TOTH

VOLUME 26 MARCH, 1938 NUMBER 3

PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers
Forthcoming Meetings

ANNUAL CONVENTION
New York, N. Y.
June 16, 17, and 18, 1938
Papers for presentation must be submitted to the Secretary
by not later than April 15, 1938

JOINT MEETING
American Section, International Scientific Radio Union
and
Institute of Radio Engineers
Washington, D. C.
April 29 and 30, 1938

ATLANTA SECTION
March 17, 1938

CHICAGO SECTION
March 11, 1938

CINCINNATI SECTION
March 15, 1938

CLEVELAND SECTION
March 24, 1938

DETROIT SECTION
March 18, 1938

LOS ANGELES SECTION
March 15, 1938

MONTREAL SECTION
March 9, 1938
April 13, 1938

NEW YORK MEETING
April 6, 1938

PHILADELPHIA SECTION
April 7, 1938

PITTSBURGH SECTION
March 14, 1938
April 19, 1938

TORONTO SECTION
March 14, 1938

WASHINGTON SECTION
March 14, 1938
April 11, 1938

TOTH

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 26 March, 1938 Number 3

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Part I

Part II

Technical Papers

The Institute of Radio Engineers

GENERAL INFORMATION

Institute. The Institute of Radio Engineers was formed in 1912 through the amalgamation of the Society of Wireless Telegraph Engineers and the Wireless Institute. Its headquarters were established in New York City and the membership has grown from less than fifty members at the start to several thousand.

Aims and Objects. The Institute functions solely to advance the theory and practice of radio and allied branches of engineering and of the related arts and sciences, their application to human needs, and the maintenance of a high professional standing among its members. Among the methods of accomplishing this is the publication of papers, discussions, and communications of interest to the membership.

Proceedings. The Proceedings is the official publication of the Institute and in it are published all of the papers, discussions, and communications received from the membership which are accepted for publication by the Board of Editors. Copies are sent without additional charge to all members of the Institute. The subscription price to nonmembers is $10.00 per year, with an additional charge for postage where such is necessary.

Responsibility. It is understood that the statements and opinions given in the Proceedings are views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole. Papers submitted to the Institute for publication shall be regarded as no longer confidential.

Reprinting Proceedings Material. The right to reprint portions or abstracts of the paper, discussions, or editorial notes in the Proceedings is granted on the express condition that specific reference shall be made to the source of such material. Diagrams and photographs published in the Proceedings may not be reproduced without making specific arrangements with the Institute through the Secretary.

Manuscripts. All manuscripts should be addressed to the Institute of Radio Engineers, 330 West 42nd Street, New York City. They will be examined by the Papers Committee and the Board of Editors to determine their suitability for publication in the Proceedings. Authors are advised as promptly as possible of the action taken, usually within two or three months. Manuscripts and illustrations will be destroyed immediately after publication of the paper unless the author requests their return. Information on the mechanical form in which manuscripts should be prepared may be obtained by addressing the secretary.

Mailing. Entered as second-class matter at the post office at Menasha, Wisconsin. Acceptance for mailing at a special rate of postage is provided for in the act of February 28, 1925, embodied in Paragraph 4, Section 412, P. L. and R., and authorization was granted on October 26, 1927.

Published monthly by
THE INSTITUTE OF RADIO ENGINEERS, INC.
Publication office, 450–454 Ahnaip St., Menasha, Wis.
Business, Editorial, and Advertising Offices
Harold P. Westman, *Secretary*
330 West 42nd Street, New York, N. Y.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED FEBRUARY 2, 1938

Transferred to the Fellow Grade

New York	New York, c/o Bell Telephone Labs., Inc., 463 West St.	Kelly, M. J.
	New York, c/o Bell Telephone Labs., Inc., 463 West St.	Llewellyn, F. B.

Transferred to the Member Grade

Connecticut	Bridgeport, 348 McKinley Ave.	Dome, R. B.
District of Columbia	Washington, 2123 Tunlaw Rd., N.W.	Norton, K. A.
	Washington, Federal Communications Commission	Webster, E. M.
Maryland	Chevy Chase, 6305 Hillcrest Pl.	Jett, E. K.
Massachusetts	Cambridge, General Radio Co., 30 State St.	Bousquet, A. G.
	Chicopee Falls, c/o Westinghouse Elec. & Mfg. Co.	Burnside, C. J.
	North Weymouth, 9 Brewster Pl.	Hollis, H. H.
New Jersey	Camden, RCA Manufacturing Co., Inc., RCA Victor Division	Engstrom, E. W.
	Camden, RCA Manufacturing Co., Inc., RCA Victor Division	Schrader, H. J.
	Deal, c/o Bell Telephone Labs., Inc.	Sterba, E. J.
	Haddonfield, 247 Merion Ave.	Trouant, V. E.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Iams, H.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Nergaard, L. S.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	North, D. O.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Orth, R. T.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Rose, G. M., Jr.
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	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Stinchfield, J. M.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Division	Zottu, P. D.
	Interlaken, 302 Grassmere Ave.	Burrows, C. R.
	Verona, 18 Winding Way	Spitzer, E. E.
New York	New York, Western Union Telegraph Co., 60 Hudson St.	Arnold, J. W.
	New York, General Radio Co., 90 West St.	Ireland, F.
	Port Jefferson, L.I., 108 Prospect St.	Carter, P. S.
	Riverhead, L.I., c/o RCA Communications, Inc.	Crosby, M. G.
	Riverhead, L.I., 179 Woodhull Ave.	Trevor, B.
	Schenectady, General Electric Co., 1 River Rd.	Darlington, E. S.
	Schenectady, General Electric Co., 1 River Rd.	Metcalf, G. F.
	Schenectady, 1413 Hawthorn St.	Priest, C. A.

Elected to the Associate Grade

Alabama	Leighton, Box 211	McCoy, J. H.
California	Los Angeles, 511 E. 6th St.	Schaefer, R. M.
District of Columbia	Washington, 1514 Spring Pl., N.W.	Gamwell, T. M.
	Washington, 1615 New Hampshire Ave., N.W.	Harrell, E. E.
	Washington, 4633 Davenport St., N.W.	Schleter, G. C.
Georgia	Atlanta, 976 Drewry St.	Burke, J. M., Jr.
	Atlanta, Rm. 318, 51 Ivy St., N.E.	Crowson, F. B.
Illinois	Chicago, 1154 Merchandise Mart	Radius, C.
	Chicago, 5216 W. Monroe St.	Wright, R. W.
Iowa	Sioux City, 1921 W. 4th St.	Lien, C. E.
Maryland	Silver Spring, 1711 Bradford Rd.	Sharpless, W. R.
Massachusetts	Winchester, 54 Hemingway St.	Gaffney, F. J.
Michigan	Highland Park, 10 Eason St.	Penhollow, H. A.
Missouri	Doe Run	LeGrand, J. S.
	Kansas City, 408½ W. 75th St.	Crane, E. J.
	Kansas City, 2730 Troost Ave.	Ferguson, L. T.
New Jersey	Bloomfield, 55 Monroe Pl.	Spangenberg, L.
	Jersey City, 125 Summit Ave.	Cotter, F. M.
	Plainfield, 1287 Florence Ave.	Johnson, G. D., Jr.
New York	Brooklyn, 66 Howard Ave.	Scholer, R. A.
	Endicott, International Business Machines Corp.	Palmer, R. L.
Pennsylvania	Philadelphia, 5419 Germantown Ave.	Packer, W. H.
	Philadelphia, 7866 Devon St.	Snell, P. A.
Virginia	Arlington, 1022 N. Edgewood St.	Hauber, E. N.
Wisconsin	Milwaukee, 2016 W. Burleigh	Merten, D. J.
Canada	Montreal, Que., 204 Hospital St.	Macleod, D. N.
	Toronto, Ont., 236 Gainsborough Rd.	Hedley, C. E.
	Vancouver, B.C., 1927 Georgia St., W.	Watson, J. W.
	Winnipeg, Manit., Canadian Westinghouse Co.	Parker, H.
Cuba	Vedado, Havana, La-Voz-Del-Aire, Calle G y 25, Box 2294	Guiral, R. L.
Czechoslovakia	Prague, Elektropopper	Horvath, A.
England	Honley, Nr. Huddersfield, Yorks., "Farcroft"	Garside, J. H.
	Worthing, Sussex, 20 Leighton Ave.	Gill, F. W.

Geographical Location of Members Elected

France	Nancy, Meurthe et Moselle, 76 Ave. Foch	Lochard, J. C.
India	Bangalore, Electrical Communication Engineering Dept., Indian Institute of Science, P. O. Hebbal	Karve, K. R.
	Dacca, East Bengal, Physics Dept., Dacca University	Khastgir, S. R.
South Africa	Cradock, Union Bldgs.	Theron, C.
Straits Settlements	Singapore, W/T Transmitting Station, R.A.F. Seletar	Colbon, C. V.
	Singapore, W/T Transmitting Station, R.A.F. Seletar	Pook, B. T. T.

Elected to the Junior Grade

New York	White Plains, 70 Robertson Ave.	Locanthi, B.
New Zealand	Christchurch, 116 St. Albans St.	Lee, W. C.

Elected to the Student Grade

Indiana	West Lafayette, 238 East Cary Hall	Gibson, O. B.
Kansas	Manhattan, 723 Moro	Pfeffer, W. J.
Massachusetts	Boston, 526 Beacon St.	Ferry, J., Jr.
	Cambridge, M.I.T. Dormitories	Landay, R. B.
New York	New York, 1435 University Ave.	Lippencott, G. H.
	New York, 666 W. 188th St.	Torian, J. T.
North Carolina	Chapel Hill, 10 Pettigrew	Rockwell, P.
Virginia	Blacksburg, Route 1, Box 119-A	Martin, E. T.

* * *

Proceedings of the Institute of Radio Engineers
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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 Admissions Committee. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before March 31, 1938. These applications will be considered by the Board of Directors at its meeting on April 6, 1938.

For Transfer to the Fellow Grade

New York	New York, 730 Fifth Ave.	Wilmotte, R. M.

For Election to the Fellow Grade

England	Ewell, Surrey, 34 Ewell Downs Rd.	Bishop, H.
	London, W.1, Broadcasting House	Ashbridge, N.
	London, W.1, Broadcasting House	Hayes, L. W.
Java	Bandoeng, Kromboutweg 2	Einthoven, W. F.

For Transfer to the Member Grade

Massachusetts	Cambridge, General Radio Co., 30 State St.	Webster, W. G.
New Jersey	East Orange, 364 Elmwood Ave.	Hiller, H. E.
	Harrison, RCA Manufacturing Co., Inc., RCA Radiotron Div.	Herold, E. W.
	Red Bank, Bell Telephone Labs., Inc., Box 107	Sharpless, W. M.
New York	New York, Columbia Broadcasting System, Inc., 485 Madison Ave.	Goldmark, P. C.

For Election to the Member Grade

District of Columbia	Washington, 3433 Munitions Bldg.	Lawlor, R. D.
New Jersey	Hoboken, Stevens Institute of Technology	Stockwell, F. C.
	Livingston, Box 157	Reise, H. A.
	Newark, 200 Mt. Pleasant Ave.	Webster, F. D.
New York	New York, Bell Telephone Labs., Inc., 180 Varick St.	Coram, R. E.
Argentina	Buenos Aires, Cia Standard Electric Argentina, Cangallo 1286	Andrews, W. J.
	Buenos Aires, c/o Cia Internacional de Radio, Defensa 143	Scott, R. H.
Australia	Sydney, N.S.W., Philips Lamps (A/sia) Ltd., 69–73 Clarence St.	Dudman, V. H.
England	Harrow, Middx., 9 Wellacre Rd., Kenton	McPherson, W. L.

For Election to the Associate Grade

Illinois	Chicago, 60 E. 25th St.	Gibbs, E. D.
	Chicago, 2850 Luna Ave.	Kenworth, W.
	Chicago, 60 E. 25th St.	Perong, A. R.
Indiana	Gary, 3757 Broadway	Hesky, E. E.
	Indianapolis, 4029 S. Bowman Ave.	Coake, C. F.
	Indianapolis, 34 W. Ohio St.	Van Sickle, E.
	Valparaiso, Stiles Hall	Prewitt, C. C.
Kentucky	Winchester, 127 Hickman St.	Squibb, W. F.
Maryland	Annapolis, 214 King George St.	Ballou, W. H.
Massachusetts	Salem, 6 Hancock St.	Longfellow, B. S.
	Westfield, 58 Arnold St.	Thomas, F.
New Jersey	Bloomfield, 202 Newark Ave.	Hayes, W. A.
	Camden, 1022 N. 31st St.	Kinsell, W. L.
	Montclair, 8 Holland Ter.	Goldsmith, T. T., Jr.
	Rutherford, 245 W. Passaic Ave.	Simpson, W. F.
New York	Astoria, L. I., 22-62—23rd St.	Dolphy, E. L.
	Binghamton, 69 Mason Ave.	Decker, G. A.
	Brooklyn, 155 Parkville Ave.	Vantine, H., Jr.
	Jackson Heights, L. I., 40-15—81st St.	Resides, W. C.
	Long Island City, L. I., 43-09—47th Ave.	LeCount, V. V.
	New York, 254 W. 105th St.	Farfel, V.
	New York, c/o National Broadcasting Co., 30 Rockefeller Plaza	Ghirlando, F. L.
	New York, 305 W. 71st St.	Landsberg, K. U.
	New York, 349 W. 21st St.	Mavrogenis, A.
	New York, 5 W. 63rd St.	Ryan, C. E.
	New York, 20 E. Broadway	Wai, H. C.
	Richmond Hill, L. I., 10737—118th St.	Wright, G. S.
	Rocky Point, L. I., RCA Communications, Inc.	Cook, C. P.
	Schenectady, General Electric Co., General Eng. Lab.	Gardner, G. F.
	Schenectady, 1121 Parkwood Blvd.	Mikelson, W.

Ohio	Cleveland, c/o The Harris Calorific Co., 5501 Cass Ave.	Jerauld, A. N.
Pennsylvania	Emporium, P.O. Box 253	Hammond, R. P.
	Emporium, 225 E. Fourth St.	Lucas, J. T.
	Emporium, 403 Woodland Ave.	Minno, J. L.
	McKeesport, 3516 York Ave.	McMillen, G.
	Philadelphia, 4929 Knox St.	Reed, W. O.
	Pittsburgh, 246 Oakland Ave.	Drabik, E. J.
Rhode Island	Pawtucket, 80 Spring St.	Thornley, H. W.
Washington	Puget Sound, U. S. Naval Radio Station	Conyngham, E. F
	Spokane, 322 S. Washington St.	Planting, M. F.
	Tacoma, 1019 E. 54th St.	Briggs, D. H.
Canada	Charlottetown, P. E. I., 15 Pownal St.	Coffin, G. C.
	Palmerston, Ont.	Gray, J. E.
	Peace River, Alta., Box 422	Hargreaves, F.
Cuba	Havana, P.O. Box 647	Karman, R. J.
England	Beeston, Nottingham, Westlands, Bramcote Dr., W.	Hunt, W. E.
	Chelmsford, "Ardwyn," Longstomps Ave.	Price, T. H.
	Daventry, Northants., B. B. C. Empire Broadcasting Station	Brownless, S. F.
	Eltham, London, S.E.9, 34 Dunvegan Rd.	Hayward, R. K.
	Farnborough, Hants., "Lissenden," Hillfield Rd.	Pegler, G. D.
	Farnborough Green, Hants., "Sunnyside," Farnborough Rd.	Smith, C. H.
	Flixton, Man., 58 Tintern Ave.	Tomlin, G. M.
	Newcastle-on-Tyne, Northumberland, "Riggmore," West Rd., Ponteland	Forster, A.
	Uplands, Bristol 3, 19 Alexandra Rd.	Brookes, A. E.
Fiji Islands	Suva, c/o Amalgamated Wireless (A/sia) Ltd.	Exon, F. C.
Germany	Berlin-Steglitz, Heinrich Seidelstr. 4	Wolff, H. H.
India	Bhavnagar, Masoomali Jaferali's Bungalow, Peile Garden Back Rd.	Avasty, K. S.
	Calcutta, 25 Chowringhee Rd.	Munge, S. W.
	Lahore, Punjab, 21 Nisbet Rd., Dinga Singh Bldg.	Dass, I. L.
	Lahore, Punjab, c/o R. S. L. Ishar Das Kapur, Palms Church Rd.	Kashyap, K. L.
Manchukuo	Shingking, Kokuka Kotsubu	Matsudaira, H.
Newfoundland	St. John's, 176 Pennywell Rd.	Brown, W. A.
Poland	Warsaw, 341 Srochowska	Rajski, C.
South Africa	Port Elizabeth, 27 Smith St.	Pretorius, P. G.
Straits Settlements	Singapore, Posts and Telegraphs Dept., Paya Lebar Wireless Station	Talbot-Jones, R. V
Sweden	Stockholm, Royal Technical University, Valhallavagen	Sundquist, A.

For Election to the Junior Grade

Illinois	Chicago, 1515 Monroe St.	Shelby, V. L.

For Election to the Student Grade

California	Berkeley, 1802 LeRoy Ave.	Livingston, R. S.
	Berkeley, 2434 Channing Way	Silverman, I. I.
	Stanford University, Box 1231	Breymayer, K.
Indiana	Angola, 406 W. Gale St.	Lee, D. B.
	Angola, 411 S. Darling St.	Turner, P. M.
	Fort Wayne, 201 W. Brackenridge St.	Johnson, H., Jr.
	West Lafayette, 314 W. Stadium Ave.	Mirkin, M.
Minnesota	Minneapolis, 1607 Clinton Ave. S.	Bartholomew, D.
	Minneapolis, 3042—44th Ave. S.	Johnson, W. G.
	Minneapolis, 318 Electrical Engineering Bldg., Univ. of Minnesota	Klima, W. M.
	Minneapolis, 531 Walnut St., S.E.	Sabine, L. E.
	Minneapolis, 1119 James Ave. N.	Sackter, M. L.
Missouri	Warrensburg, 313 W. Gay St.	Curnutt, C. R.
New Jersey	Union City, 414 New York Ave.	Treuhaft, M.
New York	Flushing, L. I., 50–21 Parsons Blvd.	DeWitt, D.
	New York, John Jay Hall, Columbia Univ.	Neumann, A. J.
	New York, 106 W. 103rd St.	Puig, G.
	Richmond Hill, L. I., 104–58—122nd St.	Hausz, W.
Ohio	Columbus, 28 E. 12th Ave.	Anderson, A. E.
Pennsylvania	Bala-Cynwyd, 405 Leveringmill Rd.	Smith, W. D., Jr.
Washington	Seattle, 4237—12th N.E.	Havens, B. L.

* * *

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INSTITUTE NEWS AND RADIO NOTES

February Meeting of the Board of Directors

A meeting of the Board of Directors was held on February 2 and attended by C. M. Jansky, Jr., acting chairman; Melville Eastham, treasurer; E. H. Armstrong, H. H. Beverage, Ralph Bown, J. E. Brown, F. W. Cunningham, Alfred N. Goldsmith, Virgil M. Graham, R. A. Hackbusch, L. C. F. Horle, A. F. Murray, B. J. Thompson, H. M. Turner, and H. P. Westman, secretary.

M. J. Kelly and F. B. Llewellyn were transferred to the Fellow grade and the following were transferred to Member grade: J. W. Arnold, A. G. Bousquet, C. J. Burnside, C. R. Burrows, P. S. Carter, M. G. Crosby, E. S. Darlington, R. B. Dome, E. W. Engstrom, H. H. Hollis, H. A. Iams, Frederick Ireland, E. K. Jett, G. F. Metcalf, L. S. Nergaard, D. O. North, K. A. Norton, R. T. Orth, C. A. Priest, G. M. Rose, Jr., Bernard Salzberg, H. J. Schrader, E. E. Spitzer, E. J. Sterba, J. M. Stinchfield, Bertram Trevor, V. E. Trouant, E. M. Webster, and P. D. Zottu.

Thirty-nine applications for Associate membership, two for Junior, and eight for Student grade were approved.

The Auditor's report covering the fiscal year ending December 31, 1937, was considered.

The President was authorized to appoint a committee of three to make an analysis of the Institute's investment portfolio and submit recommendations for any changes which seem desirable.

The Secretary's Report for 1937 was accepted. Excerpts from it appear elsewhere in this issue of the PROCEEDINGS.

As a service to the membership, the PROCEEDINGS will accept without charge advertisements offering positions to engineers.

1938 Convention

In order to avoid an overlap with another meeting which was previously scheduled, the dates for the 1938 convention were changed from June 20–22 to June 16–18. The convention will be held in New York City with headquarters at the Hotel Pennsylvania.

Joint Meeting of the Institute and the American Section of the International Scientific Radio Union

The annual joint meeting of the Institute of Radio Engineers and the American Section of the International Scientific Radio Union will be held in Washington, D. C., on April 29 and 30, 1938. This will be a two-day meeting instead of the usual one-day meeting held in past years. This meeting is an important feature of the week which attracts to Washington every year an increasingly large number of scientists and scientific societies. Papers on the more fundamental and scientific aspects of radio will be presented. A program of abstracts will be printed and mailed to those interested before the meeting. Therefore, the abstracts will be required by April 1. Correspondence should be addressed to S. S. Kirby, National Bureau of Standards, Washington, D. C.

Institute Meetings

ATLANTA

The annual meeting of the Atlanta Section was held on January 20 at the Atlanta Athletic Club with N. B. Fowler, chairman, presiding. There were forty-three present.

J. H. DeWitt, Jr., chief engineer of WSM, of Nashville, Tenn., presented a paper on "The Doherty Amplifier." He reviewed first the fundamental theory of the class B radio-frequency amplifier pointing out the factors limiting the maximum efficiency obtainable with low distortion and full modulation. He then outlined the theory of operation of the Doherty amplifier and discussed its practical application to broadcast transmitters. The various circuits employed were described and methods of adjustment were outlined. The discussion was completed with a treatment of push-pull operation and the application of stabilized feedback.

A low-powered transmitter was used to demonstrate the phase relations and wave forms of certain circuit voltages and methods of adjustment were demonstrated with the aid of a cathode-ray oscilloscope. The paper was concluded with a discussion of the design of the 5-kilowatt amplifier in the WSM auxiliary transmitter. Some facsimile transmissions by WSM were mentioned briefly.

In the election of officers, C. F. Daugherty of Station WSB, was named chairman; Ben Akerman of Station WGST, was elected vice chairman, and J. G. Preston of the United States Radio Monitoring Station at Marietta, was elected secretary-treasurer.

BUFFALO-NIAGARA

G. C. Crom, Jr., chairman, presided at the January 12 meeting of the Buffalo-Niagara Section which was attended by sixteen and held at the University of Buffalo.

E. C. Williams of the General Electric Company, presented a paper on "Applications of Ultra-High Frequencies." His discussion was limited to police-radio systems and the disadvantages encountered in the application of medium-high frequencies to the service were outlined. Interference in one service area from another and variations between day and night transmission can be reduced by using ultra-high-frequencies between 30 and 42 megacycles. An outline was presented of one- and two-way transmission between fixed and mobile transmitters, between mobile transmitters, and between mobile units through the intermediary of a fixed unit. The use of remote fixed-tuned receivers, connected by land wire to the transmitting station, was described. Methods of coupling ultra-high-frequency transmission lines to antennas of different design were also described.

CHICAGO

Two meetings of the Chicago Section were held in January and one in February, at Fred Harvey's Union Station Restaurant.

The January 7 meeting was attended by one hundred and ten and presided over by J. E. Brown, chairman.

A paper on "Directional Broadcast Antennas" was presented by V. J. Andrew, consulting engineer. Dr. Andrew introduced his subject with an outline of some of the circumstances necessitating directional characteristics for broadcast radiation. The use of arrays of vertical radiators to obtain directivity was described. Examples were given of the geometrical placement of towers and the requisite phasing of antenna currents to achieve specified radiation patterns. The design procedure for matching networks between transmitter and transmission line and the line and tower was given. The paper was followed by an extended discussion participated in by Messrs. Brown, Robinson, and Sandretto.

The January 21 meeting, also presided over by Chairman Brown, was attended by two hundred and thirty-five. A paper on "Snow Static Effects in Aircraft Radio" was presented by H. M. Hucke, chief communications engineer for United Airlines and Transport Corporation. The blanking of signals by the characteristic whining interference known as snow static was described. This form of static does not require snow. The meteorological conditions under which it occurs were described. A transport plane used as a flying laboratory and its equipment for measuring potentials on the plane, the atmosphere through which it flies, and the degree and nature of snow-static interference were described. As a result of experiments it was concluded that static originates with a corona discharge from a point on the plane and is caused by the high potential which the plane acquires in flying through the ionized atmosphere. Discharge currents as great as two milliamperes were recorded in flight from a point on the plane. Although the discharge is direct current, its random variation contributes high-frequency components which cause the interference. The characteristic of the interference is related to the potential built up on the plane. Ground experiments in which the plane was mounted on insulating pedestals and charged to high potentials with a direct-current generator displayed the results observed in flight. The radio-frequency field surrounding the plane and caused by the corona discharge was plotted and the relation of the antenna location to the interference determined. The susceptibility of different antenna types was observed and while the shielded loop was best, it was not good enough as long as it was located in the field of the radio disturbance. It was found that placing a very fine point some distance back of the tail of the ship and connected electrically to the ship through a high resistance localized the discharge at that point and the interference field disappeared from around the ship itself. The development of a trailing-wire type of snow-static suppressor in a dependable form for application to transport ships has been undertaken. The paper was discussed by Messrs. Andrew, Ford, Kadow, and Robinson.

The meeting on February 4 was presided over by V. J. Andrew, vice chairman, and attended by one hundred and sixty.

"Broadcast Studio Acoustics" was the subject of a paper presented by George Nixon of the development and research group of the National Broadcasting Company. He presented first various empirical reverberation-time formulas and discussed their usefulness and limitations. An improved technique for the measurement of reverberation time and the absorption coefficients of acoustic materials was described. He outlined the choice of acoustic materials, the sound isolation required in studios, and the precautions employed to insure maximum isolation.

The discussion of the paper brought out the relationship between the directional characteristics of microphones and the characteristics of the studio, opinions accounting for "live-end" and "dead-end" studio design, and the dependence of the reverberation time on atmospheric humidity.

CINCINNATI

The January 13 meeting of the Cincinnati Section was held jointly with the local section of the American Institute of Electrical Engineers in the auditorium of the Cincinnati and Suburban Bell Telephone Company. L. R. Culver, chairman of the American Institute of Electrical Engineers Section, presided. There were one hundred and fifty present.

"Chemistry and the Telephone" was the subject of a paper presented by B. L. Clarke of the Bell Telephone Laboratories. In it Dr. Clarke reviewed the problems of the chemist arising from the use of telephones and presented statistics showing the quantities of some of the materials employed. It was pointed out that the chances of the average subscriber having a failure caused by a poor contact is only about seven times that of his chances of dying. He described and demonstrated by means of a projector, methods used in analyzing very small quantities of material in which the most useful tool proved to be a strip of filter paper impregnated with the reagent. The paper was closed with a demonstration of crystallization occurring under polarized light.

CONNECTICUT VALLEY

A meeting of the Connecticut Valley Section was held on December 3 at the United Electric Light Company's auditorium in Springfield, Massachusetts. D. E. Noble, chairman, presided and there were thirty-five present.

J. R. Nelson, engineer of the Raytheon Production Corporation, presented a paper on "Noise in Vacuum Tubes and their Associated Circuits." It was pointed out that the most important source of noise arises from thermal agitation and it was demonstrated mathematically that the square of the effective noise voltage in an amplifier-tube circuit is proportional to the width of the frequency band being amplified, to the amplification, and to the resistive component of the impedance connected between the input terminals of the amplifier. Experimentally determined graphs of the noise levels of various types of tubes were shown. The 6J5G, one of the best of modern triodes, has a noise level of 0.85 microvolt, absolute, as compared with 1.7 microvolts for a 27. The 6J7 was shown to have a lower noise level than the 6K7. Among the oscillators, a plot of injection voltage versus noise showed the 6J8G to be superior to the 6A8 and the 6L7G. The parallel operation of tubes and changes of connections to give pentode or triode operation were discussed as they affect noise. The advantages of using coupled input circuits from a signal-to-noise-ratio standpoint were outlined.

The January 6 meeting was held at Yale University, New Haven, Connecticut. E. Sanders, vice chairman, presided and there were seventy present.

"The Fine Structure of Television Images" was the subject of a paper by A. V. Loughren, engineer of the Hazeltine Service Corporation. The basic principles of scanning were discussed. It was pointed out that the cosine-curve shape of the elements obtained in electronic scanning as contrasted with mechanical scanning, permitted a greater tolerance in line width without seriously changing the transverse brightness of a flat field. An analysis was presented in detail of the extreme case of a narrow bright line on a black field. From it were developed equations for the spot size and shape, as well as the characteristics of the electrical circuit necessary to meet these requirements.

DETROIT

On December 17, R. L. Davis, chairman, presided over the annual meeting of the Detroit Section which was attended by fifty and held in the conference room of the Detroit News.

"Recent Frequency Allocations" was the subject of a paper by E. C. Denstaedt, supervisor of radio for the Detroit Police Department.

In the election of officers, E. H. Lee, inspector-in-charge of the Federal Communications Commission engineering department field section, was named chairman; F. S. Kaserman, radio engineer for the United States Lighthouse Service was elected vice chairman; and R. J. Schaefer of the Briggs Manufacturing Company was elected secretary-treasurer.

The January 21 meeting, held in the Detroit News conference room was attended by eighty and presided over by F. S. Kaserman, vice chairman.

"Recent Applications of Photocells and Gaseous-Type Tubes" was the subject of a paper by Ralph Powers, chief physicist of the Electronic Control Corporation of Detroit. A machine to replace the present filing system for letters was described. Each letter is photographed on one frame of 35-millimeter motion-picture film. On the succeeding frame appears a picture of a black screen on which are a series of white dots forming a code representing either letters of the alphabet, numbers, a series of numbers, or a filing chart. The white dots on the blackboard which is photographed for the code, are set up through a system of white telephone drops.

To find a letter the operator sets up on a keyboard, similar to that of a typewriter, the code designation of the letter. The series of frames which comprise the code are projected upon a screen of photocells and amplifiers. When the frame of the film which contains the correct code is projected, it causes all the preselected photocells to operate. This stops the selecting mechanism and allows the desired letter to be projected on a screen. To reduce the space requirements for the bank of photocells, the head-on-type tube is used and enclosed with an amplifier in a case about 1¾ inches square and 18 inches long. The amplifier is a 57 directly coupled to an 885, the output of which operates a relay. A large machine of this type will employ approximately 1600 photocells and two-stage amplifiers. The machine is being adapted for computing so that it will add, subtract, multiply, and divide.

