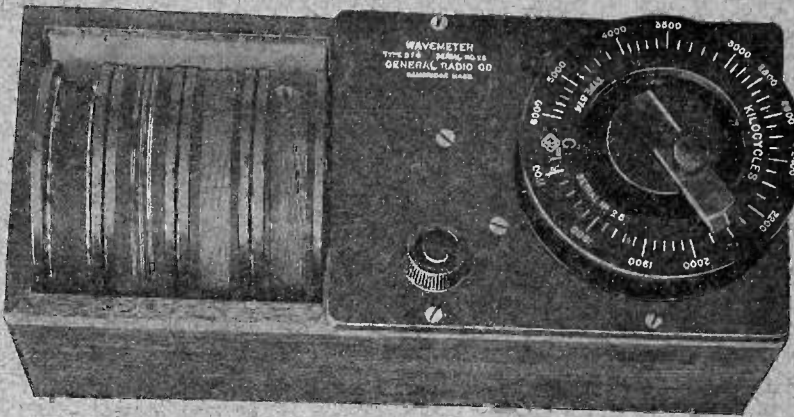

Type 574 Wavemeter

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