The use of a curtain of light as a safety device for punch presses and its ability to increase the speed of the press, were described. An electric timer for determining the length of time a punch press was closed was discussed and its usefulness on work requiring critical heat treatment outlined. The paper was concluded with a description of the use of a narrow ribbon of light approximately 0.015 inch wide in production work requiring critical adjustment of parts.

EMPORIUM

Two meetings of the Emporium section were held in January at the American Legion rooms, and both were presided over by A. W. Keen, chairman.

The meeting on January 7 which was attended by fifty, was addressed by Haraden Pratt, president of the Institute. As chief engineer of the Mackay Radio and Telegraph Company he presented a paper on "The Development of Radio Telegraphy." Dividing years into decades, he outlined first the work of Hertz, Maxwell, and Marconi in the period from 1890 to 1900, and then covered development to date. He next presented the history of the Mackay Radio and Telegraph Company which name was taken in 1927. Previously it was known as the Federal Telegraph Company and was organized about 1910. The services provided by that organization were outlined and the buildings and equipment which comprise the facilities of the company were described. The paper was discussed by Messrs. Bachman, Erickson, West, and Wise.

The January 27 meeting was attended by forty. W. N. Parker, research engineer of the Philco Radio and Television Corporation, presented a paper on "A Unique Method of Modulation for High-Fidelity Television Transmitters." A summary of this paper appears on page 132 of the February, 1938, issue of the PROCEEDINGS.

INDIANAPOLIS

The following five meetings of the Indianapolis Section were held at the Indianapolis Athletic Club and all, except that of November 19, were presided over by V. C. McNabb, chairman.

D. E. Foster, engineer of the RCA License Laboratories, presented a paper on "Modern Radio-Receiver Design" at the September 29 meeting which was attended by sixty-one. He outlined the organization personnel concerned in the development of a new receiver and showed the relations between sales, executive, and engineering departments and their individual responsibilities in bringing a new receiver to the point of release for manufacture. The major design subdivisions were then treated in detail and included the rectifier and filter circuits, the audio-frequency amplifier, the detector, and radio-frequency selection and amplification. Complete receiver designs typical of the various price groups were described. The paper was discussed by Messrs. DeRosa, Ellis, French, Mallory, and Reinhart.

The October 29 meeting was attended by fifty-seven and a paper on "Volume Expansion—An Aid to High Fidelity" was presented by L. A. DeRosa, engineer for P. R. Mallory & Company. The subject was introduced with a discussion of the various physiological factors involved in high-fidelity reproduction. Artificially generated subjective tones introduced at low volume levels improve quality by giving more nearly the same sound pattern to the auditory senses than is expressed when the original source is at a high acoustic level. The necessity for bass compensation was indicated by a reference to various groups of ear characteristics at various sound levels. The effects of sudden shocks to the auditory senses by sharp transition to high acoustic levels is a means of expression used by composers to secure desired effects. By means of volume-expansion circuits, the improvement in quality resulting from an increased dynamic range was demonstrated. The necessity of time lag in expansion systems to hold the odd-order effects to a tolerable value, was emphasized. The paper was closed with a description of the practical design of such expansion circuits. It was discussed by Messrs. Mallory, McNabb, Passow, and Ware.

The November 19 meeting was presided over by C. F. Wolcott, vice chairman, and there were thirty-one present.

A paper on "British Radio Design" was presented by H. C. Rowe, Jr., of the Rowe Radio Research Laboratory Company. Mr. Rowe was assisted by A. E. Gunthermann. The paper contained a summary of the speaker's observations of television developments in England. The results obtained were considered to be unusually good and receivers could be purchased for the equivalent of between $175 and $600.

A triple-detection receiver employing automatic frequency control of the fixed oscillator was described. Various discriminating- and control-circuit arrangements were discussed and methods of incorporating the oscillator and automatic frequency control in a single tube mentioned. American and British receivers were compared on the basis of characteristics, circuits, and appearance. A number of foreign radio parts and two complete British receivers were exhibited.

The December 10 meeting was attended by forty-seven. The paper was on "Electronic Music" and presented by Alfred Crossley, consulting engineer.

The history of the development of this field was presented first and followed by a discussion of the Everett Orgatron. Problems of developing amplifiers and loud speakers capable of reproducing the full range of tones generated by vibrating reeds were outlined. It was pointed out that by controlling the harmonic content of complex musical tones, it is possible to produce sounds unlike any caused by natural acoustic disturbances.

The paper was discussed by Messrs. French, Mallory, Wolcott and others, and the meeting was closed with a demonstration of an electric organ.

The December 27 meeting was held in co-operation with the American Association for the Advancement of Science and was attended by twenty-nine. Five papers were presented.

The first was "A Theoretical Consideration of Spark and Continuous-Wave Resonance Curve," by R. R. Ramsey, professor of physics at Indiana University. It was pointed out that with spark generators a double-peaked resonance curve is obtained when close coupling is used. This was formerly said to show that closely coupled circuits produce two frequencies. Modern radio oscillators do not produce this curve under the same circumstances. The characteristics of spark generators were used as experimental proof of the fallacious assumption that the addition of two sine-wave frequencies produced two new combinational frequencies.

The second paper was on "The Theory of the Diode Vacuum-Tube Voltmeter," by C. B. Aiken, assistant professor of electrical engineering at Purdue University. The current-voltage characteristic of a diode was expressed mathematically and analyzed. It was shown that the rectification efficiency and input resistance of a grid-leak-and-condenser diode circuit can be expressed entirely in terms of the leak resistance, the amplitude of the impressed alternating voltage, a single tube parameter determined by the cathode temperature, and an adjustable constant which is related to the voltage across the leak under nonsignal conditions and which may be adjusted by the value of bias applied to the grid. The effects of varying these factors were shown both mathematically and graphically. The effect of an internal resistance in the circuit to which the diode voltmeter is connected was treated. The possibility of calculating the performance and characteristics of a diode detector under the action of an unmodulated wave with a previously unobtainable accuracy was pointed out.

"Heising Modulation in Receiving Circuits" was presented by Herbert Hazel of Indiana University. He discussed the possibilities of using the Heising system of modulation in receiving circuits and presented experimental evidence to support the view.

H. S. Knowles, chief engineer of the Jensen Radio Manufacturing Company presented a paper on "The Theoretical and Practical Principles of the Coupling of a Compound Sound Radiator to the Acoustic Load." It covered the history of the use of baffles with loud speakers. Developments in acoustic phasing and methods used commercially to achieve this effect were described.

"The Fine Structure of Television Images" was presented by H. A. Wheeler of the Hazeltine Service Corporation. A summary of this paper which was written by H. A. Wheeler and A. V. Loughren is contained in the report of the meeting of the Connecticut Valley Section which appears elsewhere in this issue.

Los Angeles

The following eight meetings were held by the Los Angeles Section. Unless otherwise indicated the meetings were held in the Los Angeles Junior College.

The March 9, 1937, meeting was presided over by Douglas Kennedy, chairman, and attended by ninety-nine.

A paper on "Direct-Reading Instruments" was presented by A. E. Thiessen of the General Radio Company. A number of new audio-frequency and radio-frequency devices were described and displayed. The paper was discussed by Messrs. Hawkins and Nikirk. The meeting was closed with the projection of a motion picture taken with the Edgerton Stroboscope showing slow-speed reproduction of high-speed action.

The April 20 meeting was held in the studios of KFWB and presided over by R. O. Brooke, vice chairman. One hundred and ten were present.

"A 5-Kilowatt Transmitter" was the subject of a paper by E. Frost, transmitter sales engineer for the RCA Manufacturing Company. It covered the electrical and mechanical design of the new transmitter installed at KFWB. Through the use of controlled reverse feedback, a maximum distortion of 1.5 decibels occurs in the range from 30 cycles to 10,000 cycles. The transmitter is located about four miles from the studios. The radiator is a vertical mast 325 feet high, which is connected to the transmitter through a buried transmission line approximately 100 feet long.

C. M. Mugler, engineer for the Acoustical Engineering Company discussed "Acoustic Treatment as Applied to KFWB." He covered the studio design as viewed from the acoustic requirements for broadcast pickup purposes.

L. G. Hewitt, chief engineer of KFWB presented the final paper on "Studio Speech and Control Equipment of KFWB." In it he described the control system for both local and network programs and described the facilities for recording on acetate discs.

The meeting was closed by an inspection trip through the studios and the transmitter building.

The June 15 meeting was attended by forty-five and presided over by Chairman Kennedy.

F. E. Terman, professor of electrical engineering at Stanford University, presented a paper on "High-Efficiency Linear Amplifiers and Grid-Modulated Amplifiers of the Doherty Type." In it he described the system of high-level radio-frequency amplification in which two stages are coupled through a quarter-wave transmission line. The efficiency was stated to approximate that of a class C amplifier while the distortion was negligible. Following the paper, an inspection trip of the radio laboratories at the Los Angeles Junior College was made.

Chairman Kennedy presided at the September 21 meeting which was attended by thirty.

George Downs, engineer for the Lansing Manufacturing Company, presented a paper on "Late Developments in High-Fidelity Loud-Speaker Systems." He dealt chiefly with systems suitable for theater use. Improvements in low-frequency response were accomplished by properly loading the low-frequency reproducing units by means of a folded baffle having an approximately exponential rate of flare. The high-frequency unit contained a relatively large diaphragm and a short cellular horn giving substantially uniform distribution over a wide angle. A dividing electrical network distributed the proper frequency ranges to the loud speakers. A demonstration employing a high-fidelity radio-broadcast receiver closed the paper.

The October 26 meeting was attended by fifty and held in the studios of KEHE, with Chairman Kennedy presiding.

"Circuit-Control Facilities of a Modern Broadcast Network" was the subject of a paper by C. B. Juneau, superintendent of plant operation for the Hearst radio system. The paper covered the design considerations of a broadcast studio which is to be the control point for a network. Flexibility is required to permit programs originating in the studio or picked up locally to be distributed to a part or all of the network, or handled by the local station alone. Programs from other stations on the network may be distributed similarly. Following the paper an inspection tour of the studios and control rooms was made.

The November 9 meeting was held jointly with the local section of the American Institute of Electrical Engineers and presided over by Chairman Kennedy. There were fifty present.

J. O. Perrine of the American Telephone and Telegraph Company presented a paper on "Waves, Words, and Wires." A summary of this paper appears on page 13 of the January, 1938, PROCEEDINGS.

The annual meeting was held on December 21 and attended by forty-one. Chairman Kennedy presided.

A symposium on portable transmitting equipment used for broadcast-pickup purposes was composed of the following papers:

"Ultra-High-Frequency Pack Transmitter," by G. W. Curran of the KDI engineering department.

"Don Lee Mobile Short-Wave Trucks," by Frank Kennedy, chief engineer of KHJ.

"Routine Use of Short-Wave Pickup Equipment at KFOX," by L. B. Weston, engineer of KFOX.

The equipment described covered the complete range of portable transmitting equipment used for broadcast-pickup service. They range from an 8-pound transmitter of about 70-watts output to equipment mounted in trucks capable of delivering about 200 watts of power. The usual operating procedure is to establish a receiving station in as desirable a location as can be obtained in the time available. Low noise level, close proximity to the pickup point, and adequate wire-line facilities to the broadcast transmitter are the essential requirements. The low-power battery-operated sets are used where extreme portability is necessary. The distance to the receiving point should not exceed a mile. The larger equipment is supplied from the regular power circuits or from gasoline-engine-driven generators. These are used at remotely located points such as off-shore islands. For intercommunication among the three operating points for cuing purposes, a receiver is located at the pickup point and cuing may be obtained directly from the broadcast transmitter. The larger equipments also include a second transmitter for communication purposes. The transmitter oscillators are all crystal controlled. The equipment described was on display.

In the election of officers that followed, R. O. Brooke of the National Broadcasting Company was named chairman; F. G. Albin, vice chairman; and A. C. Packard of the Columbia Broadcasting System was elected secretary-treasurer.

On January 25 a seminar meeting on "Volume Control, Manual Mixing, and Automatic Program Limiters" was held at the National Broadcasting Company's studios in Hollywood. There were one hundred and thirty-five present and R. O. Brooke, chairman, presided. The discussion on "Automatic-Volume-Limiting Amplifiers" was led by R. Stanton of KNX. It covered the operating principles and characteristics of such devices and recommendations as to their usage and limitations.

The "Administration of Radio Networks" was covered by E. H. Schreiber, of the Southern California Telephone Company, and included a description of volume ranges, frequency limitations, and capabilities of toll circuits. Operating practices in toll systems were discussed.

"Volume-Control Problems in Motion-Picture Recording" was the subject covered by Bert Miller of Warner Brothers First National Studios. In it, Dr. Miller presented the problems encountered in recording for films, the types of volume indicators used by the studios, microphone technique, and modern motion-picture-studio equipment.

"Disk-Recording Levels" which covered the limitations of lateral recording and the problems encountered in the volume control of these recordings together with the design and construction of cutting heads and types of record material employed, was presented by Robert Callumm of Recordings, Inc.

Following the presentation of this material, a comprehensive discussion on program-control problems was led by the chairman.

MONTREAL

The November 17 meeting of the Montreal Section was held in the Engineering Institute of Canada auditorium. There were forty-five present and A. M. Patience, chairman, presided.

G. H. Riches, patent attorney, presented a paper on "The Trials and Tribulations of an Inventor." In it he pointed out that while an invention should be covered completely, claims should not be made of great length as the value of a patent claim in his opinion varies about inversely as the cube of the number of words used. Types of patents which are valuable and those which are not were outlined. Methods of choosing an attorney were discussed. The raising of capital to market an invention, and the outright sale of a patent or its disposition on a royalty basis were considered. The rights of the employer and employee inventor were outlined. The paper was discussed by Messrs. Chipman, Fisher, Lajoie, and Lanoue.

On December 8 a meeting of the Montreal Section was held at McGill University with Chairman Patience presiding. There were fifty-eight present.

"Thermionic Emission" was the subject of a paper by H. W. Parker, physicist for Rogers Radio Tubes. The subject was introduced with a discussion of the various principles underlying electron emission. Thermionic emission is caused by heat; photo emission, by light; auto-electronic, by a voltage gradient and work function; secondary emission, by impact; positive-ion emission, by impact; and electronic emission by cosmic rays. The differences between the atomic structures of conductors and insulators were explained. A number of slides were shown of electron microphotographs of activated and deactivated cathodes and the effect of temperature on the activation process. The paper was discussed by Messrs. Jaederholm, Oxley, Sillitoe, and Thomson.

The January 12 meeting was attended by sixty-two. It was held in the Engineering Institute of Canada auditorium and presided over by C. B. Fisher, vice chairman.

"Some Noncommunication Applications of Electron Tubes" was presented by D. G. Fink, managing editor of *Electronics*. Modern concepts of the electron as a particle with a wave aspect were presented. The electron was said to be the most mobile thing known to engineering. The field of electronic engineering was outlined and included such subjects as X-ray tubes, high-frequency tubes of the acorn type, electron optics, the electron microscope and telescope, large metal tubes for industrial applications such as mercury-arc rectifiers, thyratrons, and kenotrons, beam power tubes, Iconoscopes, Kinescopes, phototubes, and amplifiers similar to those used in the various electronic organs. The paper was discussed by Messrs. Fisher, Moore, Oxley, and others.

NEW ORLEANS

On December 7 a meeting of the New Orleans Section was held in the Association of Commerce Building. G. H. Peirce, chairman, presided and there were twenty-nine present.

N. B. Fowler, section inspector of the southern division of the American Telephone and Telegraph Company, presented a paper on

"Teletypewriter Systems of the American Telephone and Telegraph Company," in the discussion of which almost everyone present participated.

NEW YORK MEETING

"The Nature and Properties of Wave-Guide Transmission" was the subject of an experimental lecture presented by G. C. Southworth of the Bell Telephone Laboratories at the February 2 meeting of the Institute in the Engineering Societies Building in New York City. H. H. Beverage, our immediate past president, presided in the absence of President Pratt who is attending the Cairo conference.

In a short historical introduction, Dr. Southworth pointed out that in the rapid development of electrical transmission by wire-line and radio methods, a third, quite different method sometimes called wave-guide transmission had been almost completely overlooked. It consists of extremely high frequency waves transmitted through dielectric wires and through hollow metal pipes. The losses incidental to this new form of transmission are less than by radio and also less than when the same frequencies are transmitted by wire lines. These extremely high frequencies imply broad bands of communication channels.

The main part of the lecture consisted of some twenty separate experiments each demonstrating a particular feature or property of wave-guide transmission. Using a frequency of 1500 megacycles ($\lambda = 20$ centimeters) he showed, by means of a small probe, the nature of four of the many types of waves that may be transmitted through circular guides. In some the lines of force are in a grid pattern across the guide, others are radial, and some are circular. There is a minimum diameter of a guide below which waves of this frequency cannot be propagated. It depends on the type of wave and on the dielectric constant of the enclosed material. This was demonstrated first by using air-core guides of different diameters and later by smaller guides of high-dielectric-constant material.

Other experiments verified the wave characteristics as determined by the probe. Various component "circuit" elements used in wave-guide measurements were demonstrated. They included resonant cavities that act like tuned circuits and also mesh filters that pass certain types of waves and reject others. A short wave-guide line of flexible metal tubing about $2\frac{1}{4}$ inches in diameter was used to transmit a frequency of 3200 megacycles ($\lambda = 9.4$ centimeters) across the platform. The losses were relatively low. The primary source was a special negative-grid tube mounted inside the pipe.

A lengthy discussion followed the paper. The attendance was 650.

PHILADELPHIA

The January 6 meeting of the Philadelphia Section was held at the Engineers Club and attended by one hundred and sixty. A. F. Murray, chairman, presided.

"A New 5-Kilowatt Air-Cooled Vacuum Tube and its Application" was the subject of a paper by T. A. Smith, of the engineering products division of the RCA Manufacturing Company. The basic principles of disposing of heat developed in tube elements was discussed for both air- and water-cooled systems. Difficulties encountered in water-cooling make desirable the utilization of air to as great an extent as possible. Two 5-kilowatt tubes differing chiefly in amplification factor were described. They are the RCA-891-R and the RCA-892-R tubes. The 5-kilowatt broadcast transmitter, the first of such equipment to be offered without water-cooling, was described and the design features which distinguish it from previous practice indicated. One of the large air-cooled tubes was exhibited and it was pointed out that the copper fin structure employed as a heat radiator contained forty pounds of metal. The paper was discussed by Messrs. Barton, Leitch, and Wolff.

"The Rôle of Rags in Industry" was the subject of the second paper, by H. G. Steadman, engineer of the Spalding Fibre Company. It described how rags and fibre are converted into various forms of insulating materials. The processes are long and require an elaborate amount of equipment. Some motion pictures of the manufacturing processes were shown.

On February 3 the Philadelphia Section met at Swarthmore College. Chairman Murray presided and there were one hundred and seventy-five present.

A. J. Allen, chief physicist of the Biochemical Research Foundation of the Franklin Institute presented a paper on "The Cyclotron: An Apparatus for Research in Physics, Chemistry, and Biology." Dr. Allen presented a description of a cyclotron and its use in studying atomic structures and biochemical effects. The cyclotron is essentially an instrument for producing high-speed projectiles and is the simplest device yet developed for accelerating light atoms to high speeds. The one being built at the Bartol Foundation will be capable of accelerating deuterons to a velocity equivalent to eleven million electron-volts. This corresponds to a speed of about 20,000 miles per second. A description of the construction and operation of the device was given and its applications in physics, chemistry, and biology indicated. This device has already permitted the production of more than two hundred and twenty new atoms, all of which are unstable. The high-energy particles produced have been primarily used to explore the internal structure of the atom by the physicist. The chemist uses it to obtain unstable radioactive atoms. As chemical indicators it is relatively simple to know exactly where a radioactive atom is in any set of complicated chemical reactions. For biologists, the cyclotron provides a new type of radiation, neutrons. Experiments already indicate they have a selective action on different types of cellular organisms and cancerous tissue seems to be much more susceptible to this radiation than is normal tissue. The factor is greater for X-rays, however. There is a possibility of using artificially produced radioactive substances in place of the natural substances, such as radium. Chemical characteristics and half-life of the artificial radioactive substances offer a considerable variety of choice for various uses.

PITTSBURGH

On December 21 a meeting of the Pittsburgh Section was held at Carnegie Institute of Technology, R. T. Gabler, chairman, presiding. There were twenty-five present.

A paper on "Requirements and Methods of Electrotherapeutic Apparatus" was presented by P. L. Jenny of the department of radiation and physical therapy of the West Pennsylvania Hospital. Dr. Jenny, who is both a doctor of medicine and a graduate electrical engineer, explained simple equipment to produce "faradic" and "galvanic" currents. It was noted that chemical changes are primarily responsible for therapeutic results in the case of "galvanic" currents, whereas "faradic" currents cause muscle twitching and are useful in relieving pain and promoting healing in certain types of injuries. The early forms of therapeutic apparatus employing spark technique were described. High-frequency current was applied in a manner to produce heat in specific bodily tissues. The application of the vacuum tube brought about the use of medium- and high-frequency diathermy machines; one such device produces heat in inner body tissues by induced currents.

Frequencies between 10 and 20 megacycles are commonly used. The frequency will be a compromise between the requirements for electric surgery, high-frequency heating by electromagnetic induction, and heating by means of an electric field. In general, low frequencies are more suitable for electric surgery; ultra-high frequencies of about 50 megacycles are suitable for heating through the action of an electric field. The paper was closed with a discussion of clinical results obtained with these devices in the treatment of a number of common diseases.

The second paper on the "Development of X-Ray Apparatus for

Therapeutic Uses" was presented by H. W. Jacox, director of the department of radiation and physical therapy of the Western Pennsylvania Hospital. In it Dr. Jacox presented the history of X-rays from their discovery by Professor Roentgen in 1896. At that time static machines were used in this work. They were followed by the induction coil, the direct-current interrupter, the Snook interrupterless transformer, the disk-type rectifier switch, and the self-rectifying machine. In 1919 came the application of the shockproof hot-cathode tube which was followed by the present-day leaded-glass tube with insulated high-tension wires. Some of the many uses of these tubes in therapeutics were mentioned and the improved flexibility, convenience, and reliability of the modern apparatus were pointed out.

In the discussion following the papers, both authors emphasized that electrotherapeutics is not in any sense a cure-all, but that it possesses the capability of producing desirable results when properly applied. The paper was discussed by Messrs. Allen, Krause, Stark, and Work. After the meeting adjourned, three electrotherapeutic equipments were demonstrated.

On January 18 the Pittsburgh Section met at the Carnegie Institute of Technology. Chairman Gabler presided and there were forty present.

"Developments in Broadcast Antennas" was the subject of a paper by R. H. Harmon, chief engineer of the broadcast division of the Westinghouse Electric and Manufacturing Company. The paper covered the new KDKA tower antenna. The first tower erected fell because of a break in one of the guy wires. The second tower was successfully erected. It weighs 60 tons which together with the additional weight of twenty tons caused by the downward pull of the guy wires makes a total weight of 80 tons on the base insulator. The radiation characteristics of this three-quarter-wave antenna which is insulated at the middle, were then discussed. It was pointed out that the insulation at the middle resulted in reduced high-angle radiation and a strong ground wave. To obtain high-angle radiation, 8 quarter-wave antennas were placed about the tower and fed in proper phase relation to produce the desired pattern. The ground system was made up of 360 radial wires, each 700 feet long and buried 10 inches beneath the surface. The paper was discussed by Messrs. Krause, Place, Stark, Sunnegren and others.

ROCHESTER

The February 3 meeting of the Rochester Section was held jointly with the local section of the American Institute of Electrical Engineers at the Sagamore Hotel. There were one hundred and forty-two present and B. M. Werly presided.

J. S. Starrett, of the Radiotron Division of the RCA Manufacturing Company, presented a paper on "Nonradio Applications of Vacuum Tubes." He described a new phototube of rather small size which necessitated new manufacturing technique. Because of its small size, it is expected that the cell will find many industrial applications. Construction of present metal tubes was discussed and it was pointed out that they were accepted more readily by industrial engineers than glass tubes. Some applications of tubes were then discussed and included devices for color comparison in coffee roasting, an automobile speed-indicating device, safety equipment for use on industrial machines, burglar alarms, and an oscillator connected to concealed conductors to make special gas-filled glassware glow in various colors when placed near the conductors. The meeting was closed with a description and demonstration of a new tube used in measuring the strength and direction of magnetic fields.

SAN FRANCISCO

The San Francisco Section met on January 19 at the Pacific Telephone and Telegraph Company auditorium. There were fifty-seven present and the meeting was presided over by Noel Eldred, chairman.

"Development and Installation of Ultra-High-Frequency Control and Signal Channels at New York and San Francisco" was the subject of a paper by Paul Byrne, engineer for the International Telephone and Telegraph Company. The paper concerned the use of high-frequency radio channels between the central stations and the transmitting and receiving stations of telegraph companies as a substitute for the wire lines normally used. The short distances involved make the use of these ultra-high frequencies between 86 and 110 megacycles ideal. The central station is usually located in the city and the transmitting and receiving stations in rural districts from 10 to 50 miles distant. A typical control transmitter is crystal controlled and the frequency multiplied a number of times to reach the desired value. A carrier of about 70 watts is modulated in the final amplifier by 8 audio frequencies which are keyed independently of each other. In the installation between Palo Alto and San Francisco, a distance of about 25 miles, increasing the antenna height by only 15 feet to reach positions for optical sight produced a gain of 16 decibels. Additional increases of 45 feet, 50 feet, and 50 feet more, produced gain increments of 8, 6, and 2 decibels, respectively. A discussion of problems caused by fading and noise concluded the paper which was discussed by a number of those present. Motion pictures showing the making of the 200-inch reflector for the Mt. Palomar Observatory were shown.

The February 2 meeting, which was attended by twelve and held in Manning's Coffee Cafe, was presided over by C. J. Penther, vice chairman. Seminar discussions on two papers were held.

The first paper "Distortion in Diode Detector Circuits," by A. W. Barber which was published in the April issue of *Radio Engineering*, was led by C. F. White. The second paper on "Note on Large Signal Diode Detection," by S. Bennon, published in the December issue of the PROCEEDINGS, was under the leadership of C. H. Sphar.

SEATTLE

The January 28 meeting of the Seattle Section was held at the University of Washington. A. R. Taylor, chairman, presided and there were forty present.

L. B. Cochran, assistant professor of electrical engineering at the University of Washington, presented a paper on "Time-Measured Telephone Service." A history of the development of time-measuring devices for telephones was presented. The Telechronometer, a device for measuring the length of time a telephone is used for outgoing calls, was described. It employs a pole-changer at the central office which changes the polarity of the central battery supply onto the calling subscriber's line at definite intervals which are controlled by a master clock. A polarized solenoid attached to the subscriber's line is actuated by this change in polarity and drives a metering device. This device was used in the Everett-Washington exchange for over four years and provoked an extensive controversy. It was finally ordered out of service by the state. Messrs. Bach, Foss, Libby, Mendenhall, North, Rupp and others participated in the discussion.

TORONTO

There were two meetings of the Toronto Section in January, held at the University of Toronto, and presided over by W. H. Kohl, chairman. The first, on the 10th, was attended by eighty-five and at it D. G. Fink, managing editor of *Electronics* presented a paper on "Recent Advances in Electronic Technology." This was basically the same paper as that presented by the same author at the January 12 meeting of the Montreal Section and described elsewhere in this issue. It was discussed by Messrs. Choat, Hepburn, Kohl and others.

The meeting on the 24th was attended by sixty-seven and N. M. Potter, engineer for the National Carbon Company presented a paper on "The Inside Story of the Radio Battery." The paper was preceded by the showing of a motion picture describing the manufacture of dry batteries and the Eveready air cell. Their operating characteristics were also covered.

It was pointed out that battery receivers present a problem of supplying adequate performance with minimum battery consumption and without serious change in operation over a two-to-one variation in voltage during the life of the B batteries used. Graphs were shown of the performance characteristics of typical receivers throughout the B-voltage range. The advantages of reducing the bias-battery voltage or using self-bias to maintain sensitivity and reduce harmonic distortion at the reduced battery voltages were indicated. A method of reducing B-battery drain by overbiasing the output tube in receivers employing class A amplifying systems was described. It was suggested that an extra control might be provided with one position for most economical operation. For the few cases where maximum output is required, the other position which would supply normal bias might be used. A receiver equipped with meters was used to demonstrate this means of increasing B-battery economy.

WASHINGTON

On January 10, two hundred and twenty-five members and guests attended a meeting of the Washington Section in the Potomac Electric Power Company auditorium. E. H. Rietzke, chairman, presided.

W. N. Parker of the Philco Radio and Television Corporation presented a paper on "A Unique Method of Modulation for High-Fidelity Television Transmitters." A summary of this paper appears on page 132 of the February, 1938, issue of the PROCEEDINGS. The paper was discussed by Messrs. Baily, Jackson, Lyons, and Rietzke.

◆

REPORT OF THE SECRETARY

1937

THE following report on the operation of the Institute during 1937 is published for the information of the membership.

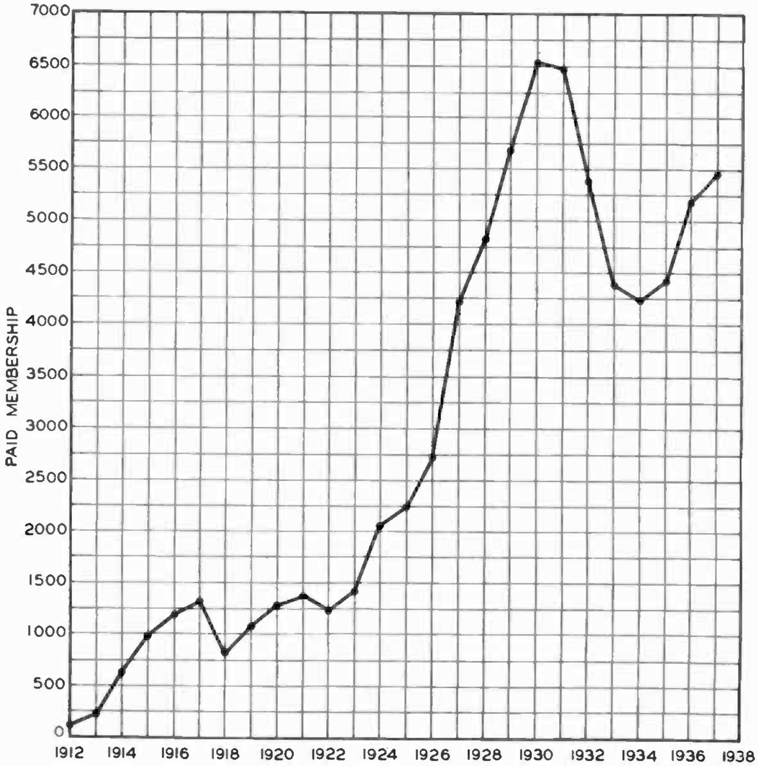

Fig. 1

GENERAL

During 1937 the membership of the Institute continued to increase, receipts exceeded disbursements, a few more pages than were published in the previous year have appeared in the PROCEEDINGS, and the Institute committees and sections continued their activities without substantial change. The securities in which a portion of the Institute's reserve funds are invested have shown a substantial decline in market value.

MEMBERSHIP

The paid membership at the end of 1937 was 5459, a net gain of about five per cent over the previous year. A graph showing the fluctuations in Institute membership is given in Fig. 1.

Table I shows the geographical distribution of membership. Approximately 24 per cent of the total membership is located outside of the United States. This proportion has not varied greatly during the past several years.

TABLE I

Geographical Distribution of Members

4145	United States	52	India
5	Alaska	1	Iraq
2	Arabia	5	Irish Free State
19	Argentina	28	Italy
1	Ascension Island	119	Japan
67	Australia	5	Latvia
3	Austria	1	Lithuania
7	Belgium	3	Malta
2	Bolivia	8	Mexico
17	Brazil	1	Morocco
1	British Honduras	14	Netherlands
5	British West Indies	31	New Zealand
215	Canada	1	Nicaragua
6	Canal Zone	1	Norway
2	Ceylon	1	Palestine
3	Chile	1	Paraguay
43	China	4	Peru
6	Colombia	7	Philippine Islands
2	Costa Rica	9	Poland
4	Cuba	5	Porto Rico
1	Cyprus	2	Portugal
5	Czechoslovakia	2	Rumania
17	Denmark	11	Scotland
1	Ecuador	1	Siam
3	Egypt	0	Spain
398	England	8	Straits Settlements
1	Estonia	1	Sumatra
3	Federated Malay States	11	Sweden
38	France	10	Switzerland
1	French Somaliland	1	Tanganyika Territory
1	Friendly Islands	2	Tasmania
12	Germany	1	Turkey
1	Greece	36	Union of South Africa
2	Guam	1	Uruguay
1	Guatamala	4	U.S.S.R.
13	Hawaiian Islands	7	Venezuela
1	Honduras	1	Virgin Islands
6	Hungary	3	Wales
	Total	5459	

The Admissions Committee, which investigates all applications for professional grade memberships, acted on and approved seven applications for transfer to Fellow and twelve for admission to Member; 15 of 17 applications for transfer to Member grade were approved. In addition, the committee acted on 80 applications proposed by the Membership Committee. In these cases the members will be invited to transfer.

TABLE II

Membership Distribution by Grades

	Number	Per Cent
Fellow	136	2.5
Member	624	11.4
Associate	4291	78.6
Junior	48	0.9
Student	360	6.6
	5459	100.0

Table II gives the distribution of members by grades on both a numerical and percentage basis.

New applications for membership during 1937 totaled 751, compared with 871 for 1936.

PROCEEDINGS

There were 1654 pages of editorial material in Volume 25 of the PROCEEDINGS, a very slight increase over the contents of the preceding volume. The variation in the number of pages published during the past twenty-five years is plotted in Fig. 2.

Fig. 2

The Papers Committee reviewed 137 manuscripts and the Board of Editors handled 149. There were 114 papers accepted for publication, 17 returned to the authors for revision, and 18 rejected. In addition, 16 book reviews were prepared and published.

SECTIONS

Data on the membership and meetings held by our twenty sections are given in Table III.

MEETINGS

In addition to the 189 section meetings and 7 New York meetings, there were 4 general meetings which are noted below.

On April 30, a joint meeting of the American Section of the International Scientific Radio Union and the Institute was held in Washington, D. C. There were 14 technical papers presented during the day and the attendance was about 150.

TABLE III

SECTION MEMBERSHIP AND MEETINGS

	Membership as of Dec. 31, 1937	Meetings Held 1935	Meetings Held 1936	Meetings Held 1937	Average Attendance at 1937 Meetings*	Per cent of Membership at 1937 Meetings
Atlanta	26	9	10	10	25	96
Boston	217	8	5	6	63	29
Buffalo-Niagara	49	9	7	10	35	71
Chicago	288	8	10	10	132	46
Cincinnati	95	9	9	8	53	56
Cleveland	72	9	8	7	24	33
Connecticut Valley	102	7	8	7	45	44
Detroit	106	10	10	10	51	48
Emporium	97	1	14	15	59	61
Indianapolis**	53	—	—	10	50	94
Los Angeles	191	11	11	8	40	21
Montreal**	92	—	—	5	64	70
New Orleans	23	0	1	6	22	96
Philadelphia	360	9	9	8	253	70
Pittsburgh	56	9	8	9	25	45
Rochester***	42	12	10	12	—	—
San Francisco	166	10	14	17	45	27
Seattle	42	9	8	10	49	112
Toronto	86	8	8	12	73	85
Washington	225	10	11	9	92	41
	2388	148	161	189	1200	

* Does not include joint meetings with other societies.

** Established, December, 1936.

*** Eight meetings credited for 1937 Rochester Fall Meeting. All meetings held jointly with other societies.

The Silver Anniversary of the founding of the Institute was celebrated at the annual convention which was held in the Hotel Pennsylvania in New York City, on May 10, 11, and 12. The attendance, which was greater than for any previous Institute convention totaled 1189 of whom 76 were women. There were 30 papers presented during five technical sessions. The exhibition included 41 booths. The Medal of Honor and the Morris Liebmann Memorial Prize were presented during the banquet.

Spokane, Washington, was the location of the first Pacific Coast general meeting sponsored by the Institute. There were 95 registered for the program which was held on September 1 and 2. Nineteen papers were presented during the four technical sessions. This meeting was co-ordinated with the Pacific Coast Convention of the American Institute of Electrical Engineers.

November 8, 9, and 10 were the dates of the Rochester Fall Meeting at which a total registration of 513 was obtained. There were 19 papers presented during 8 technical sessions. All available booth space was occupied by 35 exhibitors.

TECHNICAL COMMITTEES

Thirteen meetings of Institute technical committees were held. They were devoted chiefly to the completion of standardization reports but each of the committees prepared reports on developments in its field which were submitted to the Annual Review Committee.

The Technical Committee on Electroacoustics held one meeting during the year and completed its standards report. Its annual review material was prepared by correspondence.

The Technical Committee on Electronics held two meetings and its subcommittees were responsible for seven meetings in the completion of its standardization work and annual review report.

The Technical Committee on Radio Receivers held no meetings but the balance of its report was completed by correspondence and is now pending final action by the Standards Committee. Its annual review was prepared by correspondence.

The Technical Committee on Television and Facsimile held one meeting which was devoted chiefly to the preparation of its annual review report.

The Technical Committee on Transmitters and Antennas completed its work at the end of 1936 and held no meetings during 1937. Its annual review was prepared by correspondence.

The Standards Committee held two meetings to act on reports submitted to it by technical committees.

GENERAL COMMITTEES

Awards Committee. The Awards Committee held one meeting and prepared recommendations for the presentation of the two annual awards issued by the Institute.

The Institute Medal of Honor for 1937 was awarded to Melville Eastham for his pioneer work in the field of radio measurements, his constructive influence on laboratory practice in communications engineering, and his unfailing support of the aims and ideals of the Institute.

The Morris Liebmann Memorial Prize was presented to William H. Doherty for his improvement in the efficiency of radio-frequency power amplifiers.

Constitution and Laws Committee. The Constitution and Laws Committee held four meetings and completed its revision of the Institute Constitution. This report will be submitted to the Board of Directors in 1938.

New York Program Committee. Three meetings of the New York Program Committee were held during the year to plan for the New York meetings of the Institute.

Nominations. The Nominations Committee held one meeting and prepared its slate of candidates for the various elective offices. These recommendations were submitted to the Board of Directors.

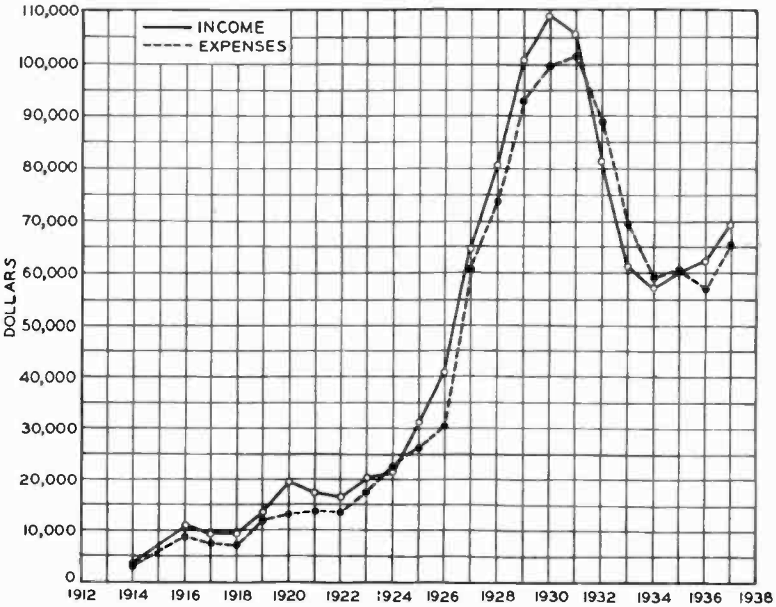

Fig. 3

Sections Committee. The Annual Meeting of the Sections Committee was held in New York City during the Silver Anniversary Convention. Representatives from most of our sections were present and numerous problems met in the operation of sections were discussed.

Tellers Committee. The Tellers Committee met once and counted the votes cast in the balloting for officers.

FINANCES

The balance sheet taken from the auditor's report on his examination of the Institute's books is given at the end of this report. Fig. 3 is a graph of income and expenses for the life of the Institute.

HEADQUARTERS STAFF

The headquarters staff constitutes thirteen persons, two fewer than at the end of 1936.

DEATHS

With deep regret we list the names of twelve members who died during the year.

Bates, C. W.
Ferris, Malcom
Goddard, J. B.
Levine, I. B.
Marconi, Guglielmo
Mason, D. P.
McClelland, A. C.
Rafferty, F. A.
Rossi, R. J. T.
Warner, H. J.
Weeks, W. E.
Weston, J. L.

ACKNOWLEDGMENT

It is obvious that as extensive and complex a business as is carried on by the Institute must require the services of many individuals: our committee lists contain over 200 names. While it is the privilege of the Secretary to prepare this brief report, the activities of this large number of members whose efforts have made possible the progress indicated deserve the sincere thanks of all members who must rely on others for the operation of their society.

Respectfully submitted,

Harold P. Westman

Secretary

The Institute of Radio Engineers, Inc.
COMPARATIVE BALANCE SHEET
December 31, 1937 and 1936

ASSETS	December 31, 1937	December 31, 1936	INCREASE DECREASE
CURRENT ASSETS			
Cash	$26,720.61	23,787.78	2,932.83
Accounts Receivable—Current:			
Dues	392.57	420.00	27.43
Advertising	349.69	265.00	84.69
Reprints	38.37	72.05	33.68
Inventory	9,238.93	7,500.99	1,737.94
Accrued Interest on Investments	345.00	308.33	36.67
TOTAL CURRENT ASSETS	37,085.17	32,354.15	4,731.02
INVESTMENTS—AT COST (Market Value 12/31/37 $15,947.50)	37,200.37	37,470.37	270.00
FURNITURE AND FIXTURES AFTER RESERVE FOR DEPRECIATION	2,278.53	2,054.63	223.90
PREPAID EXPENSES			
Unexpired Insurance Premiums	57.76	67.32	9.56
Stationery Inventory—Estimated	200.00	200.00	
Convention Expense	378.40		378.40
TOTAL ASSETS	$77,200.23	72,146.47	5,053.76

LIABILITIES AND SURPLUS	December 31, 1937	December 31, 1936	INCREASE DECREASE
ACCOUNTS PAYABLE	$ 189.98	390.05	200.07
SUSPENSE	20.87	24.64	3.77
ADVANCE PAYMENTS			
Dues	1,837.30	1,500.53	336.77
Subscriptions	4,119.35	3,524.48	594.87
Advertising		59.33	59.33
Convention		25.00	25.00
TOTAL LIABILITIES	6,167.50	5,524.03	643.47
FUNDS			
Morris Liebman Memorial Fund, Principal and Unexpended Income	10,077.87	10,077.87	
Associated Radio Manufacturers Fund	1,997.80	1,997.80	
TOTAL FUNDS	12,075.67	12,075.67	
SURPLUS			
Balance, January 1	54,546.77	49,051.98	5,494.79
Add—Operating Profit for Year	4,410.29	5,494.79	1,084.50
SURPLUS—DECEMBER 31	58,957.06	54,546.77	4,410.29
TOTAL LIABILITIES AND SURPLUS	$77,200.23	72,146.47	5,053.76

Patterson and Ridgeway
Certified Public Accountants
74 Trinity Place
New York, N. Y.

Corrections

Bernard Salzberg has brought to the attention of the editors the following corrections to his paper, "On the Optimum Length for Transmission Lines Used as Circuit Elements," which appeared in the December, 1937, issue of the PROCEEDINGS:

Equation (1) should read:

$$Z \cong \frac{Z_0 \cdot k\theta}{\cos^2\theta + k^2 \cdot \theta^2 \cdot \sin^2\theta} + j\frac{Z_0 \cdot \sin\theta \cdot \cos\theta}{\cos^2\theta + k^2 \cdot \theta^2 \cdot \sin^2\theta}. \tag{1}$$

Equation (2) should read:

$$Z \simeq \frac{Z_0 \cdot k\theta}{\sin^2\theta + k^2 \cdot \theta^2 \cdot \cos^2\theta} - j\frac{Z_0 \cdot \sin\theta \cdot \cos\theta}{\sin^2\theta + k^2 \cdot \theta^2 \cdot \cos^2\theta}. \tag{2}$$

Equation (3) should read:

$$\frac{r}{Z_0} \cong \frac{k\theta}{\cos^2\theta + k^2 \cdot \theta^2 \cdot \sin^2\theta} + \frac{\sin^2\theta}{k\theta} \cdot \frac{1}{1 + k^2 \cdot \theta^2 \cdot \tan^2\theta}. \tag{3}$$

Equation (4) should read:

$$\frac{r}{Z_0} \simeq \frac{k\theta}{\sin^2\theta + k^2 \cdot \theta^2 \cdot \cos^2\theta} + \frac{\sin^2\theta}{k\theta} \cdot \frac{1}{\tan^2\theta + k^2 \cdot \theta^2}. \tag{4}$$

The authors have brought to the attention of the editors the following corrections to "The Ultra-Short-Wave Guide-Ray Beacon and Its Applications," by E. Kramar and W. Hahnemann, which appeared in the January, 1938, issue of the PROCEEDINGS.

In Fig. 1 the numerals of the abscissa should read 10, 60, 110, 210, and 310 instead of 0, 50, 100, 200, and 300. There is also one change in ordinate, wherein the numeral 0.5 of the millivolt per meter scale should read 0.2.

The caption of Fig. 19 should read "Map showing the locations of Lorenz poor-visibility instrument landing systems in Europe. (Standard of April 1, 1937.)"

* * *

Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

TECHNICAL PAPERS

RADIO PROGRESS DURING 1937

PART I—REPORT BY THE TECHNICAL COMMITTEE ON ELECTROACOUSTICS*

INTRODUCTION

THE advance in applied acoustics in radio consists of the refinement and improvement of existing equipment, combined with developments designed to meet the requirements of new projects. This report divides the field into the following subjects: loud speakers, head telephone receivers, microphones, studios, electromechanical instruments, and measuring instruments and techniques.

LOUD SPEAKERS

Direct radiator loud speakers have been improved by advancements in the design of the mechanism and of the acoustic means for coupling between the driving system and the air at low frequencies

The acoustic labyrinth[1] has been improved by employing a new material for the lining. This material, besides having very desirable acoustic properties, is self-supporting, so that it obviates the use of metal lath which was a feature of the old construction.

A loud speaker for use in monitoring booths and review rooms to simulate the quality of sound motion-picture reproduction has been developed. The cabinet is designed on the principle of a Helmholtz resonator to improve the low-frequency response. The low-frequency driving mechanism consists of a conventional permanent-magnet dynamic loud speaker. The high-frequency unit consists of a short four-cell horn coupled to a dynamic mechanism. A suitable 800-cycle cross-over network and tone control, together with an adjustment for mechanical phasing of the high- and low-frequency units, permit matching of this loud speaker to the acoustic characteristics of the individual room where it is used.

The introduction of the acoustic phase inverter[1,2] into the mid-price range console class has been made possible by the development of a

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* Decimal classification: 621.385.97.

[1] "Radio progress during 1936," PROC. I.R.E., vol. 25, p. 166; February, (1937).

[2] B. R. Carson, K. A. Chittick, D. D. Cole, and S. V. Perry, "New features in broadcast receiver design," *RCA Rev.*, vol. 2, pp. 45–59; July, (1937).

simple rigid nonvibrating curved panel for enclosing the back of the loud-speaker to provide the capacitive element of the acoustic system. This method of improving low-frequency response has also been applied to a table model during the past year. In addition to improving the quality of reproduction, it has reduced acoustic feedback.

A means for improving the response of a loud speaker in a cabinet consists of a short straight-axis horn associated with the rear radiating portion of a diaphragm. This device has the economic merit of reducing the air-borne acoustic forces upon the walls of the cabinet, permitting a much lighter and, consequently, cheaper cabinet construction. Also, a suitable design allows the cabinetmaker much greater latitude since cavity resonances are largely eliminated, the speaker and horn combination being the dominant element in the circuit.

A study of the mechanical constants revealed the fact that there was a definite oscillatory system existing in most edge structures. An annular flexing edge for a cone diaphragm in which secondary resonances occurring from this area are eliminated without unduly restricting the amplitude range of the compliance has been developed. By confining the constants of the system between the cone proper and the mounting gasket to compliance only, it has been found possible to eliminate nearly all of the irregularities in the response characteristic occurring in the range from 800 cycles to 2000 cycles. This type of a cone edge usually produces low-frequency amplitude distortion since its action may either cause rectification or restriction. In general, this does not seem to be a commercial hindrance, since usually the distortion is purely harmonic and does not contain objectionable transient components.

Considerable research has been done in the field of fibers used in cone diaphragms. It has been found possible, through various combinations of materials, to influence greatly the high-frequency response of cone diaphragms. The introduction of fibers such as wool into the composition of the cone results in greatly increased mechanical resistance. This possibility has been utilized for two different purposes: first, to reduce the high-frequency response for such applications as the automotive-header loud speakers, and second, as a flexing edge of this soft material to be used in conjunction with a somewhat harder body where it is desired to reduce the amplitude at resonance and to minimize secondary edge resonances.

Extensive use has been made of corrugated disks as an outside suspension for centering the voice coil. This type of suspension provides a means of shielding the air gap against foreign particles, a relatively small stiffness which improves the low-frequency response by reducing distortion, and high rigidity in a lateral direction for keeping the voice coil aligned in the air gap.

Compliances have been used in the cone near the coil to effect a sharp high-frequency cutoff. In addition, this compliance reduces the mass reactance before cutoff and thereby increases the response in this region.

In the allied field of sound re-enforcing and public address, two permanent-magnet loud speakers of 60 and 100 watts power rating have been developed. Indestructible materials such as bakelite and metals have been used to insure a long and useful life. High efficiency over a wide range is obtained by means of a multiple-flare horn. The use of a permanent-magnet field eliminates the expense of wiring and providing a means for field supply.

Intercommunicating systems have become popular. The acoustic components are, of course, the microphone and the loud speaker. Most of the systems employ magnetic or dynamic loud speakers similar to those used in small radio receivers. In general the same unit, with suitable compensation, is also used as the microphone. Small loud-speaker units suitably compensated are also used in those systems where a separate unit is employed for the microphone and the loud speaker.

HEAD TELEPHONE RECEIVERS

A crystal-type high-fidelity headphone has been developed for use in exact monitoring work of radio broadcasting and motion-picture recording. The new headphone has a uniform response to 12,000 cycles. The impedance of a pair of these headphones is very high, 80,000 ohms minimum at any frequency, consequently the power-source characteristics are not affected. The sensitivity is approximately one volt per dyne per square centimeter at 1000 cycles. These headphones are exceptionally rugged and will withstand a considerable amount of mechanical abuse with little danger of breaking the crystal element or changing the frequency response.

An extremely lightweight crystal headphone with high output has been developed. The cases and caps are of aluminum. The cases are hermetically sealed so that even the most adverse atmospheric conditions cannot damage them. The cases are small, measuring $2\frac{1}{8}$ inches in diameter by 5/16 of an inch thick. The impedance of the headphone is of course high, being of the order of 16,000 ohms at 1000 cycles Driving impedance of any value from 100,000 ohms down may be used without destroying the quality. However, if an impedance higher than this is used there will be a loss of high-frequency response. The response covers the range from 60 to 10,000 cycles.

MICROPHONES

The manifold problems of sound collection are so varied and wide in scope that it has not been possible to develop a universal microphone which adequately satisfies all the requirements under all conditions. Directional and nondirectional microphones have definite applications: nonuniform response over a limited range may be fitted for pickup and transmission under certain conditions, weight and size may sometimes be a consideration, while for other uses high output may be more desirable than small weight, etc. Consequently, each year new microphones are developed to satisfy some new problems in sound pickup or to effect an improvement over existing microphones used in some collection problem.

A high-impedance bidirectional crystal microphone has been developed consisting of a diaphragm-type stiffness-controlled crystal unit operated on the pressure-difference principle. A simple passive network is employed to render the output voltage uniform at all frequencies and substantially in phase with the sound pressure. This unit has been combined with a nondirectional crystal element to give a unidirectional microphone with a cardioid polar directional characteristic. A convenient and useful feature of this microphone is the provision of a switch for convenient connection of either one or both elements of the microphone to the output terminals, thus making available any one of the three basic response characteristics; that is, nondirectional, bidirectional, or unidirectional to suit operating conditions. The front-to-back discrimination in the unidirectional position is about 20 decibels between 100 and 5000 cycles. No special amplifier characteristics are required for use with this microphone.

Heretofore, in the cases where a microphone having greater directivity than the unidirectional combination of a pressure gradient and pressure microphone was required, the microphone associated with a parabolic reflector has been the only type available. This reflector is directional because its sound-concentrating property is a function of the angle of sound incidence. However, this property is also a function of the frequency, and the normal incidence response of the microphone is therefore distorted. A new highly unidirectional microphone has been obtained by coupling a moving-coil microphone to an acoustic impedance element composed of a bundle of 50 $\frac{3}{8}$-inch diameter thin-walled aluminum tubes whose lengths vary by equal increments from $1\frac{1}{4}$ inches to five feet. The function of this variation in length is twofold. First, the multiple resonances of the individual tubes occur at intervals so close together that the net effect of the bundle is that of an acoustic resistance over a fairly wide frequency range. The high quality of the attached microphone is therefore not impaired. Second, high directivity is secured, because for sound incidence other than normal each tube introduces a different path length with phase cancellation resulting at a composition chamber between the microphone and ends of the tubes. Since this microphone does not distort the quality of direct sound, high-quality pickup may be secured without equalization. The directionality is equivalent to that of a parabola three feet deep and three feet in diameter, but the light weight of five pounds and small diameter of three inches render it more convenient for ordinary use.

STUDIOS

The design of studios for sound collection has advanced to the point where it is possible to state with reasonable assurance the requirements for good acoustics under a variety of conditions. That is to say, the design of studios is now a fairly definite and precise engineering job.

Sound-absorbing materials for practically every conceivable use have been developed. A tremendous amount of data has been gathered on the properties of sound absorbers. Therefore, this phase of the subject seems to be quite complete.

The problem of the distribution of sound in rooms is extremely complicated. It is quite well known that the performance of radio receivers varies considerably in different rooms. It appears that the difference cannot be attributed to reverberation alone. The free vibrations,[3] (characteristic frequencies or eigentones) of a room have been studied. These investigations indicate a better knowledge of the resonance in rooms is required before it is possible to understand and control the phenomena of intensity distribution and reverberation which are so closely related to room resonance.

ELECTROMECHANICAL INSTRUMENTS

A new sound-on-disk recorder has been developed[4] in which the principle of feeding part of the output of the system back to the input of the associated driving amplifier in properly controlled relationship is used. This principle, which is widely used in feed-back amplifiers, replaces the usual practice of providing dissipative elements for the control of an electrically driven vibrating system. Heretofore no practical application of feedback to electromechanical systems has

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[3] V. O. Knudson, "Recent progress in acoustics," *Jour. Soc. Mot. Pic. Eng.*, vol. 29, pp. 233–247; September, (1937).

[4] L. Veith and C. F. Wiebusch, "Recent developments in hill-and-dale recorders," *Jour. Soc. Mot. Pic. Eng.*, vol. 30, pp. 66–104; January, (1938).

been made, possibly because the requirements for stable operation of such systems are difficult of achievement. Through recent developments these requirements have been satisfactorily met. The new recorder is capable of recording on wax or direct-recording material without appreciable effect on its characteristics, which include a uniform response from 30 to 12,000 cycles and exceptional freedom from distortion products. The recorder is extremely simple and affords easy means for field calibration from the feed-back element whose output is in direct proportion to the stylus velocity. These means also make available a monitoring voltage which, properly amplified, gives a precise aural picture of the stylus behavior during recording.

Vertical and lateral high-fidelity crystal phonograph pickups have been improved with low stiffness and low moment of inertia. The stiffness is of the order of 1.5×10^6 dynes per square centimeter. Both types operate satisfactorily with as little as 0.4-ounce needle pressure, although one ounce is recommended for general use. This pressure is easily adjusted by means of a sliding weight. The 12-inch aluminum arm is curved in order to reduce tracking error to a minimum. The frequency response is flat from 30 to 10,000 cycles for either type when fed into the following loads: 30,000 ohms resistance in series with 0.03 microfarad for the vertical pickup, and 15,000 ohms in series with 0.03 microfarad for the lateral model.

A method of recording sound magnetically on steel tape[5] similar in principle to that of the Poulsen Telegraphone has been developed. By making use of perpendicular instead of longitudinal magnetization the speed of the tape may be reduced to 8 inches per second for recording speech. The low tape speed eliminates many of the difficulties encountered with those systems which made use of longitudinal magnetization. The ratio of the signal-to-ground noise has been substantially reduced. The recording medium is a steel tape having a thickness of two mils and a width of 50 mils.

MEASURING INSTRUMENTS AND TECHNIQUES

A distortion meter has been developed for measuring the total harmonic content generated in audio-frequency systems. The meter is used in conjunction with a beat-frequency oscillator having very low harmonic content in the output. A part of the output of the oscillator is fed to the system to be tested and another part to the analyzer. The output of the device to be tested is fed into the harmonic analyzer. The amplitude and phase relations of the fundamentals, from

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[5] C. N. Hickman, "Magnetic recording and reproducing," *Jour. Acous. Soc. Amer.*, vol. 9, pp. 77–78; July, (1937). (Abstract.)

the oscillator and device to be tested, are adjusted by means of suitable networks so that none of the fundamental remains. The remainder is the total harmonic generated in the system under test. This is measured by means of a root-mean-square meter.

A system known as the velocity bridge has been developed for obtaining the velocity of the voice coil of a dynamic loud speaker. The loud speaker to be tested is balanced against a similar loud speaker blocked. When a voltage is applied to the bridge the output is proportional to the back electromotive force generated in the loud speaker or to the velocity of the voice coil in a dynamic loud speaker. This system permits recording a graph of the voice-coil velocity versus frequency with automatic or semiautomatic recording equipment, and thereby removes this class of measurement from the point-by-point method which has been used in the past.

An instrument for obtaining a visual indication of the response-frequency characteristics of such audio-frequency apparatus as microphones, loud speakers, transformers, amplifiers, etc., has been developed. The indicating device is a 5-inch cathode-ray tube with a long-persistence screen. By this means as many as 4 or 5 response curves can be compared simultaneously. The maximum frequency range is 30 to 15,000 cycles per second, but it is possible to observe any desired portion of this range. The sensitivity of the instrument is continuously variable from a full-scale of 6 decibels to a full-scale of 48 decibels. The equipment is portable and alternating-current-operated. Although designed for laboratory use, this apparatus should find other applications such as factory test, field studies in theaters, etc.

In the conventional arrangement for measuring the indoor response of a radio receiver, the pencils of sound reflected from the floor are stronger than any other primary reflections; this is particularly true in the case of the rotating microphone. Due to the dimensions and geometry, the floor reflection causes a marked change in the response characteristic in the mid-frequency range. This effect is so pronounced that often times other effects which seriously impair the response characteristic are masked and may go undetected. First-order floor reflections may be eliminated by the use of an inclined deflector, which becomes the floor in front of the receiver to be tested, arranged so that sound reflected from this new floor will not strike the microphone. The response characteristic obtained under these conditions is free of first-order floor reflection effects.

An instrument for calibrating vibration pickups has been developed. It consists of a "vibration cell" of rigid construction containing an inertia-actuated Rochelle salt crystal resonated an octave above the highest frequency to be measured. Vibrations from a Rochelle salt crystal driver, or other convenient source, are transmitted through the "vibration cell" to the pickup being calibrated, and the relative output voltages compared. This method has been very useful in checking the response-frequency characteristics of high-output vibration pickups used for field work.

A standard of low-frequency sound pressure was developed following the general theory of previous investigators. This "dynamic pistonphone" consists of a chamber about 50 cubic centimeters in volume and a piston 0.3 centimeter in diameter driven by a moving-coil mechanism, capable of executing strokes of approximately 1.0 centimeter at frequencies between 20 and 100 cycles. The stroke is measured by means of a telescope and scale. The variation in pressure may be computed from the variation in volume. A small crystal microphone is used as a pressure indicator within the pistonphone chamber and thus becomes a calibrated microphone for the measurement of sound-field pressures.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

RADIO PROGRESS DURING 1937

PART II—REPORT BY THE TECHNICAL COMMITTEE ON ELECTRONICS*

INTRODUCTION

ELECTRONICS appears to have been devoid of radical departures from the trends of the recent past. In the older applications the chief advances are additions to and refinements of the already extensive quantitative knowledge of the behavior of electronic devices. In the newer and more active fields of television and ultra-high-frequency tubes, greatest progress is reported in the extension, improvement, and refinement of methods and devices which have in the recent past been generally accepted as the most promising. It is not within the scope of this report to discuss the significance of these trends, nor to speculate on the future.

TELEVISION TUBES

Electron Optics

In the field of electron optics theoretical and experimental work has continued, so that exact expressions are now known for many of the properties of electron lenses.[1,2,3,4] The knowledge of electron optics has been used to improve electron microscopes,[5,6] the intensification of optical images,[7] and the construction of cathode-ray tubes with multiple beams.[8]

Apparatus has been developed for the automatic plotting of the paths of electrons moving through electrostatic fields.[9,10]

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* Decimal classification: R330×621.375.1.

[1] E. Brucke, "Geometrical electron optics," *Funkteck. Monatshefte* (Fernsehen und Tonfilm supplement), pp. 1–12; January, (1937).

[2] K. Diels and G. Wendt, "The eight image errors, of third order, of magnetic electron lenses," *Zeit. für tech. Phys.*, vol. 18, no. 3, pp. 65–69, (1937).

[3] E. Gundert, "Demonstration of imagery defects of electron lenses," *Phys. Zeit.*, vol. 38, pp. 462–467; June 15, (1937).

[4] A. Bouwers, "Convergence of electrons by means of magnetic coils," *Physica*, vol. 4, pp. 200–206; March, (1937). (In English.)

[5] L. C. Martin, R. V. Whelpton, and D. H. Parnum, "A new electron microscope," *Jour. Sci. Instr.*, vol. 14, pp. 14–24; January, (1937).

[6] H. Gross and G. Seitz, "Production of electron-optical pictures with photoelectrons," *Zeit. für Phys.*, vol. 105, pp. 734–737; May 29, (1937).

[7] F. Coeterier and M. C. Teves, "An apparatus for the transformation of light of long wave length into light of short wave length. III. Amplification by secondary emission," *Physica*, vol. 4, pp. 33–40; January, (1937). (In English.)

[8] M. Knoll, "Electron-optical arrangement for multiple cathode-ray tubes with incandescent cathodes," *Arch. für Elektrotech.*, vol. 31, pp. 41–42; January 23, (1937).

[9] D. Gabor, "Mechanical tracer for electron trajectories," *Nature*, vol. 139, p. 373; Februrary 27, (1937).

[10] D. B. Langmuir, "Automatic plotting of electron trajectories," *Nature*, vol. 139, pp. 1066–1067; June 19, (1937).

Television Camera Tubes

The sensitivity of the Iconoscope type of tube has been increased and the operating characteristics have been investigated further.[11,12,13] Several new kinds of pickup tubes were developed; some utilize photoconductive or photovoltaic effects, or secondary-emission amplification of an electron picture to give additional sensitivity or less spurious signal.[14,15,16]

Television Picture Tubes

The development of cathode-ray tubes has progressed to such a point that large television pictures have been shown by projection on a viewing screen.[17,18,19,20]

Advancements in theory and improvements in the practice of producing fluorescent screens have increased their efficiency and stability.[21,22,23,24] A method of measuring the color of these screens has been described.[25]

A large, continuously evacuated, direct-viewing cathode-ray tube permitting an 18- ×24-inch picture has been described.[26]

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[11] B. V. Krusser and N. M. Romanova, "A cathode-ray transmitting tube," *Izvestiya Elektroprom. Slab. Toka*, no. 4, pp. 20–23, (1937).

[12] V. K. Zworykin, G. A. Morton, and L. E. Flory, "Theory and performance of the Iconoscope," PROC. I.R.E., vol. 25, pp. 1071–1092; August, (1937).

[13] H. Iams, R. B. Janes, and W. H. Hickok, "The brightness of outdoor scenes and its relation to television transmission," PROC. I.R.E., vol. 25, pp. 1034–1047; August, (1937).

[14] M. Knoll and F. Schroter, "Electronic transmission of pictures and signs with insulating or semiconducting films," *Phys. Zeit.*, vol. 38, pp. 330–333; May 1, (1937).

[15] H. Iams, and A. Rose, "Television pickup tubes with cathode-ray beam scanning," PROC. I.R.E., vol. 25, pp. 1048–1070; August, (1937).

[16] "Super-emitron camera," *Wireless World*, vol. 41, pp. 497–498; November 18, (1937).

[17] D. B. Langmuir, "Theoretical limitations of cathode-ray tubes," PROC. I.R.E., vol. 25, pp. 977–991; August, (1937).

[18] R. R. Law, "High current electron gun for projection Kinescopes," PROC. I.R.E., vol. 25, pp. 954–976; August, (1937).

[19] V. K. Zworykin and W. H. Painter, "Development of the projection Kinescope," PROC. I.R.E., vol. 25, pp. 937–953; August, (1937).

[20] A. Castellani, "Projection with cathode-ray tubes," *Television*, vol. 10, pp. 413–414; July, (1937).

[21] H. W. Leverenz, "Production of cathode-ray tube screens," *Jour. Opt. Soc. Amer.*, vol. 27, pp. 25–35; January, (1937).

[22] T. B. Brown, "Brightness of cathode-luminescence at low current densities and low voltages," *Jour. Opt. Soc. Amer.*, vol. 27, pp. 186–192; May, (1937).

[23] W. B. Nottingham, "Potential and luminescence of insulated willemite cathode-ray screens," *Phys. Rev.*, series 2, vol. 51, p. 591; April 1, (1937).

[24] I. G. Maloff and D. W. Epstein, "Screens for television tubes," *Electronics*, vol. 10, pp. 31–34 and 85–86; November, (1937).

[25] G. A. Fink and R. M. Bowie, "Specification of screen color of cathode-ray tubes." Presented before Rochester Fall Meeting, November 8, 1937. *Electronics*, vol. 10, pp. 13–14; December, (1937). (Abstract.)

[26] I. G. Maloff, "Direct-viewing type cathode-ray tube for large television images." Presented before Rochester Fall Meeting, November 9, 1937. *Electronics*, vol. 10, pp. 13–14; December, (1937). (Abstract.)

Oscillograph Tubes

A new type of oscillograph tube has appeared.[27] A study has been made of the ultra-high-frequency performance of electrostatic-deflection tubes.[28]

ULTRA-HIGH-FREQUENCY VACUUM TUBES

Progress in the field of ultra-high-frequency vacuum tubes during 1937 has followed the trend of 1936 in that advancements have been made principally in tubes where the electron-transit time is a small fraction of the oscillatory period. In this group the greatest improvements have been evident in conventional negative-grid triodes including both an extension of the upper frequency limit and a substantial increase in power output in the frequency range of 50 to 1500 megacycles.

Small negative-grid triodes of unusual design have been described[29] which extend the upper frequency limit of triode oscillators to the neighborhood of 1800 megacycles and increase the upper limit of triode amplifiers. From these tubes used as oscillators, a power output of approximately 16 watts at 500 megacycles has been obtained, which is more than double the output reported last year.[30] The special feature of these tubes is that the plate and grid electrodes are supported by leads which in effect go straight through the envelope providing two independent leads to each of these elements. This double-lead construction is used to decrease circuit losses, to increase the limiting frequency, and to provide an effective means of neutralization.

The application of special lead and mounting arrangements has been extended to radiation-cooled tubes of larger sizes resulting in outputs of 400 to 600 watts at 50 megacycles.[31,32] The frequency limit of small water-cooled tubes has been extended to 300 megacycles.[33] A

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[27] M. von Ardenne, "A new polar co-ordinate cathode-ray oscillograph with extremely linear time scale," *Wireless Eng.*, vol. 14, pp. 5–12; January, (1937).

[28] H. Hinterberger, "On the behavior of a cathode-ray tube at ultra-high frequencies," *Zeit. für tech. Phys.*, vol. 18, no. 9, pp. 256–259, (1937).

[29] A. L. Samuel, "Negative grid triode oscillator and amplifier for ultra-high frequencies," PROC. I.R.E., vol. 25, pp. 1243–1252; October, (1937).

[30] "Radio progress during 1936," PROC. I.R.E., vol. 25, p. 179; February, (1937).

[31] W. G. Wagener, "Developmental problems and operating characteristics, of two new ultra-high-frequency triodes." PROC. I.R.E., vol. 25, p. 928; August, (1937). (Abstract only.)

[32] "High-frequency tube," *Comm. and Broad. Eng.*, vol. 4, p. 19; August, (1937).

[33] W. G. Wagener, "The requirements and performance of a new ultra-high-frequency power tube," *RCA Rev.*, vol. 2, pp. 258–264; October, (1937).

high-power water-cooled pentode capable of delivering 6000 watts at 50 megacycles has been described.[34]

The literature indicates a continued investigation of less conventional tubes, particularly those in which the electron-transit time is critically related to the oscillatory period.[35,36,37,38] In this group two interesting types of magnetrons have appeared. One of these [35] has the unique feature that the oscillatory circuit is connected between split end plates which are negative with respect to the cathode and receive a negligible electron current. The other new magnetron[36] has the unusual feature that the electron emission is introduced at the end of the plate cylinders, rather than uniformly along the axis of the anode as in the ordinary magnetron. This arrangement is reported to eliminate cathode bombardment.

RECEIVING TUBES

In the field of receiving tubes, although no radically new developments have been reported, progress has been made in the extension of fundamental theory, in the reduction of noise, in the simplification and improvement of tube structures, and in the use of new materials.

Theoretical studies have been made of the effects of space charge in general,[39,40] more specifically in the grid-anode region.[41] Further investigations into the theory of tube noise have been reported.[42]

The operation and design of multielectrode converter tubes have been the subject of further investigations.[43,44,45,46,47]

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[34] K. Posthumus, "The water-cooled pentode types PA 12/15 at ultra-short wave lengths," *Philips Trans. News*, vol. 4, pp. 1–12; July, (1937). (In English and German.)

[35] K. Okabe, "The electron-beam magnetron," *Electrotech. Jour.* (Japan), vol. 1, pp. 29–30; June, (1937). (In English.)

[36] Adolph Helbig, "Grid-controlled magnetron with cathode outside of anode cylinder," *Hochfrequenz. und Elektroakustik*, vol. 50, pp. 96–98; September, (1937).

[37] T. V. Ionescu, "Short-wave oscillator," *Comptes Rendus*, vol. 204, pp. 1411–1413; May 10, (1937).

[38] H. E. Hollman and A. Thoma, "Dynamics of transversely and longitudinally controlled electron beams. Part I: Static and dynamic relationships," *Hochfrequenz. und Elektroakustik*, vol. 49, pp. 109–123; April, (1937). Part II: "Ultra-dynamic conditions," vol. 49, pp. 145–160; Supplement, pp. 161–162; May, (1937).

[39] W. Kleen and H. Rothe, "Space-charge equation for electrons with initial velocity," Part II, *Zeit. fur Phys.*, vol. 104, pp. 711–723; (1937).

[40] W. Kleen, "Investigation of the space-charge law," *Die telefunken-Röhre*, pp. 66–75, April, (1937).

[41] B. Salzberg and A. V. Haeff, "Effects of space charge in the grid-anode region of vacuum tubes," PROC. I.R.E., vol. 25, p. 546; May, (1937). (Abstract.) *RCA Rev.*, vol. 2, pp. 336–374; January, (1938).

[42] W. Schottky, "The space-charge reduction of shot effect," *Wiss. Veroff. di. Siemens Werken*, vol. 16, pp. 1–41, (1937).

[43] M. J. O. Strutt, "The performances of certain types of frequency-changing tubes in all-wave receivers," *L'Onde Elec.*, vol. 16, pp. 29–44; January, (1937).

There has been evidence of continued activity in the field of beam tubes.[48,49]

Improvements have been made in getters[50] and in structures for minimizing tube noises.[51] Study of contact potential has contributed a better understanding of this subject.[52]

TRANSMITTING TUBES

Advances in large high-vacuum tubes have extended the high-frequency limit of operation. These developments are treated in the report on high-frequency-tubes.

GAS TUBES

Most of the advances in gas tubes have found application in the industrial field. Since some of them have possible use in radio, a brief summary is included here.

Considerable progress has been made in the improvement of the ignitron-type of rectifier. Individual sealed-off ignitrons have been developed for use in large multiphase rectifiers providing high-current power supplies.[53] A new type of ignitor rod for reducing the ignitor current required for reliable initiation of the cathode spot[54] has been described.

Thyratrons filled with a mixture of argon and mercury vapor have been developed.[55] These tubes are reported to have the low voltage drop which is characteristic of mercury vapor, but with critical grid

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[44] M. J. O. Strutt, "Frequency changers in all-wave receivers," *Wireless Eng.*, vol. 14, pp. 184–192; April, (1937).

[45] M. S. Krauthamer, "Some numerical data on converter tubes with two control grids," *L'Onde Elec.*, vol. 16, pp. 114–131; February, (1937).

[46] E. W. Herold, "Frequency changers in all-wave receivers," *Wireless Eng.*, vol. 14, pp. 488–489; September, (1937). A note on reference 44.

[47] T. E. Goldup, "Frequency changers," *Wireless Eng.*, vol. 14, p. 318; June, (1937). A note on reference 44.

[48] H. Rothe and W. Kleen, "Electron optics in the technics of amplifier tubes," *Zeit. für Tech. Phys.*, vol. 17, pp. 635–642, (1936).

[49] E. P. Rudkin, "The deflection amplifier as amplifier, rectifier and generator," *Wireless World*, vol. 40, pp. 299–301; March 26, (1937).

[50] E. A. Lederer and D. H. Wamsley, " 'Batalum,' a barium getter for metal tubes," *RCA Rev.*, vol. 2, pp. 117–123; July, (1937).

[51] L. C. Hollands and A. M. Glover, "Vacuum tube engineering for motion pictures," *Jour. Soc. Mot. Pic. Eng.*, vol. 30, pp. 38–57; January, (1938).

[52] E. A. Lederer, D. H. Wamsley, and E. G. Widell, "Studies of changes of contact potential," Presented before Silver Anniversary Convention, New York City, May 11, 1937. PROC. I.R.E., vol. 25, p. 545; May, (1937). (Abstract.)

[53] J. H. Cox and D. E. Marshall, "Mercury-arc rectifiers and ignitrons," Electrochemical Society, preprint 72–24, pp. 359–375, (1937).

[54] A. H. Toepfer, "Low-current ignitors," *Elec. Eng.*, vol. 56, pp. 810–812; July, (1937).

[55] G. H. Rockwood, "Thyratrons for grid-controlled rectifier service," Electrochemical Society, preprint 71–11, pp. 161–171, (1937).

characteristics that are independent of temperature over a range much wider than that of tubes containing mercury vapor alone.

Cold-cathode tubes are becoming increasingly important as control or relay devices and are capable of performing many of the functions for which small thyratrons have generally been used.[56,57,58]

PHOTOELECTRIC DEVICES

Progress in photoelectric devices has been limited largely to detail improvements in commercial tubes and to further scientific study of the photoelectric properties of thin films[59,60,61,62,63] and the characteristics and theory of barrier-layer photoelectric cells.[64,65,66,67]

A new type of phototube has been described in which the anode consists of a network of tungsten wires which may be made incandescent as a means of cleaning them, placed parallel to the cathode, saturation being obtained with only three to four volts.[68] The effect of hydrogen on reducing the time lag of argon-filled phototubes was investigated.[69]

[56] S. B. Ingram, "The 313A vacuum tube," *Bell Lab. Rec.*, vol. 15, pp. 114–116; December, (1936).

[57] K. J. Germeshausen and H. E. Edgerton, "The Strobotron," *Electronics* vol. 10, pp. 12–14; February, (1937).

[58] A. B. White, W. B. Nottingham, H. E. Edgerton, and K. J. Germeshausen, "The Strobotron—II," *Electronics*, vol. 10, pp. 18–21; March, (1937).

[59] H. C. Rentschler and D. E. Henry, "Photoelectric emission," *Jour. Frank. Inst.*, vol. 223, pp. 135–145; February, (1937).

[60] H. Mayer, "Photoelectric properties of atomic layers of potassium on platinum," *Ann. der Phys.*, series 5, vol. 29, pp. 129–159, (1937).

[61] R. A. Houstoun, "Time lag of vacuum photoelectric cell," *Proc. Roy. Soc.* (Edinburgh), part 2, vol. 57, pp. 163–171, (1937).

[62] T. Fukuror, "Photoconducting effect in thin metallic films," *Inst. Phys. and Chem. Res.* (Tokio), Sci. paper, no. 721, pp. 187–195; August, (1937).

[63] Q. Majorana, "Electrical effect of light on metallic films," *Phys. Zeit.*, vol. 38, pp. 663–667; September 1, (1937).

[64] A. W. Joffé and A. T. Joffé, "Spectral distribution of inner photoelectric effect in Cu_2O", *Phys. Zeit. der Sowjetunion*, vol. 11, pp. 241–262, (1937).

[65] L. Bergmann and R. Pelz, "Selenium rectifier photocells," *Zeit. für tech. Phys.*, vol. 18, pp. 177–191; (1937).

[66] P. Görlich, "Nature of blocking-layer in selenium rectifier photocell," *Zeit. für Phys.*, vol. 106, pp. 373–378; (1937).

[67] E. Perucca and R. Deaglio, "Blocking-layer and Hallwachs photoelectric effects," *Accad. Sci.* (Torino), Atti. 72, Disp. 3a, pp. 500–508; April–October, (1937).

[68] G. A. Boutry, "A new type of photoelectric tube," *Comptes Rendus*, vol. 204, pp. 120–122; January 11, (1937).

[69] N. R. Campbell and R. S. Rivelin, "The effect of hydrogen on the time lag of argon-filled photoelectric cells," *Proc. Phys. Soc.*, vol. 49, part 1, pp. 12–13; January 1, (1937).

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

RADIO PROGRESS DURING 1937

PART III—REPORT BY THE TECHNICAL COMMITTEE ON RADIO RECEIVERS*

NOTEWORTHY advance in the radio receiver field has occurred. The basic principles and circuits underlying the design of radio receivers have been established for a number of years and have proved to be generally satisfactory in actual use so that there has not been any tendency, nor indeed necessity, for changes of a radical nature.

Many advances in the radio receiver field are based on developments predominantly acoustic or electronic in nature which are described in the reports of the other technical committees.

TECHNICAL DEVELOPMENTS IN BROADCAST RECEIVERS

The outstanding development of the year, particularly from the standpoint of the broadcast listener, was the widespread adoption of push-button tuning, providing greater convenience and the possibility of greater accuracy in tuning than was previously obtained. The push-button systems in use during the past year were divided into three general classifications;[1] first, those types in which rotation of the tuning condenser to a predetermined point was by means of a motor set into operation by an appropriate push button; second, those types in which preset tuned circuits selectively actuated by the push buttons were used; and third, the types in which tuning condenser rotation to the predetermined point was accomplished manually.[2,3] Approximately half of the models having push-button tuning used automatic frequency control for maintaining precision of tuning. In some lower-priced models using preset circuits the conventional tuning dial was eliminated, the 6 or 8 push buttons providing the sole means of station selection.

Another device which has been developed as an aid to tuning the conventional dial consists of a brake applied to the tuning condenser shaft at the point of maximum signal intensity as the station is tuned in.[4,5]

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* Decimal classification: R360.

[1] B. V. K. French, "Push button station selection," *Electronics*, vol. 10, pp. 16–19; September, (1937).

[2] "The new receivers," *Radio Eng.*, vol. 17, pp. 5–6, 14; August, (1937).

[3] "New features make old radios look older," *Radio Retailing*, vol. 22, pp. 20–21, 46; June, (1937).

[4] C. J. van Loon, "Improvements in radio receivers," *Philips Tech. Rev.*, vol. 1, pp. 264–269; September, (1936); *Radio Eng.*, vol. 7, pp. 20–21; January, (1937) (Summarized.)

[5] "Tuning made easy," *Wireless World*, vol. 41, p. 366; October 8, (1937).

The widespread use of push-button tuning and consequent necessity of maintaining the frequency of the local oscillator constant despite variations in temperature and humidity, resulted in much attention being given to the problem of oscillator drift.[6] The causes of variation in value of the components of the oscillator circuit have been studied and parts produced with much higher stability than was formerly believed possible.[7]

Thermostatic compensators have been developed which counteract changes in oscillator frequency with temperature.

Few models, except those intended for export, have included the European long-wave or "weather band." The provision of broadcast receivers with the ultra-high-frequency band has likewise become almost nonexistent, despite an increase in the number of ultra-high-frequency transmitters and the authorization by the Federal Communications Commission of commercial programs in that range.

Abroad, considerable attention has been paid to the development of a double superheterodyne receiver for tuning over the entire European broadcast spectrum of 150 to 1500 kilocycles in a single tuning range.[8,9,10]

There has also been developed abroad a receiver which uses a 465-kilocycle intermediate frequency on medium and long waves, while for short waves the intermediate frequency is changed to 1363 kilocycles.[11]

The assignment of a standard intermediate frequency of 455 kilocycles in the United States during the past year has been of benefit to receiver designers and eventually will result in greatly decreased possibility of interference on that intermediate-frequency channel. Methods of remote control for radio receivers were disclosed, which tend to eliminate many of the undesirable features of remote control systems previously used.

One method uses impulses transmitted over the power wiring at carrier frequencies in order to eliminate the control cable between the remote unit and the receiver. By a combination of phase and frequency selection ten control functions may be obtained with only

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[6] John M. Miller, "Thermal drift of superheterodyne oscillators," *Electronics*, vol. 10, pp. 24–25; November, (1937).

[7] B. R. Carson, K. A. Chittick, D. D. Cole, and S. V. Perry, "New features in broadcast receiver design," *RCA Rev.*, vol. 2, pp. 45–59; July, (1937).

[8] R. I. Kinross, "The double superheterodyne receiver," *Wireless Eng.*, vol. 14, pp. 351–358; July, (1937).

[9] K. Nentwig, "For the single-span receiver," *Radio B. F. für alle*, no. 184, pp. 93–95; June, (1937).

[10] E. G. Beard, "Advanced receiver design," *Radio Rev. Australia*, vol. 5, pp. 3–12; January, (1937).

[11] "Olympia 1937," *Wireless Eng.*, vol. 14, pp. 545–548; October, (1937).

two carrier frequencies. This system also eliminates stand-by power when the receiver is not operating.[12] Another system of remote control makes use of a coaxial cable and the impedance-transforming properties of a resonant line to effect tuning of the receiver by means of capacitance variation at the remote point.[13]

An interesting development in short-wave reception occurred in receivers in which the short-wave broadcast bands, each about 300 kilocycles wide, were spread over a scale length of approximately 10 inches thus facilitating tuning on these bands, and through the use of antenna and radio-frequency stages fixed tuned in the center of each band, high sensitivity and good signal-noise ratio were secured. These receivers also had unusual oscillator-frequency stability, secured by choice of circuit constants and the use of thermal-compensating condensers imbedded in thermoplastic material.[7]

Another interesting device was the development of an inductive tuner, the variation of inductance being obtained by a slider continuously variable throughout the winding length by rotation. By this means a wide tuning range with uniform gain was secured.[14]

The use of the negative feed-back principle has been extended and new applications developed.[15,16] The application of inverse feedback has led to wide use of pentodes and beam power tubes in the output stages of receivers with high output power and low distortion.[17,18,19] Inverse feedback has also been used to obtain frequency discrimination,[20] and receivers have appeared on the market in which negative feedback, varying in magnitude with audio frequency, has been used to obtain tone compensation as the audio volume is varied and also for tone-control purposes. One European receiver uses a new method

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[12] S. W. Seeley, H. B. Deal, and C. N. Kimball, "Teledynamic control by selective ionization and its application to the remote control of receivers," Presented before Rochester Fall Meeting, November 9, 1937; presented before New York meeting December 1, 1937. *RCA Rev.*, vol. 2, pp. 303–316; January, (1938).

[13] J. F. Ramsay, "Remote tuning control," *Wireless World*, vol. 41, pp. 231–232; September 3, (1937).

[14] Paul Ware, "A new inductive tuner," presented before Indianapolis section, June 24, 1937. Proc. I.R.E., This issue, pp. 308–320.

[15] J. R. Day and J. B. Russell, "Practical feedback amplifiers," *Electronics*, vol. 10, pp. 16–19; April, (1937).

[16] F. E. Terman, "Feedback amplifier design," *Electronics*, vol. 10, pp. 12–15; January, (1937).

[17] B. D. H. Tellegen and V. Cohen, "Inverse feedback," *Henriquez Wireless Eng.*, pp. 226–229, September 31, (1937).

[18] P. K. Turner, "Negative feed-back," *Wireless World*, vol. 41, pp. 386–387; October 15, (1937).

[19] Tendencies in receiver design, *Wireless World*, vol. 41, pp. 226–229; September 3, (1937).

[20] G. H. Fritzinger, "Frequency discrimination by inverse feedback," Proc. I.R.E., vol. 26, pp. 207–225; February, (1938).

of varying resistance of a small lamp in the negative-feed-back path in accordance with the signal volume to provide volume expansion.[19]

A combination of negative and positive feedback to secure advantages in reduction of distortion or improvement in selectivity has been reported.[21,22]

There has been a wide extension of the use of phase-inverting systems for push-pull audio-frequency amplifiers, several improved and simplified circuits having been developed for that purpose with the result that resistance coupling has almost entirely superseded the use of transformers in push-pull stages.

Several interesting auxiliary uses for the suppressor grid in radio-frequency pentodes have been developed, among them being the application of feedback thereto to improve intermediate-frequency transmission characteristics and the application of automatic-volume-control voltage to improve greatly the receiver overload characteristics.

There has been continued development in automatic-frequency-control circuits leading to further improvement in operation and simplified construction.

Improvements have been made in the design and utilization of first detectors for superheterodyne receivers.[23] The second detector has also been the subject of improvement, receivers having appeared in which the infinitei-mpedance diode or negative-feed-back triode type detector has been used with consequent improvement in selectivity and modulation-handling capability.[24]

The acoustic characteristics of radio receivers have also continued to receive attention, several receivers having appeared on the market embodying new applications of the acoustic phase-inversion principle with resultant improvement in fidelity and freedom from cabinet resonance.[7,25]

Extensive utilization of permanent-magnet dynamic speakers of high sensitivity and good fidelity occurred, particularly on battery receivers, and has permitted attainment of better acoustic output with less current consumption.[11]

[21] F. Vecchiacchi, "Resistenze negative ed elevate selettività ottenute stabilmente per mezzo di reazioni positiva e negativa," *Alta Frequenza*, vol. 6, pp. 351–364; June, (1937).

[22] E. L. Gintzon, "Balanced feed-back amplifiers," presented before Pacific Coast Meeting, Spokane, Washington, September 1, 1937. Proc. I.R.E., vol. 25, p. 926; August, (1937). (Abstract.)

[23] M. J. O. Strutt, "Frequency changers in all wave receivers," *Wireless Eng.*, vol. 14, pp. 184–191; April, (1937).

[24] W. N. Weeden, "New detector circuit," *Wireless World*, vol. 40, pp. 6–8; January 1, (1937).

[25] H. S. Knowles, "Extending the audio range of loud-speakers," presented before Connecticut Valley Section, March 25, (1937). Proc. I.R.E., vol. 25, p. 661; June, (1937). (Abstract.)

A new type of antenna installation has been developed primarily for all-wave receivers which gives greater ease of installation and has improved noise-reduction qualities.[26]

AUTOMOBILE RECEIVERS

In automobile antennas there has been an increase in the number of installations using roof and telescopic cowl types and this year some car models had the running boards insulated from the car body to act as an antenna. Push-button tuning appeared on automobile receivers also for the first time during the past year.[27]

A large variety of designs of antenna for mounting on the car roof appeared in 1937, antenna-input systems having been developed specifically for coupling to roof- or rod-type antennas with resultant improvement in sensitivity and signal-to-noise ratio.[28]

The vibrator used to convert direct current from the automobile storage battery to the higher potentials required by the receiver has been improved in reliability and life.[28]

OTHER CLASSES OF RECEIVERS

The problems of radio in aviation have had considerable attention during the past year, in both communication and direction finding, and notable achievements have resulted.[29,30] The shielded-loop antenna has been developed as a solution to the difficult and important problem of rain static,[31] improved radio-beacon indicators have appeared, new means of course-width indication have been developed, as has a meter for providing private fliers with an "on-course" indication.[32,33] Further extension of ultra-high frequencies for marker beacons, blind landing, and other air-navigation purposes occurred.[31]

A new method of great interest and usefulness for the testing and

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[26] W. L. Carlson and V. D. Landon, "A new antenna kit design," *RCA Rev.* vol. 2, pp. 60–68; July, (1937).

[27] "Radio at New York auto show," *Radio Today*, vol. 3, p. 18; November, (1937).

[28] Jerome C. Smith, "Automobile receiver design," *RCA Rev.*, vol. 1, pp. 94–112; April, (1937).

[29] W. E. Jackson, "Improvements in air navigation radio facilities," presented before Washington Section, June 14, 1937. PROC. I.R.E., vol. 25, p. 936; August, (1937). (Abstract.)

[30] H. M. Hucke, "The communications systems and radio research of United Air Lines," presented before Seattle Section, March 26, 1937. PROC. I.R.E., vol. 25, p. 668; June, (1937). (Abstract.)

[31] F. X. Rettenmeyer, "Some problems of aviation radio," *RCA Rev.*, vol. 1, pp. 113–118; April, (1937).

[32] E. D. Blodgett, "Features and theory of operation of an aircraft radio compass, the functions of its controls and its operational characteristics," presented before Philadelphia Section, May 8, 1937. PROC. I.R.E., vol. 25, p. 801; July, (1937). (Abstract.)

[33] Ralph M. Heintz, "Aircraft radio equipment trends," presented before Pacific Coast Meeting, Spokane, Washington, September 1, 1937. PROC. I.R.E., vol. 25, p. 926; August, (1937). (Abstract).

calibration of radio compasses in a shielded room by means of crossed loops has been devised.[34]

The marine radio direction finder has appeared in new, inexpensive, compact models suitable for small pleasure craft and fishing boats.[35,36]

Automatic receivers capable of sounding an alarm upon reception of distress signals have been put into use as the culmination of several years of development. These devices are designed for extreme reliability and positive alarm action from distress signals in continuous operation without the attendance of a radio operator and must discriminate between the prescribed type of distress signal and all other types of signal and interference.[37,38,39]

There have been important developments in receivers designed for the reception of frequency-modulated waves, the extension of the superheterodyne principle to receivers for 17-centimeter waves with much better signal-to-noise ratio,[40] and the application of noise suppressors to receivers designed for specific applications in the ultra-high-frequency spectrum.

THE BROADCAST RECEIVER INDUSTRY

The quantity of radio receivers manufactured in the United States during 1937 is estimated at between 7,000,000 and 7,500,000, which was 10 to 15 per cent less than the all-time record of 8,250,000 produced in 1936.

The average list price for all receiver models was $67.50 as compared with $65.00 for the preceding year. The number of models introduced did not differ materially from that of recent years, the total being somewhat over one thousand models.[41]

Tables giving the general specifications for all models announced

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[34] R. J. Framme, "Novel method of testing aircraft radio compass," presented before Cincinnati Section, April 27, 1937. PROC. I.R.E., vol. 25, p. 659 June, (1937). (Abstract.)

[35] "Radio compasses for small boats," *Electronics*, vol. 10, pp. 9–11; April, (1937.)

[36] H. B. Martin, "Small vessel direction finders," *RCA Rev.*, vol. 2, pp. 69–80; July, (1937).

[37] "Automatic SOS alarms," *Electronics*, vol. 10, pp. 20–23; April, (1937).

[38] I. F. Byrnes and H. B. Martin, "Automatic alarm," *RCA Rev.*, vol. 1, pp. 49–64; January, (1937).

[39] S. D. Browning, "Mackay Radio and Telegraph Company auto alarm type 101-A," presented before New York Meeting, April 7, 1937. PROC. I.R.E., vol. 25, p. 664; June, (1937). (Abstract.)

[40] A. H. Reeves and E. H. Ullrich, "Superheterodyne reception of micro-rays," *Elec. Com.*, vol. 16, pp. 153–157; October, (1937).

[41] "The new 1937–38 sets analyzed," *Radio Today*, vol. 3, p. 16; August, (1937).

during the first half of the year have been published[42,43] and from those tables the following data have been prepared.

Of the total number of models introduced, 289 were consoles and 588 table models. The chair-side model increased in popularity, 40 being of this type. There was likewise an increasing interest in phonograph reproduction, 106 such models being manufactured. Portable models numbered 38 and the number of models incorporating some type of automatic tuning was 142.

The average 1937 console model had a list price of $100.89, 9½ tubes, a 10-inch speaker, and a power output of 6¼ watts. The average table model had a list price of $41.68, 6¼ tubes, a 6½-inch speaker, and a power output of 3 watts.

The number of models using metal tubes in the majority of sockets decreased during the year from approximately 60 to 30 per cent, the use of octal-based glass types increasing from 25 to 55 per cent, the remaining 15 per cent being glass tubes with the older-type base.[41]

There has been a tendency toward use of voltage-reducing resistors in tube envelopes, in some cases several of these resistor units being used in a single receiver model to increase the apparent number of tubes for commercial designation purposes.

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[42] "Complete line prices and specifications," *Radio Retailing*, vol. 22, pp. 40–56; June, (1937).

[43] "Sales features and specifications of the 1937–38 radio sets," *Radio Today*, vol. 3, pp. 34, 38–39; July, (1937); and "Specifications of 1937–38 farm radio sets," *op. cit.*, pp. 24, 62, 64.

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Volume 26, Number 3 *March, 1938*

RADIO PROGRESS DURING 1937

PART IV—REPORT BY THE TECHNICAL COMMITTEE ON TELEVISION AND FACSIMILE*

TELEVISION and facsimile have continued to be largely experimental in nature. In a few instances, the ultimate broadcast service has been approximated to the extent that regularly scheduled television programs were transmitted. In the United States the Federal Communications Commission has licensed a number of broadcast stations to use their existing channels and facilities for experimental facsimile broadcasting between midnight and 6:00 A.M. For experimental television, the Federal Communications Commission has allocated 19 channels, each of 6-megacycle width. The lower frequency limits of these channels are: 44, 50, 66, 78, 84, 96, 102, 156, 162, 180, 186, 204, 210, 234, 240, 258, 264, 282, and 288 megacycles.[1]

Certain of the standards for television broadcasting, recommended by the Radio Manufacturers Association,[2] have been used by some active experimental groups. Other transmission characteristics under active consideration at the close of the year were (1) whether the direct-current component is to be transmitted directly or indirectly and (2) the type of synchronizing signal.

TELEVISION APPARATUS

Much of the important television development concerned tubes, and is described in the report of the Technical Committee on Electronics. Picture pickup devices, including camera tubes, for direct and for film transmission have been improved as to sensitivity and fidelity. Most of the organizations active in the United States have utilized electronic scanning at 441 lines per picture, interlaced, and a field frequency of 60 per second. In Great Britain the standard is 405 lines, interlaced, and a field frequency of 50. German standards were revised[3,4] to 441 lines and a field frequency of 50. Amplifier, synchroniz-

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* Decimal classification: R583.

[1] Order No. 19 of the Federal Communications Commission, October 13, 1937. This order (effective October 13, 1938, in the absence of protest) allocates frequencies between 30 and 300 megacycles to various radio services, assignments in this range having previously been on an experimental basis.

[2] A. F. Murray, "Television standards and frequencies" *Communications*, vol. 17, p. 20, November, (1937).

[3] George Weiss, "The question of the German television standards," *Funkteck. Monatshefte* (Fernsehen und Tonfilm supplement), no. 6, June, (1937).

[4] F. Banneitz, "The new television standards of the German Post Office," *Funkteck. Monatshefte* (Fernsehen und Tonfilm supplement), no. 11, November, (1937).

ing-pulse circuits, and modulating systems have been used in forms permitting increased definition, better gradation, and improved stability. A modulation arrangement involving the use of a quarter-wave transmission line as a controlled variable impedance has been described.[5]

Television picture tubes have been improved in definition by the further application of electron optics, and in color and brilliance, by the development of new screen material. Television receivers incorporating both sound and picture apparatus, have been used in the field.[6,7,8,9] Projection-type tubes[10,11,12,13] and mechano-optical systems[14] for showing relatively large pictures have been demonstrated.

In Germany, the long-distance commercial two-way telephone-television system operating on 180 lines has been extended. In the United States, apparatus for wire transmission of television was demonstrated between New York and Philadelphia. The transmitting apparatus scanned motion-picture film at 240 lines and 24 frames per second. In this work the difficulties of transmitting low frequencies were avoided by the use of a double-modulation system which raised the frequency spectrum by 144 kilocycles.[15]

TELEVISION FIELD TESTS

Extensive field tests under actual or approximate conditions of home broadcast reception, have been carried on.[16,17,18] In Great

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[5] W. N. Parker, "A unique method of modulation for high-fidelity television transmitters," presented before the Rochester Fall Meeting, Rochester, N. Y., November 9, 1937, and the New York meeting, January 5, 1938. *Electronics*, vol. 10, pp. 11–14; December (1937). (Summary.)

[6] "Experimental high-fidelity television," Radio-Craft, p. 86, August, (1937).

[7] D. C. Espley and G. W. Edwards, "Television receivers (description of G.E.C. receivers)," *Gen. Elec. Co. Jour.* (England), vol. 8, no. 2; May, (1937).

[8] "Television receivers at radio Olympia, 1937," *Jour. Tel. Soc.*, vol. 2, part 8, p. 280; June, (1937).

[9] J. Sieger, "German television progress," *Tel. and Short-Wave World*, vol. 10, p. 541; September, (1937).

[10] J. Reick, "Image brightness in picture projection technique," *Zeitsch. V.D.* I, vol. 81, no. 6; June, (1937).

[11] "First details of the Philips projection receiver," *Tel. and Short-Wave World*, vol. 11, p. 581; October, (1937).

[12] M. Wolf, "The enlarged projection of television pictures," *Philips Tech. Rev.*, vol. 2, August, (1937).

[13] A. Karolus, "The problem of large images in television," *Funkteck. Monatshefte* (Fernsehen und Tonfilm supplement), no. 3, March, (1937).

[14] F. Okolocsany, "The wave-slot, an optical television system," *Wireless Eng.*, vol. 14, pp. 527–536; October, (1937).

[15] "Coaxial cable television transmission," *Communications*, vol. 17, pp. 9–11; November, (1937).

[16] R. R. Beal, "Equipment used in the current RCA television field tests," *RCA Rev.*, vol. 1, pp. 36–48; January, (1937).

[17] R. R. Beal, "RCA developments via television," *Jour. Soc. Mot. Pic. Eng.*, vol. 29, pp. 121–143; August, (1937).

[18] "Philco shows 441-line television," *Electronics*, vol. 10, p. 3; March, (1937).

Britain a daily service is provided and home receivers are on the market.[19,20,21,22] Much attention has been given to improved technique of program presentations,[23] including provision for the showing of events taking place outside of the studio.[24] As part of the field tests much attention has been given to the measurement of ultra-high-frequency propagation,[25] the comparison of horizontally and vertically polarized waves, and the suppression at the receiver of one picture side band.[26] In general, the field work has been on the basis of increased definition and higher carrier power.[27,28]

FACSIMILE APPARATUS

Useful developments have been made in pickup devices, particularly in those which reproduce from a continuous strip of subject copy. Apparatus weight and size have been reduced to increase portability. Modulation systems utilizing new principles have been developed to improve stability and gradation. Improved definition based on scanning rates of 80, 100, and 125 lines per inch has been largely used.

At the reproducing end, photographic apparatus has had further application in long-distance radio services, Carbon-paper mechanical recording has been used experimentally in an ultra-high-frequency radio service between New York and Philadelphia as well as in home-type recorders. Electrolytic and thermal recording papers have been improved as to contrast, gradation, color, and permanence of record. Recorders utilizing them have also had experimental broadcast use. Self-contained receiving units, combining a radio receiver and a facsimile reproducer, have been built.

Work was done on the development of automatic synchronization and control accessories, the utility of these instruments being primarily

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[19] "Field strength measurements of the Alexandra Palace transmissions," *Tel. and Short-Wave World*, vol. 10, p. 265; May, (1937).

[20] H. M. Lewis and A. V. Loughren, "Television in Great Britain," *Electronics*, vol. 10, pp. 32–35, 60–61; October, (1937).

[21] "Television" (1937), His Majesty's Stationery Office, (London).

[22] G. H. Watson, "The E.M.I. television receiver," *Jour. Tel. Soc. Gr. Brit.*, vol. 2, p. 7; March, (1937).

[23] R. M. Morris and R. E. Shelby, "Television studio design," *RCA Rev.*, vol. 2, pp. 14–29; July, (1937).

[24] "A. P. 1936–37," *The Listener*, January, (1938).

[25] H. H. Beverage, "Some notes on ultra-high-frequency propagation," *RCA Rev.*, vol. 1, pp. 76–87; January, (1937).

[26] W. J. Poch and D. W. Epstein, "Partial suppression of one side band in television reception," PROC. I.R.E., vol. 25, pp. 15–31; January, (1937); *RCA Rev.*, vol. 1, pp. 19–35; January, (1937).

[27] J. W. Conklin and H. E. Gihring, "Television transmitters operating at high powers and ultra-high-frequencies," *RCA Rev.*, vol. 2, pp. 30–44; July, (1937).

[28] "New 441-line high-fidelity television demonstrated," *Short-Wave and Television*, p. 7, May, (1937).

in the projected service of home broadcast facsimile. The new synchronizing methods have value also in commercial message service.

FACSIMILE FIELD TESTS AND SERVICES

No reports of facsimile services or field tests abroad are available, but in the United States there have been numerous tests under conditions simulating both commercial long-distance message services and home picture reception. In addition, an experimental service between New York and Philadelphia has been maintained throughout the year. Wire services,[29] both for press photographs and message text, have been extended.

ACKNOWLEDGMENT

The preceding report has been restricted to articles published during 1937 (primarily in English). The Committee expresses its grateful acknowledgment to those companies which have furnished helpful technical data and annual progress reports to it.

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[29] "News pictures by wire," *Electronics*, vol. 10, pp. 12–17, 82–83; November, (1937).

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Volume 26, Number 3 *March, 1938*

RADIO PROGRESS DURING 1937

Part V—Report by the Technical Committee on Transmitters and Antennas*

Introduction

DEVELOPMENTS in transmitters and antennas have consisted principally in perfecting and extending the application of important innovations previously noted in these reports.

Antennas

The trend in broadcast antennas continues toward the constant-cross-section, guyed structure, built to the economical height of approximately 0.55 wavelength, for maximum primary service area free from fading. There have been accumulated more data on characteristics, particularly those concerning the relations of antenna dimensions and form, fading characteristics, and ground-system design.[1,2]

As a means of improving unsatisfactory current distribution in a tower, resulting from a restriction in height, or other reasons, sectionalizing and top-loading have been receiving further attention.[3]

The shunt-excited antenna, introduced in 1936, is now in extensive use.[4]

Application of antenna arrays to the field of broadcasting has increased.[5,6] Such arrays provide directive patterns of various shapes and are used to improve service in the primary area, or to protect other stations from interference, or both. Ordinarily, two elements, spaced and phased as required to produce a certain pattern, are adequate, although in certain cases three elements are being used.

New developments in directive antennas for point-to-point communication have been made. A new receiving antenna system[7] has been developed and tested, employing sharp vertical-plane directivity

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* Decimal classification: R350×R320.

[1] Raymond F. Guy, "Notes on broadcast antenna developments," *RCA Rev.* vol. 1, pp. 39–63; April, (1937).

[2] G. H. Brown, R. F. Lewis, and J. Epstein, "Ground systems as a factor in antenna efficiency," Proc. I.R.E., vol. 25, pp. 753–787; June, (1937).

[3] G. H. Brown and J. G. Leitch, "The fading characteristics of the top-loaded WCAU antenna," Proc. I.R.E., vol. 25, pp. 583–611; May, (1937).

[4] J. F. Morrison and P. H. Smith, "The shunt-excited antenna," Proc. I.R.E., vol. 25, pp. 673–696; June, (1937).

[5] G. H. Brown, "Directional antennas," Proc. I.R.E., vol. 25, pp. 78–145; January, (1937).

[6] Irving Wolff, "Determination of the radiating system which will produce a specified directional characteristic," Proc. I.R.E., pp. 630–643; May, (1937).

[7] H. T. Friis and C. B. Feldman, "A multiple unit steerable antenna for short-wave reception," Proc. I.R.E., vol. 25, pp. 841–917; July, (1937).

which can be steered to suit the varying angles at which short radio waves arrive at a receiving location. The system consists of an end-on array of antennas of fixed directivity, whose outputs are combined in phase for the desired angle. The antenna outputs are conducted over coaxial lines to the receiving building, where the phasing is accomplished by means of rotatable phase shifters, each set constituting a separately steerable branch. One branch serves as an exploring circuit for determining the angles at which waves are arriving. The remaining branches may be set to receive at these angles. The propagation times corresponding to the different angles are equalized by audio-frequency delay networks before the outputs are finally combined.

One experimental multiple-unit system comprises 6 rhombic antennas, three-quarters of a mile long. Two receiving branches are provided in addition to a monitoring branch. Experience with this system shows that it gives a signal improvement of about 8 decibels referred to 1 of the 6 antennas alone, and a substantial quality improvement due jointly to the diversity action and the reduction of selective fading. As a result of preliminary tests, a system 2 miles long is believed to be practicable and desirable, and should give a signal improvement of about 13 decibels, referred to 1 rhombic antenna.

Establishment of scheduled transmissions for television broadcasting has offered an opportunity to gather valuable data on propagation on frequencies between 40 and 56 megacycles. Results of observations made at Riverhead, N. Y., on transmissions from London and Berlin have been summarized to support the conclusion that propagation on these frequencies results from refraction phenomena in the ionosphere much the same as in the case of lower frequencies.[8]

A comprehensive review of data accumulated on ultra-high-frequency radio-wave propagation has been made and supplementary quantitative measurements carried out using facilities made available by transmitter installations in several high buildings in New York City. General conclusions drawn from this survey are that ultra-high-frequency signals are attenuated according to the inverse-square law of the distance, for grazing incidence within the optical range, and according to an inverse-exponential law of the distance, in which the exponent increases with frequency, for the range beyond the horizon.[9,10]

Further valuable investigation of the properties of the ionosphere

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[8] H. O. Peterson and D. R. Goddard, "Field strength observations of transatlantic signals 40 to 45 megacycles," *RCA Rev.*, vol. 2, pp. 161–170; October, (1937); Proc. I.R.E., vol. 25, pp. 1291–1300; October, (1937).

[9] H. H. Beverage, "Some notes on ultra-high-frequency propagation," *RCA Rev.*, vol. 1, pp. 76–87; January, (1937).

[10] P. von Handel and W. Pfister, "Ultra-short-wave propagation along the curved earth's surface," Proc. I.R.E., vol. 25, pp. 346–363; March, (1937).

and of the propagation of radio waves of various frequencies has been reported during the year.[11,12,13]

This year has seen continued activity on the investigation of upper-air phenomena using radio transmitting and instrumental means carried aloft on small unmanned balloons. The study of cosmic-ray intensities, vertical distribution of solar ultraviolet radiation intensities, and meteorological quantities, such as barometric pressure, air temperature and humidity, and cloud heights and vertical thickness are some of the properties of the upper atmosphere which have been studied. The United States Weather Bureau and the United States Navy Department have been active in service tests of radio meteorograph for replacing the present use of airplanes in taking upper-air meteorological soundings. The results of all of the tests have led to the inauguration of routine radio meteorograph operation at 12 stations.

Mention was made in the last review of the allocation survey made by the Federal Communications Commission in co-operation with the radio industry. There were obtained in this survey over four thousand continuous 24-hour field-intensity records over a period of 3 months. The data obtained related to the fading characteristics of radio waves in the secondary service areas, the conductivity of the earth in various sections of the country, the fading during twilight hours, the period of fading as a function of frequency, and the field intensity in the secondary service areas of broadcast stations at various distances, as affected by fading. During the past year a further analysis of this material has been made, which has resulted in the development of a theory of broadcast sky-wave transmission. A method of computing and combining the various waves reflected one or more times at the ionosphere before reaching the receiving antenna, has given results in very good agreement with the experimental data obtained by the survey. The general conclusions reached have been as follows:

At short distances, the type of transmitting and receiving antenna used and the characteristics of the ionosphere are of primary importance, while at the longer distances, it is the ground conductivity along the path and the frequency which are of primary importance. The theory was developed primarily to furnish an explanation of broadcast frequency propagation at night, but may be extended to other frequencies and to other times of the day and season, through

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[11] Neil H. Williams, "Production and absorption of electromagnetic waves from 3 cm to 6 mm in length," *Jour. App. Phys.*, vol. 8, pp. 655–659; October, (1937).

[12] G. C. Southworth, "Some fundamental experiments with wave guides," Proc. I.R.E., vol. 25, pp. 807–822; July, (1937).

[13] G. C. Southworth, "New experimental method applicable to ultra-short-waves," *Jour. App. Phys.*, vol. 8, pp. 660–665; October, (1937).

generalization of the theory of the effect of the ionosphere and further experimental investigation. A considerable amount of data on the effects of the antenna itself has resulted from the work of the survey.

TRANSMITTERS

Transmitter development has in general been in the direction of higher power at higher frequencies, improved power conversion efficiencies for modulated services, simplified operating adjustments, and better appearance of the equipments.

Experimental television equipment has been increased in power output and the modulation frequency band has been widened by special modulator circuits and compensating networks. Transmission-line sections are being employed as impedance transformers, metallic insulators, impedance inverters, and as simple reactances. New tubes such as the RCA-888 and others have simplified ultra-high-frequency apparatus problems.[14,15,16,17]

In the standard broadcast-transmitter field, a transmitter having 5 kilowatts carrier output is now available using forced air-cooling of the final radio-frequency and high-level modulator tubes. Formerly, the highest powered broadcast transmitter available without water-cooling was 1 kilowatt. The necessary cooling is effected by means of copper fins, silver soldered to the tube anode, the whole assembly of tube with fins being set in a porcelain insulator which also serves as an air guide.[18]

For large broadcast transmitters the high-efficiency circuit with low-level modulation described last year has been used more extensively.

Considerable attention has been given to the appearance of equipment, especially in broadcast transmitters and studio apparatus. In some instances a complete enclosure of the apparatus is being employed with forced air ventilation through the necessary air filter. This dusttight arrangement is of greatest benefit where the equipment is designed for 24-hour per day service, such as at airway beacon stations.[18]

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[14] J. W. Conklin and H. E. Gihring, "Television transmitters operating at high powers and ultra-high frequencies," *RCA Rev.*, vol. 2, pp. 30–44; July, (1937).

[15] W. G. Wagener, "The requirements and performances of a new ultra-high-frequency power tube," *RCA Rev.*, vol. 2, pp. 258–264; October, (1937).

[16] A. L. Samuel, "A negative grid triode oscillator and amplifier for ultra-high frequencies," Proc. I.R.E., vol. 25, pp. 1243–1252; October, (1937).

[17] B. Salzberg, "On the optimum length for transmission lines used as circuit elements," Proc. I.R.E., vol. 25, pp 1561–1564; December, (1937).

[18] J. P. Taylor, "A 5-kilowatt air cooled broadcast transmitter," *Communications*, vol. 17, pp. 7–9; October, (1937).

At several transmitting stations the practice has been followed of coupling the radio-frequency transmission line into the center of a vertical radiator approximately one-half wave in length. The principle of reversed feedback, either including radio-frequency rectification or covering only the audio-frequency system, is being widely employed for improvement of fidelity and reduction of noise in modulated transmitters.[18]

New methods of cutting quartz crystals have been developed[19] to produce oscillators having low temperature coefficients while leaving the crystal amenable to a limited amount of adjustment in frequency and temperature coefficient after rough grinding. Progress has been made in the generation of harmonic frequencies in crystals to the extent that crystal output frequencies as high as 30 megacycles have been obtained. Transmitter design is employing tetrode and pentode power tubes increasingly since their use simplifies circuit arrangements, especially where the frequency must be variable.

In the field of lightweight and portable equipment, transmitters weighing less than two pounds including batteries are in general use for meteorological balloon sounding. The transmitter includes instrumental means which vary a characteristic of the emission, such as the modulating frequency, in accordance with the variation of atmospheric pressure, temperature, and humidity of the upper air.[20,21,22] For broadcast remote pickup of sports and similar events, more compact and lighter weight knapsack equpiment has been developed. For commercial aircraft use, an improved multichannel transmitter and associated receiver are now available, giving considerably greater flexibility and simplified operation in the selection of communication channels.

A number of important developments of a system nature have appeared during the year. A high-power, high audio-frequency quality transmitter utilizing frequency modulation is being built near New York. Experimental work on aircraft beacon apparatus using ultrahigh frequencies has gone forward with promising results.[23] At conven-

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[19] S. C. Hight and G. W. Willard, "A simplified circuit for frequency substandards employing a new type of low-frequency zero-temperature-coefficient quartz crystal," Proc. I.R.E., vol. 25, pp. 549–563; May, (1937).

[20] H. Diamond, W. S. Hinman, Jr., and F. W. Dunmore, "Radio methods for the investigation of upper-air phenomena with unmanned balloons," *Jour. Aer. Sci.*, vol. 4, pp. 241–248; April, (1937); Proc. I.R.E., vol. 25, p. 540; May, (1937). (Summary.) Presented before Silver Anniversary Convention, New York City, May 10, 1937.

[21] O. C. Maier and L. E. Wood, "The Galcit radio meteorograph," *Jour. Aer. Sci.*, vol. 4, pp. 417–422; August, (1937).

[22] Villa Väisälä, "The Finnish radio sound," Mitteilungen des Meteorologischen Institutes des Universität Helsingfors, vol. 35, pp. 1–28, (1937).

[23] E. Kramar and W. Hahnemann, "The ultra-short-wave guide-ray beacon and its application," presented in part before Silver Anniversary Convention May 10, (1937); Proc. I.R.E., vol. 26, pp. 17–44; January, (1938).

tional aircraft beacon frequencies, the use of a 5-tower antenna system is increasing. This permits transmission of weather information without interruption of the normal directive beams.[24] Semimobile apparatus has been applied successfully to police and fire boats. The trend in police-station transmitters has been in the direction of better fidelity. Automatic means have been employed on mobile transmitters to compensate for variable volume resulting from voice characteristics and the distance of the speaker from the microphone. In broadcast-studio apparatus, the introduction of a volume-limiting program amplifier which suppresses the peaks of the audio-frequency waves as complete modulation is approached was made available, thereby permitting a higher average value of modulation to be used. In practice a gain of about 4 decibels in average speech input level is thus obtained.[25] For transoceanic telephone transmission, transmitters emitting a single side band were employed to advantage.

[24] W. E. Jackson and D. M. Stuart, "Simultaneous radio range and telephone transmission," Proc. I.R.E., vol. 25, pp. 314–326; March, (1937).

[25] O. M. Hovgaard and S. Doba, "Higher program level without circuit overloading," Proc. I.R.E., vol. 25, p. 542; May, (1937). (Summary.) Presented before Silver Anniversary Convention, New York City, May 12, 1937.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

A NEW SYSTEM OF INDUCTIVE TUNING*

By

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Summary—*A sliding-contact variable inductance is described wherein contact reliability over long life is secured by a unique carriage arrangement and parallel nibs at the point of contact. The coil is rotatable, the high-potential contact being taken off a ring at one end. The contactor and unused end of the coil are at ground potential.*

The entire variable coil is used and the high-frequency limit is determined by a separate adjustable "end" inductance which improves the performance throughout the high-frequency range. The high-frequency limit of a continuous operating range for a given coil is near the natural frequency of the unused part of the coil when the contact is near the high-potential end of its travel.

Wide frequency tuning ratios of the order of six to eight are feasible and all-wave continuous coverage may be effected with two switch positions instead of three as required with variable-condenser tuning. Oscillator circuits are described which yield substantially uniform voltage over a ten-to-one frequency range. This wide-range characteristic may be obtained even in the ultra-high-frequency region.

Wider ranges necessitate improvement in the tracking of the usual superheterodyne input circuit. A method for producing a fourth tracking crossover when the inductive tuner is designed for superheterodyne circuit tuning is described.

INTRODUCTION

THE purpose of tuning radio receivers is to select the desired and at the same time reject all the undesired signal voltages that may develop at the receiving antenna. It is usual to accomplish this by taking advantage of the resonant rise in the various tuning circuits we build into our receivers.

The requirements for receiver and transmitter tuning equipment are quite dissimilar. The various transmitter designs are much simpler. There we have no need for quiet operation because the tuning seldom is done while the transmitter is in operation, nor have we a need for long mechanical life. On the other hand, receiving-set tuners must be quiet in operation and possessed of exceptional life. Until recently transmitters have been almost universally inductively tuned.

The earliest tuning device for commercial receivers was an adjustable inductance comprising a cylindrical coil and a contactor sliding along it parallel to its axis. Later we had the so-called variocoupler which was an elaboration of the earlier simple coil and included a

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* Decimal classification: R382. Original manuscript received by the Institute, September 3, 1937. Presented before Indianapolis Section, June 24, 1937; presented before Radio Club of America, November 18, 1937.

tapped secondary winding with adjustable mutual coupling between the two coils.

We then had the double-roller type of tuner, that of winding a bare wire from an insulator roller on to a bare metallic roller, or in the reverse order, for varying the inductance. There also have been attempts to use the variometer as a tuning element, either alone or in conjunction with a variable condenser.

Notwithstanding the years of skillful development with the variable condenser, there is room for improvement and economy in meeting progressing requirements, and to this end a new form of slide-contact inductive tuning will be described.

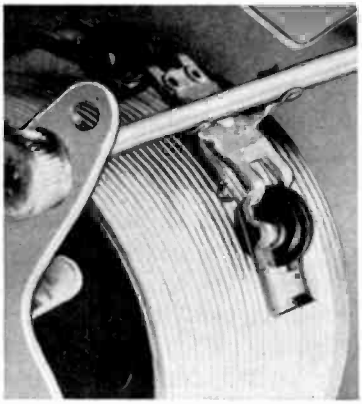


Fig. 1—Inductance with contactor trolley riding on one of the coil turns. The metal finger in contact with the coil turn is bifurcated.

MECHANICAL DESCRIPTION

A variable inductance in this system comprises a rigid coil on which a contactor is constrained to slide along the length of the conductor whenever the coil is rotated. The contactor is mounted in a carriage which may slide along the side of the coil in a direction parallel to the coil's axis. Fig. 1 is a view of the contact assembly riding against the side of the coil. The coil form has been spirally grooved and the wire is wound under tension in this groove, about two thirds of its diameter protruding. The two insulated wheels are grooved and ride as a trolley on this wire. When the coil is rotated the carriage is pushed in a direction parallel to the coil axis, depending upon the direction of rotation, the overhead rod against which the antler-shaped spring presses acting as the guide. The carriage assembly is compressed between the guide rod and coil form and thus is mounted against the side of the coil under any reasonable coil eccentricity. A bifurcated contactor spring is attached to the carriage directly between the two insulated trolley wheels and exerts a light pressure through its parallel nibs upon the conductor. The contactor spring itself is not called upon to perform any other mechanical function than that of supplying the continuous contact.

The conductor of the coil is a hard-silver-plated hard-drawn copper wire, the guide rod also being silver plated, while the contactor and the overhead antler springs are of phosphor bronze. The body of the contactor is approximately tangent to the circumference of the coil at the point of contact.

The design of the carriage assembly is such as to produce, as far as possible, rotational stability around an imaginary axis passing through the points where the two trolley wheels ride on the coil. This results in a minimum of undesired forces in directions other than that of the intended contact travel along the wire and thus reduces wear.

It has been found that a bifurcated contact spring greatly improves the contact reliability and hence enables reduction in the pressure required as a result of the diversity effect obtained. Many observations under the microscope as between one and two contacts in parallel determined this. Observations were made at various pressures and also with good and poor contact conditions. The causes of breaks were classified and the number per unit length were noted. Any minute obstruction or irregularity located along the line of contact may cause a break when one contact is employed, but it takes a much larger surface obstruction extending over 10 to 30 degrees and located in a plane perpendicular to the axis of the conductor to lift two parallel contacts.

The bifurcation should be longitudinal with respect to the conductor, so that the inductive path length is the same measured from the point of contact of either nib on the conductor to any other point on the coil.

Fig. 2 (b) shows a broadcast-range coil on the left and an ultra-high-frequency coil tunable to 100 megacycles. The large coil is mounted on a copper shaft which passes through the hub. When mounted with the co-operating parts shown in Fig. 2 (c) a spring contactor rides on the ring surrounding the hub. This is the grid or high-potential connection. Another spring contactor rides the end of the hub and assures a steady ground connection during rotation. The ultra-high-frequency coil has its grid and ground connections taken off opposite ends. The cap at the top end in the figure supplies the grid connection while the entire coil assembly is mounted on a small copper shaft by means of a metal plug placed in the lower end of the coil form.

The two coils are mounted with shafts parallel and are driven at relative speeds inversely proportional to their winding pitches. The carriage is especially shaped to avoid undesired lateral force components and thus reduces wear.

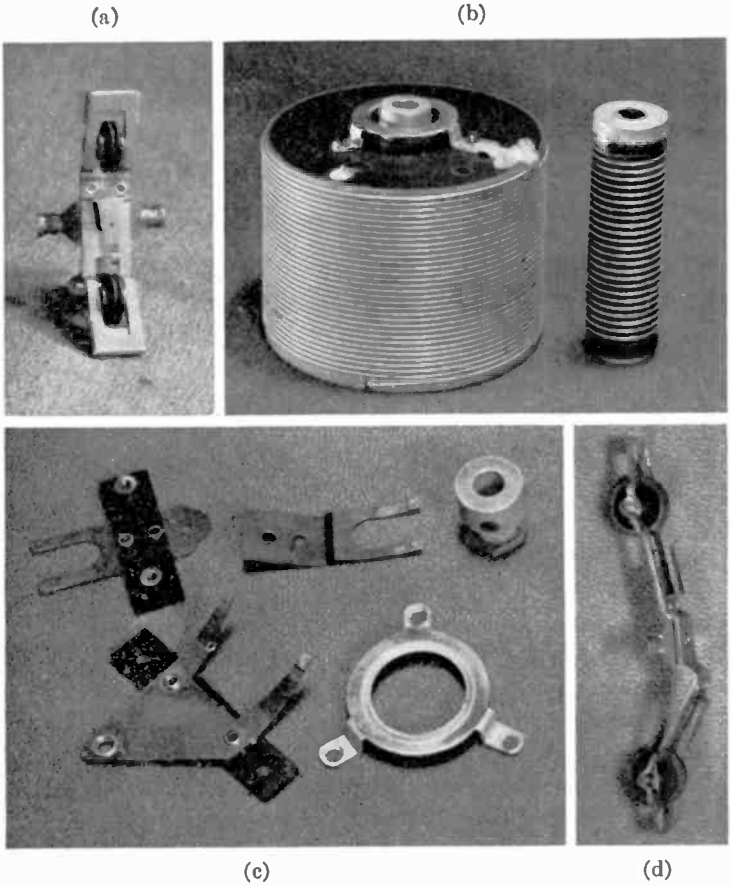


Fig. 2—(a) and (d) are contactor trolleys for single- and dual-coil assemblies. (b) shows a broadcast range and an ultra-high-frequency range coil. (c) pictures the springs, hub, and ring fittings used to make connections with the ends of the coils.

A tuning unit with the cover removed is shown in Fig. 3. The right-hand section houses a single coil of the broadcast size while the other two sections contain a large and a small coil each with the larger double-contact trolley assembly riding along with its carriage frame perpendicular to the parallel shafts of the coils. The gears for driving these coils at the correct relative speeds may be seen at the left.

To prevent the trolley assembly from running off the ends of the coils, a stop mechanism is required. It was found desirable to have the stop operable independently of the dial gear. This prevents breakage in assembly when the complete dial may not yet be in place. A pinion attached to the main shaft drives a large gear which carries a pin on its rear surface. This pin engages the spider gear shown and pushes it one notch for each revolution of the large gear, the main stop being attached on the back of the spider. With this arrangement the number of turns that can be employed between stops is equal to a multiple of the pinion-and-gear ratio, because the large gear pin must engage the spider in order to effect a stop. A shallow indexing cam on the back of the large gear engages the spider at all positions of the large gear except when the pin engages the spider.

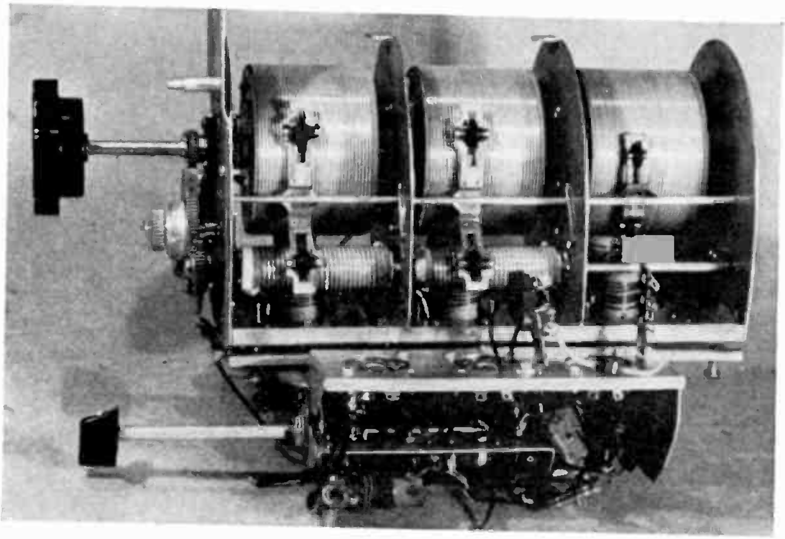


Fig. 3—A wide-frequency-range tuning unit for a superheterodyne circuit covering from 0.54 to 65 megacycles. The large coils, with two switch positions, cover from 0.54 to 18 megacycles and the two smaller coils cover from 18 to 65 megacycles. In the higher-frequency range, the radio-frequency stage is not used.

If a second gear pair like the first is added concentrically to the main shaft the ratio of the turns of the second large gear to that of the main shaft will be the square of either gear pair. Fig. 4 shows an elevator holding three pilot lights which is moved vertically by means of a cord that winds around a small windlass located just in back of the gearing.

The long primary motion of the inductive tuner enables the use of long dial scales. A spiral scale marked off on this dial and affixed concentrically to the second large gear mentioned above has an inside-to-outside radial distance equal to the elevator travel. The result is that the light behind the dial travels from end to end of the spiral when the trolley contactor travels from one end to the other of the coil. The dial is marked off with three spirals in parallel; the wave-band switch is arranged to operate the dial light corresponding to the particular band in use. Each of these spiral scales is about five feet in length; the dial is ten inches in diameter.

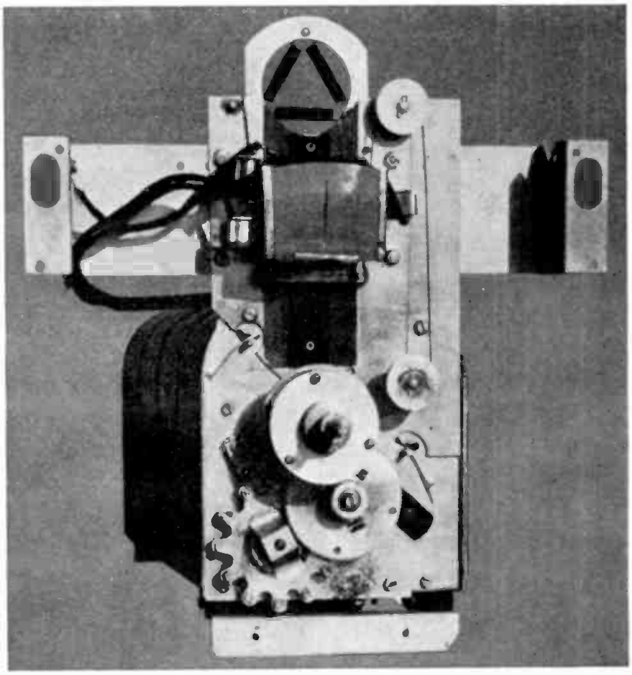
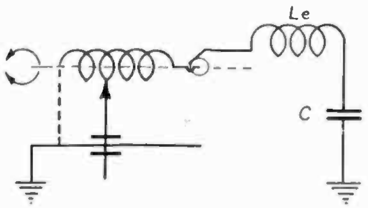


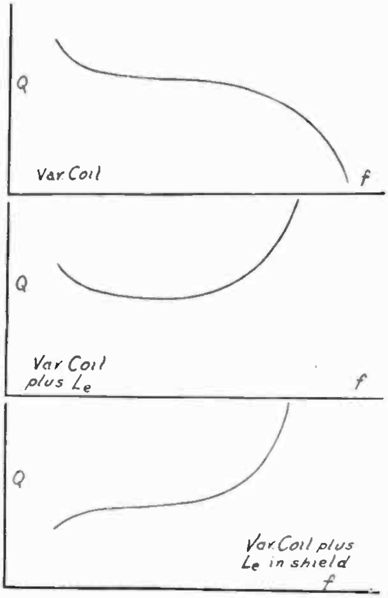
Fig. 4—Front view of a superheterodyne input tuning system. A spiral dial is driven through a gear chain from the drive shaft and the window through which the dial is viewed is raised or lowered by the operation of the drive shaft. The range switch operates the proper light to illuminate the portion of the dial in use.

Life tests indicate a practical mechanical life for these variable-inductance units of at least 30,000 round trips representing a contactor travel along the conductor of several hundred miles, depending of course on the number of turns. Of equal importance is the test for noise when the units are not in use for protracted periods of time. Observations made at two-month intervals over a period of a year, and under usual radio-receiving-set conditions, indicate that no factors develop which contribute to the production of noise.

ELECTRICAL DESCRIPTION

Electrically, a simple variable coil, with suitable terminal or end inductance and fixed-capacitance components, will operate up to a frequency near the natural period of the unused part of the coil and down to a low-frequency limit determined only by what is considered an acceptable average impedance. Cylindrical coils of acceptable broadcast gain may have unused-part natural frequencies around 20 to 35 megacycles, depending upon the radius and number of turns. The broadcast gain and step-up increase with decreasing fixed capacitance while the natural frequency of the unused part appears to be chiefly influenced by the radius, assuming constant pitch and shielding.





From $f^2 = \frac{k}{C(L_v+L_e)}$,

$$\frac{L_v}{L_e} = \frac{f_2^2}{f_1^2} - 1,$$

or

$$L_e = L_v\left(\frac{f_1^2}{f_2^2 - f_1^2}\right),$$

where,

L_v = maximum value of the variable inductance

L_e = value of the fixed end inductance

$\frac{f_2^2}{f_1}$ = tuning ratio

Fig. 5—The effect of employing a fixed end coil with the variable inductance. The variation of Q with frequency is shown by the graphs.

Fig. 5 represents a variable-inductance fixed-capacitance tuning circuit. One of the features of this system is the employment of a terminal or end inductance L_e superior in performance to an equivalent mechanically stopped-off portion of the variable inductor. The upper curve is a typical Q-versus-frequency characteristic of the variable coil.

The center curve is the same thing with a suitable end inductance added and shows the great advantage of its use. The lower curve is the center curve further affected by a shield surrounding the variable coil and having a short-circuiting effect of about six per cent on the total variable-coil inductance when the slider is at the low-frequency end of its travel. The formula shown under the circuit indicates that the inductive magnitude of L_e that may be used for a given frequency range is proportional to the maximum size of the variable coil and, roughly, inversely proportional to the square of the frequency ratio for a given variable coil. Thus a variable coil apparently small for a given frequency coverage may be made to operate as well as a larger coil if the frequency ratio is reduced. In a two-range design, for example, the variable-coil size may be reduced without impairing the over-all performance provided the lower-frequency-range ratio is restricted below that of the square root of the total frequency coverage.

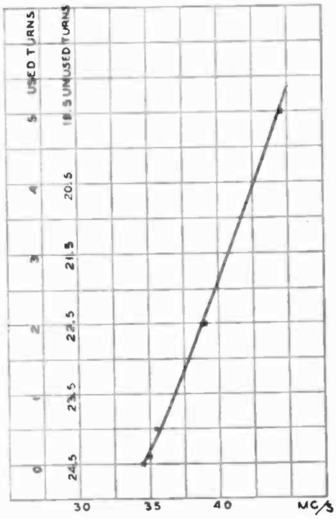


Fig. 6—The natural frequency of the coil as related to the number of used and unused turns in the circuit.

Considerable absorption takes place if the circuit is tuned past the natural frequency of the unused part of the variable coil. This is because of the mutual coupling between the used and unused parts, the natural frequency decreasing as the contactor approaches the high-frequency end of the coil. There is enough coupling in a fractional turn to cause absorption. Grounding the unused end of the coil raises the natural frequency of the unused part considerably, and the variable coils are constructed with the unused end grounded to the shaft. In a suitable coil design for all-wave coverage the broadcast performance may be improved a little by disconnecting this ground but the high-frequency range is inoperative unless it is grounded. In a certain 2.5-inch-diameter-coil design the natural frequency versus turns near the high-frequency end is shown in Fig. 6.

The importance of the end inductance is shown graphically in the curves of Fig. 7. A two-inch-diameter coil of 53 turns is made to cover 0.54 to 18 megacycles in two ranges by switching both the end inductance and fixed condenser. These characteristics are compared with the same coverages without the use of the end inductances. Note that the Q improvement due to end inductance tends to produce uniform impedance over quite a wide frequency ratio in each range. In superheterodyne circuits this high-frequency-end Q improvement tends to maintain a good image ratio as the radio-frequency-to-intermediate-frequency separation is increased.

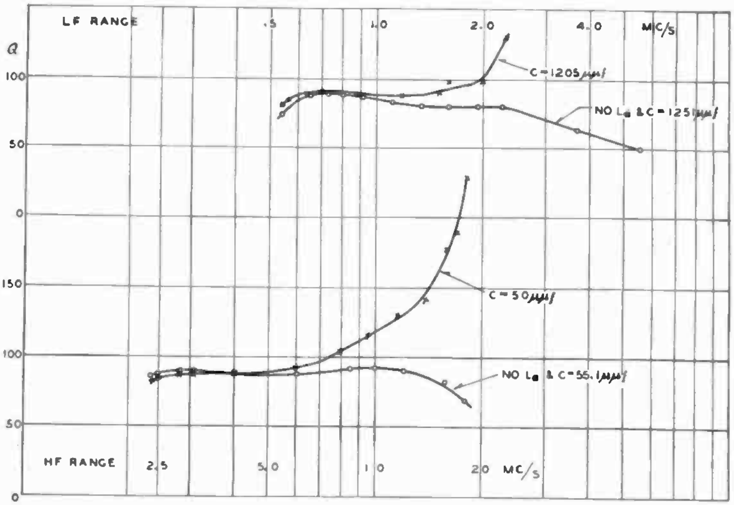


Fig. 7—Q plotted against frequency showing the effect of the end inductance L_e when used with a 2-inch-diameter coil of 53 turns of No. 22 wire, 3.4 inches long. One inch of winding is at a $\frac{1}{8}$-inch pitch and the remainder at $\frac{1}{18}$-inch. The natural frequency with 0.5 turn in use is 20 megacycles.

The increased frequency coverage of the inductive tuner over that of the variable condenser is due to two factors: (1) It is possible to reduce the inductively tuned circuit LC product to a smaller magnitude than in the case of variable-condenser tuning where the LC product minimum is limited by the minimum capacitance of the variable condenser plus the capacitance of the external circuit. (2) The lower-frequency end may be extended by increasing the number of turns comprising the variable inductance so long as the natural frequency of the unused part remains outside the operating range.

The results of inserting high-frequency iron in the low-frequency portion of a coil are noteworthy. One is the improvement toward a straight-line tuning characteristic with frequency and the other is the improvement in impedance which at any frequency setting varies inversely as the square of the fixed capacitance for constant resistance.

Another way of straightening the turns-versus-frequency characteristic is the employment of a differing pitch pattern along the axis.

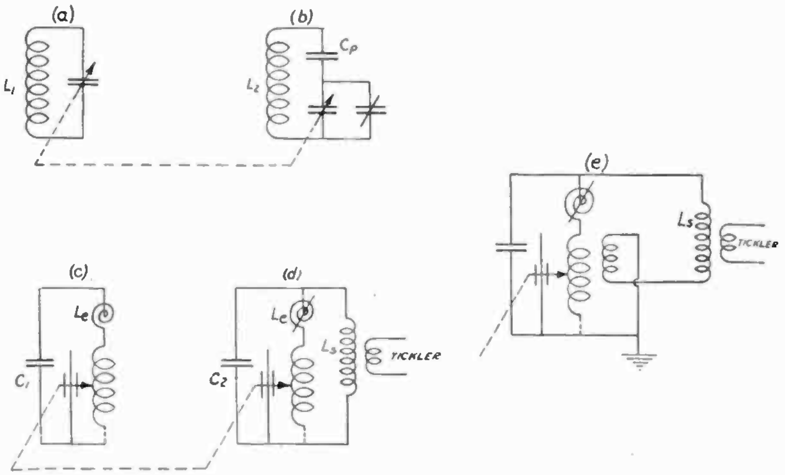


Fig. 8—(a) and (b) are the usual radio-frequency input and oscillator tuning circuits and (c) and (d) are their inductively tuned equivalents. (e) shows a method which improves the tracking for wide-frequency range circuits.

A conical design of rotating coil offers interesting possibilities of straight-line tuning, a compromise being required between high-frequency and low-frequency ranges in a two-range system unless the tuning ratio of each is the same. This is because the minimum terminal inductances would have to be the same to make the inductance vary as the square of the turns for a given incremental inductive increase per turn.

Fig. 8 (a) represents the usual radio-frequency tuning circuit while (b) is the usual oscillator circuit that accompanies (a) in the widely used fixed-intermediate-frequency superheterodyne system. Circuits (c) and (d) are, respectively, the inductively tuned equivalents of (a) and (b). The capacitance that bridges L_2 in circuit (b) varies as the product divided by the sum of C_p and the variable capacitance. In circuit (d) the inductance that bridges the fixed capacitance C_2 varies as the product divided by the sum of the inductances of the two branches, one branch being L_s and the other being the variable in series with the end inductance. The high-frequency-region adjustment for circuit (b) is the small shunt capacitance around the variable, while circuit (d) employs the end inductance L_e. As the square of the frequency varies symmetrically with respect to both C and L, the circuits (c) and (d) will produce a similar tracking characteristic to that of the condenser-tuned circuits.

In either system the deviations to be encountered between the three exact tracking points will increase with the frequency ratio coverage. It is also true that for equal tuning ratios the deviations will be larger as the frequency range is moved toward the intermediate frequency.

The feed-back tickler primary may be coupled to the end inductance, to the variable coil, or to the shunt coil as shown in (d); in fact it may be distributed between two or three of these components as desired.

In Fig. 8 (e) is shown a method of improving the tracking of wide-coverage circuits, that is, reducing the deviation which occurs between the actual signal and oscillator beat frequency and its ideal value equal to the intermediate frequency. Here the shunt coil has been divided into two parts, a small portion being placed inside and thus mutually coupled to the variable coil. The mutual coupling between the shunt and variable branches must be different for large and small settings of the variable coil and hence produces an effect that is equivalent to changing the value of the shunt circuit during tuning. Such a change would be like varying C_p along with the tuning of circuit (b). This added variable, if adjusted in magnitude and polarity may be made to provide an additional point of inflection resulting in a fourth crossover where the beat between the signal and oscillator equals the intermediate frequency.

The technique of applying the "mutual coil" is shown in Fig. 9 where the solid line represents the usual three-point track. The intermediate- and high-frequency crossovers are moved out to a higher frequency as m to m' and n to n'. This change in itself, that is, without the mutual coil in use, produces the dotted curve which shows a very large deviation in the low-frequency region. The use of the mutual coil, however, reduces this large deviation and gives the final desirable result depicted by the dot-and-dash line. Actual tracking deviation of a completed set is given in Fig. 10. This shows the signs of the extremes to be the same and the two points of inflection necessary to yield four tracking crossovers.

One of the advantages of the inductive tuner is the ease with which oscillators may be designed to operate at high frequencies. The tickler coil method of feedback may be employed to give any reasonable desired voltage without the tickler circuit "lifting" the tuning near the high-frequency extreme. This is because the impedance of the inductively tuned circuit rises as the circuit is tuned toward the low-frequency end, this rising impedance about offsetting the decreasing tickler coupling mutual reactance, as well as the descending Q. An almost constant oscillator voltage may be obtained without difficulty over a reactive tuning ratio of 100 to 1. An ultra-high-frequency oscillator of this type has been built to cover from 40 to 150 megacycles.

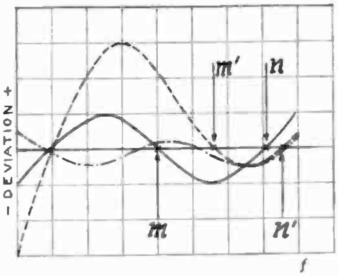


Fig. 9—Superheterodyne tracking characteristics. The solid line is the usual 3-point crossover characteristic. The dotted line shows improved high-frequency deviation resulting from circuit changes and the dot-dash line indicates the additional advantages of employing the mutual coil.

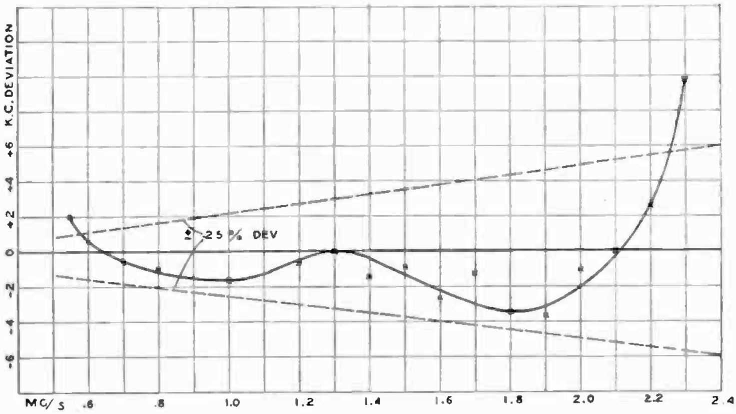


Fig. 10—Effect of the mutual coil on superheterodyne-input-circuit tracking. The deviation is that of the signal amplifier from the oscillator frequency minus the intermediate frequency.

Inherently there is nothing in the construction of these inductance units which should result in difficulties caused by microphonic action.

An experimental signal generator was constructed and with three switchable ranges covered from 90 kilocycles to 35 megacycles with a nearly constant output of 2 volts across 20 ohms in a master-oscillator-power-amplifier circuit.

The inherent high-Q low-impedance characteristics of these inductively tuned circuits when used in the broadcast band might suggest the combination of a tuned-radio-frequency amplifier followed by a diode detector. There should result greater stability than was experienced formerly with condenser-tuned circuits, and the tuned impedance of the order of 10,000 to 20,000 ohms would not be so seriously impaired by the diode load.

An interesting possibility is the application of automatic band switching along the line of mechanical travel of the variable inductances. Such an arrangement may be used to produce a "manually switchless" skip-band design. If each band should require approximately a three-to-one frequency spread the total coverage of the variable tuner would be nine-to-one, which is quite feasible. For broadcast-police coverage only, no switching would be needed, as will be seen from Fig. 7.

ACKNOWLEDGMENT

The author wishes to express his appreciation to the members of the Mallory technical staff for their aid in bringing this new tuning system to its present state of development.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

A THEORY OF NOISE FOR ELECTRON MULTIPLIERS*

By

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Summary—*The noise in secondary-emission electron multipliers is considered from a theoretical viewpoint. The noise properties of a stage are correlated with its secondary-emission properties: the mean value m and mean-square deviation* δ^2 *of the number of secondaries per primary. If* $\overline{I_{p\Delta f}^2}$ *and* $\overline{I_{s\Delta f}^2}$ *denote the mean-square noise current lying in the frequency band* Δf *in the primary- and secondary-electron currents, then* $\overline{I_{s\Delta f}^2} = m^2 \overline{I_{p\Delta f}^2} + \delta^2 2e\overline{I_p\Delta f}$ *where* $\bar{I}_p$ *is primary direct current. This result is applied to many-stage multipliers. For n similar stages* $\overline{I_{s\Delta f}^2} = \overline{M^2I^2}_{p\Delta f}{}^2 + \delta^2[M(M-1)/m(m-1)]2e\overline{I_p\Delta f}$ *where* $M = m^n$ *is the over-all gain of the multiplier.*

THE problem of noise in secondary-emission electron multipliers is essentially that of evaluating the fluctuation in the output current in terms of the fluctuation in the input current and in the manner in which the secondaries are produced, which may be ascribed to the properties of the secondary emitting surface or surfaces involved.

There are two kinds of electron multipliers, single-stage multipliers and multistage multipliers. Single-stage multipliers have only one multiplying surface. The electrons striking it form the input and the secondary electrons leaving it form the output. Multistage multipliers have several multiplying surfaces, arranged so that the output of the first surface forms the input of the second, and so on, the output of the last surface forming the output of the multiplier as a whole. In the treatment of the noise in multipliers it is desirable to obtain expressions for noise in multistage multipliers as well as single-stage multipliers.

Work previously published has not rigorously distinguished between output noise caused by noise in the input and that due to the manner in which secondary electrons are produced, which may be ascribed to the properties of the secondary emitting surfaces. Moreover, results have been borrowed with more or less justification from previous work on shot effect.

It is the purpose of this paper to derive expressions for noise in secondary-emission multipliers, of both the single-stage and the multistage varieties, using only the most elementary assumptions and borrowing methods only, and not results, from previous work in other fields.

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* Decimal classification: R138. Original manuscript received by the Institute, July 8, 1937.

In discussing noise it is first necessary to define what we mean by noise, both in the electron stream which forms the input and in the output circuit of the multiplier.

It has been found most convenient to express all results in terms of currents, and to represent these currents expanded as a Fourier series over a period T which may be allowed to increase without limit without invalidating the final results.[1] The electron current arriving at the surface of a multiplier plate may thus be represented by

$$I_p = \sum_{n=-\infty}^{n=+\infty} a_n e^{in\omega t}, \qquad \omega = \frac{2\pi}{T}. \tag{1}$$

This series will have a direct-current component or average value denoted by $\overline{I_p}$ equal to the constant term of the series, and an alternating-current component which we shall regard as noise.

The series may be equally well written in the more familiar but somewhat more awkward form

$$I_p = \sum_{0}^{\infty} 2\left| a_n \right| \cos n(\omega t + \phi_n). \tag{2}$$

It is seen that the amplitude of the component of frequency $n\omega$ is $2|a_n|$, and the mean-square value of this component is

$$\overline{I_{n\omega}{}^2} = 2\left| a_n \right|^2.$$

By adding such terms[2] we may obtain the total mean-square value of the noise-current components in the frequency range $\Delta\omega$ from $n_1\omega$ to $n_2\omega$, which we may speak of as that between ω_1 and ω_2. This noise current will be

$$\overline{I_{\Delta\omega}{}^2} = \sum_{n_1}^{n_2} 2\left| a_n \right|^2 = 2\,\overline{\left| a_n \right|^2}\,T\Delta f \tag{3}$$

where $T\Delta f = n_2 - n_1$ and $\overline{|a_n|^2}$ is the average value of $|a_n|^2$ over the range.

It is of some importance to note that the current dealt with above is not a current flowing in a conducting circuit, but a current of electrons arriving at a multiplier plate, which is considered to consist of instantaneous pulses coinciding with the arrival of electrons at the surface of the plate. The same formal expressions can of course be used for currents in a circuit connecting plates between which electrons flow. This current flows only during the transit of electrons be-

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[1] If desired, the phenomenon may be regarded as periodic over a period T.

[2] Such cross terms as $(4|a_{n_1}|\ |a_{n_2}|)\cos(\omega n_1 t+\phi_1)\cos(\omega n_2+\phi_2)$ vanish in the time average.

tween the plates. It is shown in Appendix I that if the transit time is sufficiently small the expression obtained for the electron current leaving or arriving at one of two plates between which the electrons flow and the expression of the circuit current are identical.[3] Henceforward, such currents will not be distinguished except by special note.

In the Appendix the mean-square noise output current in frequency range Δf is evaluated for a generalized device, representing the multiplier, which has the following properties: 1. The device is linear in the sense that there is no interference between the effects of different input electrons. 2. Each electron entering the input has a probability $p(g)$ of producing g electrons at the output. 3. The output electrons appear simultaneously at a time t_0 after the input electron enters the device. ($p(g)$ and t_0 are the same for all input electrons.) The mean value of g, $\bar{g}$, represents the average multiplication of the device. The expression arrived at for the noise in the output secondary current is

$$\overline{I_{s\Delta f}{}^2} = \bar{g}^2\overline{I_{p\Delta f}{}^2} + 2e\overline{I_p}(\overline{g^2} - \bar{g}^2)\Delta f. \tag{4}$$

Here $\overline{I_p}$ is the average or direct-current component of the primary or input current, $\overline{g^2}$ is the mean-square value of g, the number of electrons leaving due to the arrival of an individual electron, and Δf is the width in cycles of the frequency band considered.

The expression is immediately applicable to single-stage multipliers, since according to our assumptions the arrival of an individual electron at a multiplier plate results in the emission of some number g of secondary electrons, which form the output. Here we shall interpret (4) in terms of the operation of a single-stage multiplier.

The expression shows a mean-square output noise current consisting of two numerically additive components. The first is the mean-square input noise current multiplied by the square of the mean multiplication. This is the component of output we would expect for any input amplified by the ratio $\bar{g} = \overline{I_s}/\overline{I_p}$.

The second component is a noise introduced because an individual primary electron may not produce exactly $\bar{g}$ secondaries, but 0, 1, 2, etc., up to a very large number. It can be seen that in case each primary did produce exactly $\bar{g}$ secondaries, $\overline{g^2}$ would be equal to $\bar{g}^2$ and the second term would be zero.

For a reasonable frequency range the expression is, as has been explained, valid for either the electron current leaving the multiplier

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[3] This current is to be considered as applied to the electrodes by an external current generator.

plate or for the current in a circuit connecting an anode which collects the electrons with the multiplier plate. Assuming such a circuit had a constant resistance R for all frequencies, this second term would predict an infinite dissipation of power in the circuit due to noise current, since the power dissipation in any frequency band Δf wide is finite and the range of possible frequencies is infinite. This infinite power dissipation is avoided because of the impossibility of having a pure resistance and because (4) is valid for current in the circuit only when the transit time of an electron from plate to collector is small in comparison with $1/f$. An examination of the derivation in the Appendix will show that as the transit time is indefinitely increased, increased phase changes during transit can reduce the circuit current of a given frequency to the vanishing point although the corresponding electron current leaving the multiplier plate remains unchanged.

For convenience it seems desirable to rewrite (4) when applied to the input and output of an individual multiplier plate in terms of new quantities defined below:

$m = \bar{g}$, average number of secondaries produced by one primary

$\delta^2 = \overline{g^2} - \bar{g}^2$, mean-square deviation of this number

$b = \dfrac{\delta^2}{m^2}$, relative mean-square deviation.

Equation (4) then becomes

$$\overline{I_{s\Delta f}^2} = m^2\overline{I_{p\Delta f}^2} + 2e\bar{I}_s mb\Delta f \tag{5}$$

where $\bar{I}_s = m\bar{I}_p$ is the direct-current secondary current. We may here note that except for the factor (mb), the second term is just the mean-square noise current to be expected for shot effect in the current $\bar{I}_s$. Thus the plate of a multipler multiplies the input noise to it like a signal and adds to this a noise equal to mb times the shot noise corresponding to the output current.

As (5) is valid for any single multiplier stage whose noise input is defined, we may easily derive the expression for a multistage multiplier by considering that the secondary electron current from one multiplier plate forms the primary electron current of the next. Carrying this treatment out for an n-stage multiplier, we obtain

$$\overline{I_{n\Delta f}^2} = M^2\overline{I_{1\Delta f}^2} + 2e\bar{I}_n M\left(b_1 + \frac{b_2}{m_1} + \cdots + \frac{b_n}{m_1 m_2 \cdots m_{n-1}}\right)\Delta f. \tag{6}$$

Here $\overline{I_n{}^2{}_{\Delta f}}$ is the noise current in the output of the nth stage, $\bar{I}_1$ is the average primary current, b_r and m_r refer to the rth stage, and $M = (m_1 m_2 \cdots m_n)$, the over-all multiplication.

The first term is, of course, merely the noise in the primary electron stream as amplified by the multiplier.

It is easy to see the genesis of each component of the second term. According to (5), each stage introduces a noise proportional to the average current leaving that stage and to the product mb for that stage. This noise will be multiplied by the subsequent action of the multiplier.

The rth component in term 2 of (6) multiplied by the common factor, is

$$2e\overline{I}_nM\frac{b_r}{m_1m_2\cdots m_{r-1}}\Delta f.$$

This may be rewritten

$$[2e\overline{I}_1m_1m_2\cdots m_r\Delta f][m_rb_r][m_{r+1}\cdots m_n]^2.$$

The quantity in the first brackets is the shot noise corresponding to the output from the rth plate. $[m_rb_r]$ is the modifying factor discussed above. The quantity in the third brackets is the multiplication for all subsequent stages.

If m and b are the same for all stages, the result given in (8) may be summed to give

$$\overline{I_{n\Delta f}^2} = M^2\overline{I_{1\Delta f}^2} + 2e\overline{I}_nM\frac{\left(1-\frac{1}{M}\right)}{\left(1-\frac{1}{m}\right)}b\Delta f. \tag{7}$$

It is seen that for a given multiplication M, the most important quantity in this expression is b. As has been explained, if each primary electron produced exactly m secondaries, b would be equal to zero, and the multiplier would in itself introduce no noise, but would only amplify that present in the input.

We may rewrite (6) in terms of a relative mean-square deviation for the multiplier as a whole

$$\overline{I_{n\Delta f}^2} = M^2\overline{I_{1\Delta f}^2} + 2e\overline{I}_1M^2B\Delta f \tag{8}$$

where, according to our formula,

$$B = \left(b_1 + \frac{b_2}{m_1} + \frac{b_3}{m_1m_2} + \cdots + \frac{b_n}{m_1\cdots m_{n-1}}\right). \tag{9}$$

This gives an expression for multistage multipliers analogous to (5) for single-stage multipliers. In this form the result might have been obtained immediately, since in a multistage multiplier a primary electron in the input results in the practically simultaneous production of some number, g, of electrons in the output, and hence (4) is applicable. The only difficulty lies in arriving at the value of B, the relative mean-square deviation for the multiplier as a whole, in terms of the relative mean-square deviation b for a single stage. A direct evaluation of B in terms of its components is discussed in Appendix II.

DISCUSSION OF PREVIOUS WORK AND EXPERIMENTAL RESULTS

Most writers treating noise in secondary-emission devices have assumed for b the value given by Poisson's formula. The assumptions underlying this formula are as follows: When an electron strikes the plate any number of electrons from zero to N (where N is very large) may be emitted. The probability that any particular one out of N be emitted is m/N. When N is allowed to go to infinity while m is held constant, the Poisson distribution is obtained. For this the probability that g electrons be emitted is

$$p(g) = \frac{m^g e^{-m}}{g!}.$$

Using this distribution one easily finds that

$$\bar{g} = m$$

$$\overline{g^2} = m^2 + m$$

$$b = 1/m \text{ or } bm = 1.$$

If this distribution is assumed, and if the noise in the input is considered to be that of shot effect, as is the case in currents arising from photoelectric emission, and from thermionic emission in the absence of space charge, then we obtain

$$\overline{I_{p\Delta f}^2} = 2e\overline{I_p}\Delta f.$$

For this case (7) reduces to

$$\overline{I_{n\Delta}^2} = 2eM^2\overline{I_p}\Delta f + 2e\overline{I_n}M\left(\frac{1-\frac{1}{M}}{1-\frac{1}{m}}\right)\frac{1}{m}\Delta f = 2e\overline{I_n}\left(\frac{Mm-1}{m-1}\right)\Delta f. \qquad (10)$$

This is just the expression obtained by Zworykin, Morton, and Malter[4] by assuming

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[4] V. K. Zworykin, G. A. Morton, L. Malter, "The secondary emission multiplier—a new electronic device," PROC. I.R.E., vol. 24, pp. 351–375; March, (1936).

"1. Shot noise from an emitter is multiplied by the subsequent stages in the same way in which an ordinary signal is multiplied.

"2. Secondary emission from a target is subject to shot noise such that

$$i_n^2 = 2eI\Delta f.\text{"}$$

Here I is the output current from the plate and Δf is the frequency band.

These assumptions amount to assuming the results of the present investigation, with a value of $b = 1/m$. The experimental data obtained by these writers check the theory to within a few per cent; however, the test is not as rigorous as might appear from their tables. The total output noise they obtained by experiment and calculation is largely due to amplified shot effect in the primary current. Here the fact that bm differs from unity would affect this total noise little, although it would affect the noise introduced by the multiplier considerably. Table I shows a compilation of Zworykin, Morton and Malter's results and a calculation of bm from the data given. In their work

$$K'/K = M\left[\frac{1-\frac{1}{M}}{1-\frac{1}{m}}\,\frac{1}{m}+1\right].$$

Thus their K'/K is equal to our $M(B+1)$. Their computed value of MB, denoted by MB', thus lacks a factor mb which appears in the measured value MB. Hence $MB/MB' = mb$.

TABLE I

VALUES COMPUTED FROM THE DATA OF ZWORYKIN, MORTON, AND MALTER

No. of Stages	M Total Multiplication	K'/K Meas. $=M(1+B)$	K'/K Comp. $=M(1+B')$	MB	MB'	$\frac{MB}{MB'}=bm$	m*
3	60	77	80	17	20	0.85	3.91
3	28	40	41	12	13	0.92	3.04
3	6.8	12.1	12.3	5.3	5.5	0.96	1.90
2	29.5	36.2	36.0	6.7	6.5	1.03	5.45
1	6	7.2	7.0	1.2	1.0	1.20	6.0

* In the absence of contradictory information, we assume m is the same for all stages.

It is seen that the critical quantity affecting noise introduced by multiplication bm which should be unity according to Zworykin, Morton, and Malter's assumptions, differs from unity by as much as 20 per cent.

M. Ziegler has attacked the problem of secondary-emission noise both theoretically and experimentally.[5] His theory agrees with ours but he considers only the case of shot effect in the primary current and one stage. His values of mb differ greatly from unity. Table II shows values in the present notation computed from Ziegler's data, the secondary emitting surface consisting of activated BaO and SrO.

TABLE II

VALUES COMPUTED FROM ZIEGLER'S DATA

Volts	50	100	200	300	400	500	600	700	800
m	1	1.6	2.6	3.4	3.9	4.3	4.6	4.9	5.2
b	0.88	0.69	0.59	0.60	0.64	0.72	0.82	0.92	1.0
$1/m$	1.	0.62	0.38	0.29	0.26	0.23	0.22	0.20	0.19
bm	0.88	1.1	1.5	2.0	2.5	3.1	3.8	4.5	5.2

It is seen that at low voltages the value of b is nearly $1/m$, as it is for a Poisson distribution but that for higher voltages the values deviate, showing a considerably greater spread than would be predicted on the basis of a Poisson distribution.

Theoretical work has also been carried out by Campbell.[6] His results are essentially in agreement with Ziegler's.

Experiments have been carried out by L. J. Hayner and B. Kurrelmeyer.[7] Their results show definitely that mb is not equal to unity. They are, however, able to correlate a large amount of data by assuming that the primary electrons may be divided into three fractions, x, y, and z. The fraction x is taken to represent reflected electrons, y "buried electrons" which produce no secondaries, z electrons which produce true secondary electrons—not reflected. For the fraction z they assume that $m_z b_z = 1$. These assumptions enable them to calculate the value of m_z from noise measurements of secondary emission and they have investigated the effect of primary voltage upon this basis.

CONCLUDING REMARKS

There are, of course, limitations in the analysis as presented. There are two effects which have been neglected and should be mentioned. First, it is evident that electrons of different energies are not equivalent and an electron of higher energy produces more secondaries on the average than one of low energy. If the distribution in energy of electrons emitted by a given plate is independent of the number emitted, this spread of energy can be combined with the properties of

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[5] M. Ziegler, *Physica*, vol. 1, p. 1; January, (1936), and vol. 3, p. 307; May, (1936). For comparison with Ziegler's notation we have $J = m$, $n\delta = M^2 (b+1)$.

[6] N. R. Campbell, *Proc. Camb. Phil. Soc.*, vol. 15, pp. 117, 310, and 513; October, (1909–1910); *Phil. Mag.*, vol. 50, p. 81, July, (1925).

[7] *Physics*, vol. 6, p. 323; (1935); *Phys. Rev.*, vol. 52, p. 952; November, (1937). The writers are indebted to Professor Kurrelmeyer for several valuable discussions upon secondary emission.

the next plate and the whole analysis carried through as before. Under these conditions the quantities b and m for a plate are to be determined when electrons of varying energy strike it. If, however, the average energy per electron is low when a large number are emitted and high when a few are emitted, then essential modification will be needed. It seems unlikely that corrections along these lines will be necessary; the energies of the secondaries will probably be small compared to the voltage between stages. For such conditions, all secondaries can be regarded as having the same energy.

Second, we have not considered the possibility of electrons missing a stage entirely and perhaps striking a later stage with several times normal energy. This can quite probably be worked out along the lines used in Appendix II but since there appeared to be no immediate need for the results, it has not been attacked.

APPENDIX I

Our problem is to expand the output current from the device described in the text in terms of its characteristics and the input current. Suppose that N electrons arrive at the device during the time interval T to constitute an input current I_p. Let the rth of these arrive at instant t_r and cause the simultaneous appearance of g_r electrons at the output. (Transit time down the multiplier will be considered later.) These may be considered as being collected by an anode which is connected to the device by an external circuit. Thus an electron current flows to the device, an electron current flows from the device to the anode, and a current flows in the circuit connecting the device and the anode. Either of these latter two currents may be in some cases considered as the output current of the multiplier.

Let us denote the pulse of output current due to the rth primary electron as I_r, and expand it in the form of a Fourier series, over a period T. (The final results are independent of the length of T as long as T is large compared with the reciprocal of the lowest frequency of interest.)

$$I_r = \sum_{n=-\infty}^{+\infty} b_{rn} e^{in\omega t}, \qquad \omega = 2\pi/T.$$

Then

$$b_{rn} = \frac{1}{T}\int_0^T I_r e^{-in\omega t} dt. \tag{A1}$$

Either of two cases may be considered.

If we are interested in the electron current leaving the device or arriving at the anode, we know that this is zero except for a pulse at the instant of departure or arrival of the electrons. Thus we may consider the exponential factor as constant during the integration and take it outside the integral.

If we are interested in the circuit current, we know that this flows only during the transit of the electron from the device to the anode. If the transit angle of the electron is large compared to π, the exponential factor will so alternate during the transit time as greatly to reduce the integral. However, for audio noise frequencies at least the transit angle is very small and we may regard the exponential as constant during the period the current is flowing, and take it out of the integral.

Thus, ordinarily, for either the case of the electron current or the circuit current we may say

$$b_{rn} = \frac{e^{-in\omega t_r}}{T}\int I_r dt = \frac{eg_r}{T}e^{-in\omega t_r}.$$

(over transit time)

The total current I due to all the electrons is given by[8]

$$I = \sum_{n=-\infty}^{+\infty} b_n e^{in\omega t} = \sum_{n=-\infty}^{+\infty}\ \sum_{r=1}^{N} b_{rn}e^{in\omega t}. \tag{A2}$$

The mean-square noise current in Δf is given by (3)

$$\overline{I_{s\Delta f}{}^2} = 2\,\overline{|b_n|^2}T\Delta f. \tag{A3}$$

In this

$$\begin{aligned} |b_n|^2 &= \frac{e^2}{T^2}\left[\sum_{r=1}^{N} g_r e^{-in\omega t_r}\right]\left[\sum_{s=1}^{N} g_s e^{+in\omega t_s}\right] \\ &= \frac{e^2}{T^2}\left[\sum_{r=1}^{N} g_r{}^2 + \sum_{r=1}^{N}\sum_{s=1}^{N} g_r g_2 e^{in\omega(t_s - t_r)}\right]. \end{aligned} \tag{A4}$$

with $r \neq s$

We are interested in the value of $|b_n|^2$ which corresponds to typical

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[8] Some doubts as to the rigor of dealing with expressions like (A2) and (A3) may reasonably arise at this point. Equation (A3) is obviously in a form designed for calculating power measured by some device due to fluctuations in the electron stream and it is somewhat unphysical to make power calculations upon the electron stream without reference to the measuring device. However it may be shown by a rigorous but rather tedious analysis that if the current defined by (A2) is applied to the calculation of power in any practical circuit and the averaging over the allowed transit instants and multiplications carried out correctly the result will be the same as would be obtained by calculating with the average value of (A3).

This result, that expressions like (A3) can be used for calculations of noise power, has been arrived at previously for the case of shot noise ($I^2\Delta f = 2eI\Delta f$) by T. C. Fry, *Jour. Frank. Inst.*, vol. 199, p. 203; February, (1925), who uses a very different method of attack.

The authors are indebted to Dr. Fry for showing them that the results of their analysis can be equally well obtained by using his method.

multiplication and transit instants. Hence we should average over allowed multiplications and transit instants. Consider the g_r first. Let the probability of obtaining value x for g_r be $p(x)$. Then the average of g_r is $\Sigma x\, p(x) \equiv \bar{g}$. The average of $g_r^2 = \Sigma x^2\, p(x) = \overline{g^2}$. Every electron has the same values for these two quantities. Hence averaging over the multiplications we get

$$
\begin{aligned}
|b_n|^2 &= \frac{e^2}{T^2}\left[N\overline{g^2} + \bar{g}^2 \sum_{\substack{r=1 \\ r \neq s}}^{N} \sum_{s=1}^{N} e^{in\omega(t_s - t_r)}\right] \\
&= \frac{e^2}{T^2}\left[N(\overline{g^2} - \bar{g}^2) + \bar{g}^2 \sum_{r=1}^{N} \sum_{s=1}^{N} e^{in\omega(t_s - t_r)}\right]. \qquad \text{(A5)}
\end{aligned}
$$

Before examining this further, consider the noise in the primary current. It is determined exactly as are the b_n's save with $g_r = 1$. From (A4) we get

$$
|a_n|^2 = \frac{e^2}{T^2}\left[\sum_{r=1}^{N} \sum_{s=1}^{N} e^{in\omega(t_s - t_r)}\right]. \qquad \text{(A6)}
$$

The second term of (A5) is merely $\overline{g^2}$ times this.

Hence the mean-square noise current in the secondaries is

$$
\begin{aligned}
\overline{I_{s\Delta f}^2} &= 2|b_n|^2 T\Delta f = 2\left(\frac{Ne}{T}\right) e(\overline{g^2} - \bar{g}^2)\Delta f + \bar{g}^2 2 |a_n|^2 T\Delta f \\
&= 2e\overline{I_p}(\overline{g^2} - \bar{g}^2)\Delta f + \bar{g}^2 \overline{I_{p\Delta f}^2}. \qquad \text{(A7)}
\end{aligned}
$$

We can check our method by setting $g = 1$ so that the multiplier has no effect at all on the current and then averaging over the t's independently. This corresponds to the case of random emission such as occurs in the shot effect. Averaging over the t's in (A6) we see that only the terms with $r = s$ contribute anything, and $|a_n|^2$ becomes $e^2N/T^2 = e\,\overline{I_p}/T$. Inserting this in (A7) we obtain $\overline{I_{s\Delta f}^2} = 2e\overline{I_{p}}\Delta f$, the well-known equation of the shot effect.

It is to be noted that for (A7) we have needed to make no assumptions about the precise nature of the primary noise. No matter what form it takes it appears multiplied by $\bar{g}^2$ in the output noise. Also the first term, noise due to multiplication, is independent of the nature of the input noise and depends only on direct input current and the multiplying process.

The formula is thus applicable to a multiplier as a whole or to any individual stage or group of stages.

We should also point out that the formula is applicable even if the transit time down a whole multiplier is large provided that it is the same for all electrons. Under these circumstances we shall have to distinguish between two transit instants, t_r the transit instant of primary, and $t_r'=t_r+t_0$, the transit instant of the secondaries in the output circuit. The addition term t_0 merely changes the phase of b_n without altering its magnitude and does not affect the value of the noise current. It must, however, remain true that the transit angle between the plates in the input or output circuits be small.

APPENDIX II

We shall show here that the formula for the over-all properties M and B can be obtained by statistics rather than by noise calculations. Suppose the multiplier consists of n plates which have values $m_1, \delta_1^2, b_1; m_2, \delta_2^2, b_2; \cdots; m_n, \delta_n^2, b_n$, for their characteristics. We wish to find the mean value $\bar{g}$, and mean-square value $\overline{g^2}$ of g, the number of secondaries leaving the nth plate due to the incidence of one electron on the first plate. Comparing (4) and (8) of the text we see that $M=\bar{g}$ and $B=(\overline{g^2}-\bar{g}^2)/M^2$.

Suppose one electron strikes the first plate. Then x_1 secondaries will be produced, where according to the definitions of m_1 and δ_1^2, we have

$$\overline{x_1} = m_1$$

$$\Delta_1^2 \equiv \overline{x_1^2} - \overline{x_1}^2 = \delta_1^2 .$$

Let us denote the multiplication of plate 2 by y_2 when there are x_1 incident electrons, the number of secondaries being x_1y_2. Then the values of $\overline{y_2}$ and $\overline{y_2^2}-\overline{y_2}^2$, which are m_2 and δ_2^2 for one incident electron, are (according to well-known statistical theorems) m_2 and δ_2/x_1, respectively. Hence, averaging first over y_2, since it depends on x_1, and then over x_1, we find

$$\begin{aligned}
\overline{x_2} &= \overline{x_1y_2} = \overline{x_1m_2} = m_1m_2 \\
\Delta_2^2 &= \overline{(x_1y_2)^2} - (m_1m_2)^2 = \overline{(x_1^2 - m_1^2)m_2^2} + \overline{x_1^2(y_2^2 - m_2^2)} \\
&= \overline{(x_1^2 - m_1^2)m_2^2} + \overline{x_1^2\delta_2^2/x_1} \\
&= \Delta_1^2m_2^2 + \overline{x_1}\delta_2^2 .
\end{aligned}$$

This result is obviously in the form of a recursion formula which can be applied successively up to the nth plate. Noting that by definition, $g=x_n$, we obtain

$$\begin{aligned}
M &= \bar{g} = \overline{x_n} = m_1m_2 \cdots m_n \\
M^2B &= \overline{g^2} - \bar{g}^2 = \Delta_n^2 = \delta_1^2(m_2m_3 \cdots m_n)^2 + m_1\delta_2^2(m_3 \cdots m_n)^2 \\
&\quad + m_1m_2\delta_3^2(m_4 \cdots m_n^2) + \cdots + (m_1 \cdots m_{n-1})\delta_n^2 .
\end{aligned}$$

Recalling that $\delta^2/m^2=b$, we see that these lead to (9).

Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

A NEW PRINCIPLE IN DIRECTIONAL ANTENNA DESIGN*

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Summary—*It is shown that in certain types of directional antenna arrays the gain can be increased by arranging so that waves going from the array elements in the direction of maximum transmission are* not *strictly in phase at large distances. Three examples are given, an end-fire array and two antennas designed to radiate, as far as possible, only in a horizontal plane. In the case of the end-fire array it is shown that readjustment of any existing antenna according to the ideas proposed here will increase the gain by about 1.8.*

The other two examples correspond to the kind of directivity generally desired in a broadcast antenna. One of these consists of short antennas placed in concentric rings. A typical array of this type containing 22 short antennas with the radius of the outer ring equal to 1.39λ has a gain of 2.31 as compared with 1.56 for a vertical half-wave antenna. The other example of a horizontally radiating array consists of a single ring of short antennas. An example of this type is calculated which has a gain of 2.0 with a total of 23 antennas placed in a circle with a radius of 1.43λ. These figures are not given as the best that can be done, but only as examples.

I. Introduction

IN DESIGNING a directional antenna array the aim is to arrange matters such that the total power radiated is a minimum while maintaining the intensity radiated in some direction or directions constant. Moreover, there are other requirements not to be formulated so definitely which may perhaps be included in the statement that the antenna and associated apparatus must not cost too much. Thus, for example, we must avoid designs that are too complicated or that gain their directivity at the expense of too large a decrease in radiation resistance.

This problem might be formulated as a problem in calculus of variations, though it would be enormously complicated if the economic factors were taken in with any pretense of exactitude and, even with simplifying assumptions as to the economic factors, the problem is still intractable in the sense that we cannot hope for an exact solution.

Nevertheless, the point of view is a good one and while not pretending to find the *best* design, i.e. the one corresponding to an absolute minimum, we will show that it is possible to improve considerably on present designs.

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* Decimal classification: R125. Original manuscript received by the Institute, October 4, 1937.

II. END-FIRE ARRAY

The end-fire array is chosen as the first example to be discussed as it involves less mathematics of an unfamiliar kind than the other examples to follow.

We start by assuming that the economic questions can be approximately handled by considering that arrays of equal length cost the same. This assumption is of course subject to verification when the array design is completed.

We make this assumption definite by agreeing to make the array a fixed length, say $2z_0$, and moreover we will for convenience take $2z_0 \gg \lambda$. Then the problem is to find that current distribution which will radiate the least power while keeping the field at some distant point in line with the array constant. Also, for mathematical convenience, we shall assume that we have a continuous line of antennas all so short as to act as dipoles. Then we will show later that practical approximations to such a continuous distribution give sensibly the same results provided the elements of the array are spaced about $\lambda/3$ or less.

As remarked above, an exact solution of the variation problem is beyond the writers' ability. Instead we shall assume some current distribution which depends on one or more parameters and find what choice of parameters gives the greatest gain. Of course, we can never be sure that by so doing we will find the *best* current distribution and in fact we are not so sanguine as to hope for such a thing. On the other hand, a good choice of trial functions suggested by a good understanding of the problem may lead to a considerable improvement over present designs.

As a trial current distribution we will take the dipoles on the axis to have moments proportional to $e^{ik'z}$ with the best value of k' to be determined. The ordinary end-fire array corresponds to $k' = k = 2\pi/\lambda$.

Then by standard methods and disregarding constant factors it is easily found that the field at some large fixed distance in θ direction ($\theta = 0$ being in the line of the array) is

$$E \sim \frac{\sin (k \cos \theta - k')z_0}{(k \cos \theta - k')z_0}. \tag{1}$$

Setting up the integral for the power radiated and imposing the condition that at $\theta = 0$ the field must be constant we find that we want to minimize the expression

$$\left(\frac{k - k'}{\sin (k - k')z_0}\right)^2 \int_0^\pi \left(\frac{\sin (k \cos \theta - k')z_0}{k \cos \theta - k'}\right)^2 \sin \theta d\theta \tag{2}$$

as a function of k'. The integrations are easily done in terms of Si integrals and we find that (2) is given by

$$\frac{1}{kz_0}\left(\frac{u}{\sin u}\right)^2\left(\frac{\pi}{2}+\frac{\cos 2u-1}{2u}+Si(2u)\right) \tag{3}$$

with

$$u = (k - k')z_0. \tag{4}$$

The function (3) multiplied by kz_0 is plotted in Fig. 1 and it is seen

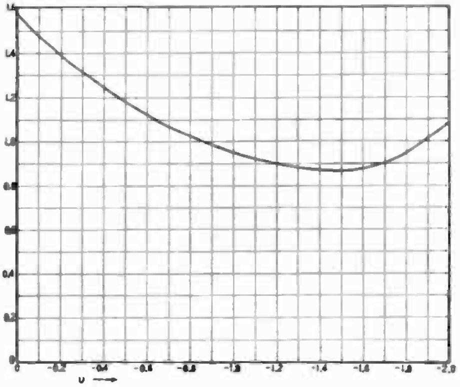

Fig. 1—Curve showing the variation with u of the power radiated from an end-fire array producing a constant signal in the desired direction. The value $u=0$ corresponds to the conventional design.

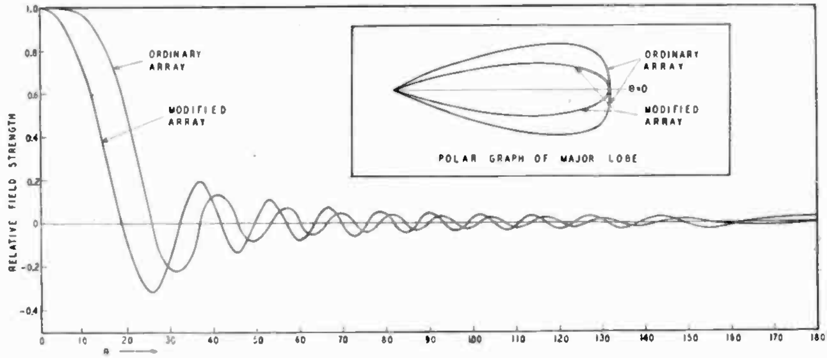

Fig. 2—Graphs showing field strength as a function of angle for normal and modified end-fire arrays, both being 10λ long. To avoid confusion the minor lobes have been omitted from the polar graph.

that the optimum value of k' is specified by $u=-1.47$ and that this value gives a power requirement of 0.55 times that corresponding to $k'=k$ which is the usual practice. The value $u=-1.47$ corresponds approximately to having the number of half waves of current along the array about one greater than the number of times a half wavelength is contained in the array length. In Fig. 2 we have plotted the field strength as a function of angle for an antenna 10 wavelengths long both for $u=0$ and $u=-1.47$.

The merit of an array is often measured by a number called the gain, which is the ratio of the power radiated by a dipole to the power radiated by the array in question when both are producing the same signal in the desired direction. For the end-fire array under discussion (3) gives

$$\text{gain} \simeq 4.83\,\frac{2z_0}{\lambda}\,. \tag{5}$$

This expression is only strictly valid for $1 \ll 2z_0/\lambda$ but will be found to be satisfactory in most practical cases.

The above figures are for a continuous distribution of dipoles. However, if, as has been assumed, the array is several wavelengths long, replacing the dipoles by antennas of height $\lambda/4$ or less will make no noticeable change. Finally it is well known that if the array elements are not separated by more than about $\lambda/3$ the effect is much the same as if a continuous distribution of antennas were used.

The only disadvantage of this array that has occurred to us is that the radiation in the preferred direction is not quite as strong as that from a conventional end-fire array with the same current in the antennas. To get the same field strength the array here proposed would need a current about 1.48 times that of the conventional array.

III. AN ARRAY WITH STRONG VERTICAL DIRECTIVITY AND NO HORIZONTAL DIRECTIVITY

Arrays of this type are easily devised provided one allows the use of radiating elements one wavelength or more high. In the region of broadcast wavelengths, however, this involves rather expensive structures and one wonders whether an array with satisfactory directional properties can be made without the use of radiators extending a considerable distance from the ground. In fact, at least one such array has already been suggested.[1] In this section we show how to devise a more or less infinite number more. Moreover one group of these arrays will be discussed in some detail in this section; another group will be studied in the following section.

For the purpose of inventing such arrays it is convenient to make use of a theory of antenna radiation as developed by one of the au-

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[1] F. E. Terman, "Radio Engineering," second edition, p. 678, McGraw-Hill Book Co.

thors.[2] Using various equations in the references cited, and disregarding constant factors, it is easily found that at a large distance from the antenna the field is proportional to[3]

$$E_\theta \sim \sum_n i^{-(n+1)} e^{in\phi} \frac{1}{\sin\theta} \int \bar{A}_{3,n} \cdot \mathbf{i} \, d\tau \qquad (6)$$

with

$$A_{3,n} = e^{i(kz\cos\theta + n\phi)} \left[\mathbf{k}_\rho i \cos\theta \frac{d}{d\rho} J_n(k\rho\sin\theta) - \mathbf{k}_\phi \frac{n\cos\theta}{\rho} J_n(k\rho\sin\theta) \right.$$
$$\left. + \mathbf{k}_z k \sin^2\theta J_n(k\rho\sin\theta) \right]. \qquad (7)$$

The notation is as follows:

ρ, ϕ, z are cylindrical co-ordinates with origin at the surface of the ground and with the z axis perpendicular thereto.

$\mathbf{k}_\rho$, $\mathbf{k}_\phi$, $\mathbf{k}_z$ are unit vectors in the ρ, ϕ, and z directions.

θ is the angle between the vertical and the line from the origin to the point at which the field is desired.

$d\tau = \rho d\rho d\phi dz$

$\mathbf{i}$ is the current density

$i = \sqrt{-1}$

Note: **Bold-face** type is used for vectors.

Only the vertically polarized component has been retained in (6).

Now let us suppose that all array elements are vertical. Then the ρ and ϕ components of A do not matter. Also, as promised above, let us take the height of the antenna to be small: thus $kz \ll 1$.

$$E_\theta \sim \sum_n i^{-(n+1)} \sin\theta \, e^{in\phi} \int \mathbf{i}_z(\rho, \phi) J_n(k\rho\sin\theta) e^{-in\phi} \rho d\rho d\phi. \qquad (8)$$

The first thing to observe is that if uniform horizontal coverage is desired, i.e., the time average of the field is to be independent of ϕ, then all but one of the terms in (8) must be substantially zero. If we

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[2] W. W. Hansen and J. G. Beckerley, "Concerning new methods of calculating radiation resistance, either with or without ground," Proc. I.R.E., vol. 24, pp. 1594–1621; December, (1936);
W. W. Hansen, "Directional characteristics of any antenna over a plane earth," *Physics*, vol. 7, p. 460; December, (1936).
W. W. Hansen, "A new type of expansion in radiation problems," *Phys. Rev.*, vol. 47, p. 139; January 15, (1935).
W. W. Hansen and J. G. Beckerley, "Radiation from an antenna over a plane earth of arbitrary characteristics," *Physics*, vol. 7, p. 220; June, (1936).
W. W. Hansen, "Transformations useful in certain antenna calculations," *Jour. App. Phys.*, vol. 8, p. 282; April, (1937).

[3] This follows from equation (18) of the second reference and (12) of the third.

wish the nonzero term to be the nth one we can accomplish this by having i be $e^{in\phi}$ times some function of ρ. It will be supposed for the moment that all terms but one have been suppressed in this way. Later, we shall have to investigate how well this assumption can be fulfilled when instead of a continuous distribution of antennas we have some practical approximation thereto.

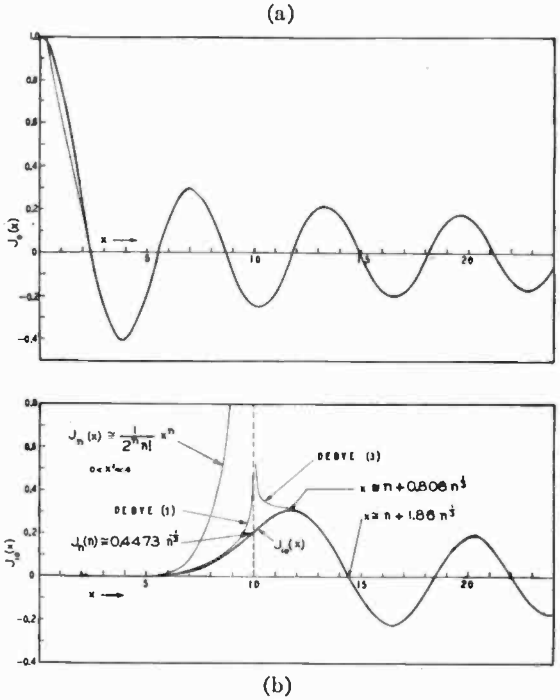

Fig. 3

(a) The heavy line is a plot of $J_0(x)$ as a function of x. The light line shows the approximation $J_0(x) \cong \sqrt{2/\pi x} \cos(x - \pi/4)$ which is good when x is large.

(b) Plot of $J_{10}(x)$ as a function of x. Also plotted are various approximations for $J_n(x)$. The two curves labeled Debye (1) and Debye (3) are graphs of the functions

$$(1) \qquad J_n\left(\frac{n}{\cosh \tau}\right) \cong \sqrt{\frac{1}{2\pi n \tanh \tau}}\, e^{n(\tanh \tau - \tau)}, \quad \sqrt{n^2 - x^2} \gg 1$$

$$(3) \quad J_n\left(\frac{n}{\cos \tau}\right) \cong \sqrt{\frac{2}{\tau n \tan \tau}} \cos\left(n \tan \tau - n\tau - \frac{\pi}{4}\right), \quad \sqrt{x^2 - n^2} \gg 1.$$

There exists a third Debye expansion valid when $x \cong n$ but this has been omitted. Also not shown is the approximation used in Fig. 3(a); namely,

$$J_n(x) \cong \sqrt{\frac{2}{\pi x}} \cos\left(x - \frac{2n+1}{4}\pi\right), \quad \frac{n^2}{2} \ll x.$$

This has been omitted because it is not a useful approximation to $J_{10}(x)$ when x is below 100 or so.

Having saved just one term of (8) and so made E independent of ϕ we now inquire how we can make E finite at $\theta=\pi/2$ and nearly zero elsewhere. For progress in this direction a knowledge of the general behavior of Bessel functions is needed. To refresh the reader's memory, Figs. 3(a) and 3(b) give plots of $J_0(x)$ and $J_{10}(x)$ together with various approximation formulas. One method is now plain. If we choose to use the nth term of (8) we can make i as a function of ρ vary about like $J_n(k\rho)$. Then when $\theta=\pi/2$, $\sin\theta=1$, the integrand in (8) will always be positive. But when θ differs greatly from $\pi/2$ the current and $J_n(k\rho\sin\theta)$ will have sometimes the same sign and sometimes the opposite and more or less complete cancellation will result. This idea may be rendered more precise by noting that

$$\int_0^\infty xJ_n(\alpha x)J_n(x)dx = \tfrac{1}{2}\delta(1-\alpha) \tag{9}$$

where $\delta(1-\alpha)$ is a function of $1-\alpha$, that is, zero when $\alpha\neq 1$ and infinite at $\alpha=1$ in such a way that the integral of $\delta(1-\alpha)d\alpha$ is unity.

Thus if we had $i\sim k_z e^{in\phi}k\rho J_n(k\rho)$ and this current distribution extended to $k\rho\to\infty$ we would get E finite at $\theta=\pi/2$ and zero elsewhere. Such an infinite antenna is not possible but one might reasonably expect that cutting off the current at some finite radius would give the same general result and this is in fact true.

Now it would be desirable to investigate the gains obtainable as a function both of the radius of the circle occupied by the antennas and of the order of the Bessel function used. However, we have not succeeded in solving this problem analytically and a numerical attack seems hardly worth while. We have therefore been satisfied with an analytic investigation of the gain as a function of antenna size for J_0 and certain special results for higher-order Bessel functions.

We consider then a current distribution consisting of dipoles oriented in the z direction and with strength $\rho J_0(k\rho)$ up to some radius and zero elsewhere. Then it is readily found that if the radius of the array is considerably larger than λ, the field near $\theta=\pi/2$ is given approximately by

$$E_\theta \sim \tan\theta\,\frac{\sin\left((1-\sin\theta)(k\rho_0-\pi/4)\right)}{\cos\theta} \tag{10}$$

where ρ_0 is the radius of the array and is chosen subject to the restriction that $k\rho_0=(m-1/4)\pi$, with m an integer. Using this approximate expression for E we can easily find the gain,

$$\text{gain} \simeq 0.707\sqrt{m-1/2}. \tag{11}$$

Remembering our experience with the end-fire array we surmise that distributing the dipoles according to $\rho J_0(k'\rho)$ might be better. This is true and it is found by some numerical work that if k' is determined by

$$\frac{k' - k}{k}\left(k\rho_0 - \frac{\pi}{4}\right) = 1.8 \tag{12}$$

then the gain is

$$\text{gain} \simeq 1.17\sqrt{m - 1/2}. \tag{13}$$

How many antennas will be needed to approximate the assumed distribution satisfactorily is the next, and somewhat tedious, question. Going in the ρ direction one ring of antennas per loop of the Bessel function is plainly sufficient. How many antennas are to be in each ring is a harder question. In a general way there must be a large enough number to keep higher-order J_n from appearing with appreciable coefficients in the expression for the field. To a very rough approximation this will be avoided if the number of antennas per ring exceeds $k\rho_0$. However, because of the rapid decrease of high-order Bessel functions on going toward $k\rho = 0$ it is not necessary that the inner rings have as many antennas as the outer. Any real solution of this problem will involve a knowledge of just how much horizontal directivity can be tolerated and will also require some cut-and-try work. As an example of the general form such a solution would take we have prepared Fig. 4 which shows a possible array with $m = 4$ which gives for the coefficients of the first few J_n the following: 1.00, 0, 0, 0, 0.17, 0, 0, 0.19, 0, 0, 0.17, gives a gain of 2.31, and does not use an impossible number of antennas.[4] By a

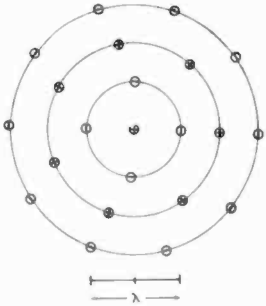

Fig. 4—Top view of multiple-ring array with $n = 0$, $m = 4$. Circles are at $k\rho$ values 0, 3.29, 6.02, 8.73 with relative currents per antenna 1, 0.50, 0.41, and 0.36. Gain = 2.31. Circles represent array elements, those with a + inside have the current flowing 180 degrees out of phase with that in the antennas labeled −.

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[4] It must be remembered that comparatively short antennas may be used. We had thought, for example, of using wooden poles like those used for power distribution which should be quite cheap by comparison with, say, a half-wave unguyed tower.

slight increase in the number of antennas the coefficients of the higher J can be greatly reduced.

It will be observed in the above case that the number of array elements in any ring is about equal to the $k\rho$ value of the ring plus one or two. This will be true in general and in consequence the total number of elements in such an array will, in the limit of large m, be a quadratic function of m. Thus the number of elements rises rapidly with m (like m^2) while the gain increases with $\sqrt{m-1/2}$.

IV. SECOND TYPE OF ARRAY TO RADIATE UNIFORMLY IN A HORIZONTAL DIRECTION

Instead of having the array extend over a number of waves of the Bessel function as in the preceding section, it is possible to get the desired directivity by putting a ring of antennas at a $k\rho$ value smaller than that corresponding to the first maximum of the Bessel function chosen.

To see how well this will work let us choose a current distribution purely for analytic convenience; namely, let there be a continuous ring of dipoles of strength $e^{in\phi}$ at a radius such that $(k\rho)^2 \ll 4$. Then J_n in the integral of (8) may be sufficiently well approximated by x^n and we find $\boldsymbol{E}_\theta \sim \sin^{n+1}\theta \, e^{in\phi}$ and from this the gain is found

$$\text{gain} = \frac{\int_0^{\pi/2} \sin^3 \theta d\theta}{\int_0^{\pi/2} \sin^{2n+3} \theta d\theta} = \frac{2}{3} \cdot \frac{1 \cdot 3 \cdot 5 \cdots (2n+3)}{2 \cdot 4 \cdots (2n+2)} \tag{14}$$

and for large values of n this is well approximated as

$$\text{gain} \cong \frac{4}{3\sqrt{\pi}} \sqrt{n+3/2} = 0.752\sqrt{n+3/2}. \tag{15}$$

For example for $n=1$ the approximation is good to five per cent and it gets better with increasing n. Besides this purely mathematical approximation we may recall that (15) depends on the assumption of a continuous ring of short antennas at radius $(k\rho)^2 \ll 4$. In Fig. 5 we have plotted the gain as a function of n and in Fig. 6 we have shown a directional pattern for $n=5$. It may be noticed that unlike any previous array known to the authors, this array produces a field that is a monotonically decreasing function of angle away from the optimum direction. In other words there are no minor lobes.

We may note in passing that this array and the two previously discussed have one feature in common; namely, that the antennas are not so placed and so phased as to make the effects add as well as possible in the preferred direction.

We consider now how such a current distribution is to be approximated in practice and how the performance of such a practical realization will compare with the results above.

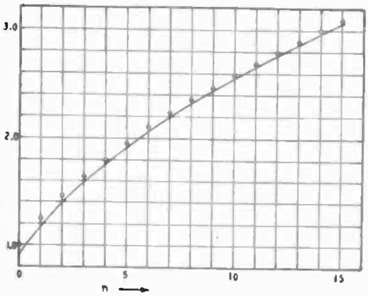

Fig. 5—Gain of a single ring of antennas, very near to the origin, as a function of n. Points are exact values, the curve is computed from the approximate equation (15).

The radius chosen for the ring will be some practical compromise between the following two conflicting requirements. First, the smaller the radius the more rapidly the Bessel function will decrease with decreasing argument and so the better the directivity. Second, the larger the radius the larger the radiation, for a given current in the elements, and so the less important the ground losses.

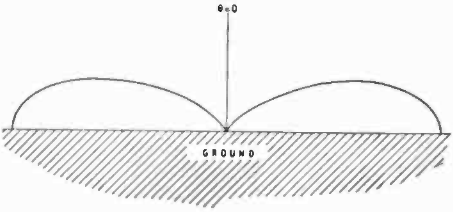

Fig. 6—Field produced by a single-ring array $n=5$, $k\rho \ll 2$.

To aid in selecting a good compromise we have prepared Figs. 7, 8 and 9.

Fig. 7 shows, for the special case $n=10$, how the directional pattern is changed by changing the radius of the ring.

From curves like those of Fig. 7 one could find, by numerical integration, the exact value of gain for any desired values of n and $k\rho$. This would be a lot of work, however, and so we have used an approximate method which works well within a limited range. We assumed that, for $0<k\rho<n$, J_n could be approximated by a single power of $k\rho$, with the power chosen to give the best fit at a $k\rho$ value corresponding to the antenna position. Then we used the approximate formula (15) and so constructed Fig. 8, which shows gain as a function of $k\rho$ for a

number of values of n. We may note that both approximations are wrong in the same direction so that the curves of Fig. 8 always underestimate the gain.

More exact values of the gain may be wanted or one might want the gain in the region above $k\rho = n$. If so, numerical integration can be used.

Another method that is perhaps easier is to work the problem in spherical co-ordinates using (4) and (5) of the first paper cited in footnote 2. It will be found that the gain comes out as a ratio of two series which converge very rapidly. Unfortunately the individual terms are some bother to compute as they involve $P_l^n(\theta = \pi/2)$, $\partial P_l^m/\partial\theta$, and $J_{l+1/2}$, functions which are not too well tabulated, especially for the high values of l and n likely to be needed in the present application. The following formulas, however, eliminate part of this trouble.

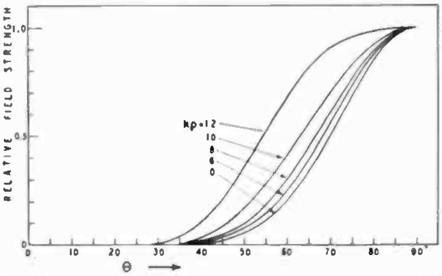

Fig. 7—Fields produced by single-ring arrays with $n = 10$, $k\rho = 12, 10, 8, 6, 0$.

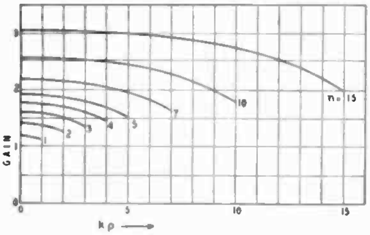

Fig. 8—Approximate values of the gain for single-ring arrays for various values of n and $k\rho$. The curves always underestimate the gain and the error becomes larger with increasing $k\rho/n$.

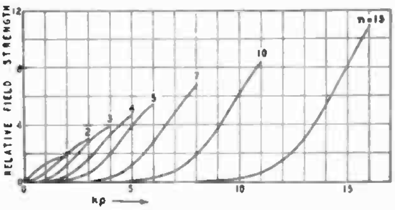

Fig. 9—Field at $\theta = \pi/2$ produced by a ring of $3n$ radiators measured in units of the field that would be produced by an isolated radiator.

$$P_l^n(\theta = \pi/2) = \frac{(l+n)!}{2^l\left(\frac{l-n}{2}\right)!\left(\frac{l+n}{2}\right)!}(-1)^{(l-n)/2}$$

$$l - n \text{ even,}$$

$$= 0, \qquad l - n \text{ odd}$$

$$\frac{\partial}{\partial\theta}P_l^n\left(\theta=\frac{\pi}{2}\right)=\frac{(l+n)!}{2^{l-1}\left(\frac{l-n-1}{2}\right)!\left(\frac{l+n-1}{2}\right)!n!}(-1)^{(l-n+1)/2} \tag{16}$$

$$l-n \text{ odd} \tag{17}$$

$$=0, \qquad l-n \text{ even.}$$

However, we have not thought it worth while at present to extend the curves of Fig. 8 into the region where calculation by one or other of the above methods is needed.

Together with Fig. 8 we need Fig. 9, which gives data from which the relative effectiveness of the array as a radiator can be found. These curves assume $3n$ radiators[5], short compared to $\lambda/4$, and give the field strength produced by the array, divided by the field strength that would be produced by a single radiator acting alone. For example if we use $n=5$ and put a ring of 15 short antennas at $k\rho=5$ ($\rho=0.795\lambda$) the field at a large distance at angle $\theta=\pi/2$ will be 3.91 times that produced by a single antenna working alone.

We now consider how many antennas must be in the ring for any given n. We first note that a ring of, say, m dipoles may be considered as built up of a sum of continuous dipole distributions, the proper sum being the summation over l of

$$e^{in\phi}\sum_{-\infty}^{+\infty}e^{ilm\phi}. \tag{18}$$

Then by reference to (8) we see that the ratio of the coefficient of the desired term in $e^{in\phi}$ to the first unwanted term which is $e^{i(n-m)\phi}$ is just $J_n/J_{|n-m|}$. Thus m must be bigger than $2n$. Just how much depends on how much variation of field with ϕ can be tolerated and is to be determined when this and the other general features of the array design are known. A value $m=3n$ is always more than enough and something of the order of magnitude $2n+3$ is perhaps the minimum tolerable. For example the antenna mentioned above with $n=5$, $k\rho=5$ gives a ratio of maximum field strength to minimum of 3.02 for 11 antennas in the ring, 1.51 for 12, 1.15 for 13, 1.04 for 14, and 1.01 for 15.

Thus the total number of elements in a single-ring J_n array is a more or less linear function of n, while the gain goes with $\sqrt{n+3/2}$. Numerical trial shows that with about 20 array elements the multiple-ring J_0 antenna gets better gain than the single-ring J_n antenna. It follows that if the total number of antennas is the important factor economi-

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[5] See later where it is shown that $3n$ radiators is enough to give very uniform horizontal coverage. If fewer antennas are used the field can be found by direct proportion.

cally the J_0 antenna will be best for low gains and the J_n for high. The transition point depends on the uniformity of coverage in the ϕ direction and other things.

V. FURTHER POSSIBILITIES

It is plain that there are an infinite number of possible arrays with vertical directivity not here explored. For example one might distribute dipoles with density $\rho J_2(k\rho)e^{i2\phi}$ and let ρ go to values large enough so that J_2 will go through several maxima and minima, say three. In fact the antenna suggested by Terman[1] is of approximately this type.

In addition to these the present methods might well be applied to the design of arrays with different directivity characteristics than those here considered. For example, it would be easy to make an array that would direct the radiation along the ground like the last two described and would also confine the radiation between specified values of the angle ϕ. Such an antenna might be useful, for example, to broadcast stations near a seacoast. Another array on which we have done some figuring involves two groups of antennas with arrangements made for disconnecting one group when desired. In the daytime one group only is used and the design is such that the radiation is confined to angles close to the ground. At night both groups of antennas are used and, in addition to the ground wave, a sky wave is radiated. Moreover, there is a zero of intensity between the radiation going upward and that going along the ground, and one may hope that, if the radiation pattern is chosen correctly, the radiation directed upward will be reflected from the Heaviside layer and add service area without coming down where the ground wave is of comparable intensity and spoiling service by introducing fading.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

EXCESS-ENERGY ELECTRONS AND ELECTRON MOTION IN HIGH-VACUUM TUBES*

By

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Summary—*In the development of magnetron oscillators, one of the principal difficulties has been the overheating of the cathode. The present article discusses an effect which is at least partially responsible for this, and which consists in the gaining of excess energy by some electrons, which then bombard the cathode. The effect is of importance also because of its bearing on transit time, orbit shape, tube noise, shape of cutoff curve, etc.*

Experimental results indicate that a Maxwellian distribution of velocities is superimposed on the orbital velocities, the energy of the random motion being derived from the orbital motion. This leads to the formation of a new type of virtual cathode about the real cathode. The properties of this type of cathode are discussed.

Subjects related only indirectly to cathode overheating, but necessary to its understanding, also are discussed, such as current flow and space-charge phenomena for cases in which electrons execute cyclic orbits. Extensive experimental data are included.

Introduction

THE overheating of the cathode in magnetrons, which occurs to some extent at all times during operation, but becomes especially troublesome at high plate voltages, has been one of the principal difficulties in the development of a satisfactory oscillator of this type. The present article is an outgrowth of a study of this effect, undertaken as a part of a development program of centimeter-wave oscillators. The work broadened out somewhat as it progressed, to include subjects related only indirectly to cathode overheating, since it became evident that cathode overheating, and magnetron behavior in general, involved some concepts not associated with more common types of vacuum tubes. For example, no detailed discussion seems previously to have been given of current and space-charge phenomena for the case in which electrons execute cyclic orbits, as in magnetrons and positive-grid tubes. It is clear that current and space charge must be vitally affected by the fact that the direction of motion of an electron may reverse many times. This reversal gives rise to such concepts as "returning current," and "number of electron oscillations." As a further example, it has been found that electrons in such tubes inter-

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* Decimal classification: R138. Original manuscript received by the Institute, June 3, 1937. Presented before American Physical Society meeting, Washington D. C., April 30–May 2, 1936. Abstract published in *Phys. Rev.*, June 1, (1936).

act so that energy exchanges occur, resulting in a Maxwellian distribution of velocities superimposed on the orbital motion. This has led to the application of the technique and terminology developed by Langmuir for the investigation of gaseous electrical discharges by probe electrodes, to the electron swarms occurring in electron-transit-time oscillators.

Any adequate treatment of magnetron or positive-grid-tube electronics must necessarily involve ideas and terms foreign to conventional tube theory. An attempt has been made in this article to state these concepts in mathematical terms appropriate to the discussion of short-wave oscillators. Extensive experimental tests have been carried out and checks of the theory made wherever possible.

The first observation of excess-energy electrons was made several years ago. In 1925 Irving Langmuir[1] observed that in certain types of high-vacuum tubes some electrons possessed the ability to pass to an electrode having a more negative potential than the cathode from which they originated. Several types of tubes were used. In one the anode consisted of a few small-sized wires close to, and paralleling, the cathode. A surrounding cylindrical electrode was negatively charged with respect to the cathode. An electron current was observed to flow to this cylinder in spite of its negative potential. Another tube was of the cylindrical magnetron type, having negatively charged end plates. A magnetic field was applied parallel to the filament, of such strength that an electron, influenced only by it and the electrostatic field, would be unable to reach the plate. In this case small electron currents flowed to the cylinder in spite of the magnetic field, and to the end plates even when they were twenty to fifty volts negative with respect to the cathode. The effect appeared not to be due to oscillations since they rarely could be detected. Langmuir showed that the electrons appeared to have a Maxwellian distribution of velocities, the temperature of which was proportional to the anode voltage.

More recently similar phenomena have been observed by several other investigators, but the true nature of the effect has not always been recognized. These recent observations have resulted from the large amount of work which has been done during the last few years on magnetron oscillator tubes for the generation of ultra-short electromagnetic waves. E. C. S. Megaw[2] noticed that the filaments of such tubes underwent electronic bombardment of sufficient intensity to cause a visible increase in brightness. However he attributed the effect

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[1] I. Langmuir, "Scattering of electrons in ionized gases," *Phys. Rev.*, vol. 26, p. 585; November, (1925).

[2] E. C. S. Megaw, "Cathode secondary emission: A new effect in thermionic valves at a very short wave length," *Nature*, vol. 132, p. 854; December, (1933).

entirely to oscillations. Slutzkin, Leljakow, and Kopilowitsch[3] observed a similar heating of magnetron filaments, but attributed it to thermal radiation from the hot plate of the tube. Later investigations by Slutzkin, Braude, and Wigdortschik[4] led to the conclusion that the effect was caused by oscillations. E. Pierret, and C. Biguenet[5] attributed it to oscillations. G. R. Kilgore[6] recognized filament bombardment as the cause of the effect, but offered no explanation. O. Pfetscher and W. Puhlmann[7] concluded that the bombardment was induced by oscillations. Two papers by I. M. Wigdortschik[8] have very recently appeared in which experiments similar to those of Langmuir are described. Evidence for a Maxwellian distribution is given, but no explanation is offered. The writer has mentioned the effect in several previous publications.[9,10,11,12]

In the cases of Pfetscher and Puhlmann, and also Megaw, definite proof has been given indicating that oscillations may cause, or augment, electron bombardment of the cathode. However, there is ample evidence that a similar effect can occur also in the absence of oscillations. The writer has observed, in the case of magnetron oscillators for nine-centimeter waves, that very marked bombardment occurs, when the tube is oscillating, but when the oscillations are stopped, considerable bombardment persists, and in some cases is even greater than during oscillation.

When gas is present in sufficient quantity, bombardment by positive ions also may occur. The intensity of this type of bombardment

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[3] Slutzkin, Leljakow, and Kopilowitsch, "Factors influencing the output and efficiency of magnetron oscillators," *Phys. Zeit. der Sowjetunion*, vol. 5, p. 887, (1934).

[4] A. A. Slutzkin, S. J. Braude, and I. M. Wigdortschik, "Production of an ion current in high vacuum by means of a magnetic field," *Phys. Zeit. der Sowjetunion*, vol. 6, p. 268, (1934).

[5] E. Pierret and C. Biguenet, "On the ultra-short waves obtained with a magnetron," *Jour. de Phys. et le Radium*, vol. 6, p. 67; April, (1935).

[6] G. R. Kilgore, "Magnetron oscillators for the generation of frequencies between 300 and 600 megacycles," Proc. I.R.E., vol. 24, pp. 1140–1157; August, (1936).

[7] O. Pfetscher, and W. Puhlmann, "Über Habann-Generatoren grosser Leistung für Ultrakurzwellen," *Hochfrequenz. und Elektroakustik*, vol. 47, p. 105; April, (1936).

[8] I. M. Wigdortschik, "Die Geschwindigkeitsverteilung der Elektronen unter dem Einfluss eines Magnetischen Feldes im Hochvakuum," *Phys. Zeit. der Sowjetunion*, vol. 10, p. 245, (1936), and "A study of the surplus heating of a cathode in a magnetron," vol. 10, p. 634, (1936).

[9] E. G. Linder, "Improved magnetron oscillator for the generation of microwaves," *Phys. Rev.*, vol. 45, p. 656; May, (1934).

[10] I. Wolff, E. G. Linder, and R. A. Braden, "Transmission and reception of centimeter waves," Proc. I.R.E., vol. 23, pp. 11–23; January, (1935).

[11] E. G. Linder, "Excess energy electrons in high vacuum tubes," *Phys. Rev.*, vol. 49, p. 860; June 1, (1936). (Abstract.)

[12] E. G. Linder, "Description and characteristics of the end-plate magnetron," Proc. I.R.E., vol. 24, pp. 633–653; April, (1936).

depends upon the amount of gas present. In the work described here it was negligible, as will be shown later.

The existence of these three different types of bombardment, i.e., (1) that due to oscillations, (2) that due to positive ions, and (3) that due to the effect discussed in this paper (scattering), is no doubt largely responsible for the divergent opinions among different investigators, and the apparent inconsistency of some previous results. The present paper will deal only with the third type of bombardment, the first two being considered comparatively well-known and understood phenomena.

No previous investigators appear to have studied the effect in very great detail. Langmuir's work seems to have been the most comprehensive, but his published account is brief, and no data are given. A small amount of data appear in the articles by Megaw, Pfetscher and Puhlmann, Wigdortschik, and the writer.

CURRENT FLOW AND SPACE CHARGE IN A MAGNETRON

The present discussion will be confined to magnetrons. Much of it obviously will be directly applicable to tubes of the positive-grid type, but no attempt will be made to point this out or discuss it in this paper. We shall consider first a simple tube consisting of a cylindrical plate *P*, Fig. 1, and a concentric filamentary cathode *C*, mounted within an evacuated envelope. A uniform magnetic field is applied normal to the plane of the figure.

In the absence of a magnetic field, electrons emitted by the cathode travel along radial paths to the plate. If a weak field is applied these paths become curved. At a certain value of field, known as the "critical" magnetic field, the curvature becomes so great that electrons are unable to reach the plate, and after approaching it closely, return again toward the cathode as shown by *T*. Further increase in magnetic field strength causes a contraction of the dimensions of this path but no essential change in its shape until the path dimensions become comparable with the cathode diameter. The latter case will not be considered here. The path *T* represents that of an undisturbed electron. It will be shown later that disturbances modify electron paths, especially near the cathode. However, the theory discussed in this section is independent of path shape, it being assumed only that electrons return periodically to the neighborhood of the cathode.

When the magnetic field exceeds the critical value, so that electrons are unable to reach the plate, the plate current is said to be "cut off." It is under this circumstance that excess-energy electrons appear. The conditions which then exist in the tube are of considerable interest, and importance.

The simplest case is that in which each electron traverses a path such as T but once, and is then recaptured by the cathode. The current I_f emitted by the cathode is then equal to the returning current I_r. The net current is zero. If electrons are emitted at the constant rate dN/dt, and if τ is the time required for one complete traversal of the path T, or radial oscillation, the number of electrons contained within the interelectrode space at any instant will be

$$N = \tau \frac{dN}{dt} \cdot \tag{1}$$

The case in which the electrons make on the average but one radial oscillation before returning to the cathode probably seldom actually occurs. Measurements made by the writer indicate that the average number of oscillations is of the order of one hundred in the tubes used in the present work. Furthermore some current always flows to the plate in spite of the magnetic field. (This will be discussed later.) Equation (1) must therefore be modified.

Assume that dN electrons are emitted in an interval of time dt short in comparison with the transit time τ. In general during any one oscillation a fraction β_1 of these will be collected by the plate, and as they return to the vicinity of the cathode another fraction β_2 of the initial total will be collected. Denote by $\beta = \beta_1 + \beta_2$ the total fraction collected in the first revolution. Then the fraction which starts from the cathode upon a second revolution will be $\alpha = 1 - \beta$. The time required for their passage of the cathode will be dt. During that interval another group of dN electrons will be emitted. Hence the total number starting on the second cycle will be $(1+\alpha)dN$. Similarly after m cycles the total number leaving the cathode will be $(1+\alpha+\alpha^2+ \cdots +\alpha^{m-1})dN$. We shall consider only cases for which $\alpha < 1$, and make no distinction between reflected and secondary electrons. If there is a large amount of secondary emission α will exceed unity and the above series will not converge. However, if $\alpha < 1$ and m is infinite this becomes $dN/(1-\alpha)$. It is assumed here that the fraction lost on successive revolutions is a constant. This is probably not strictly true, so that α should be regarded as a mean value.

The total number of electrons in the interelectrode space may be found by taking the sum of all the above groups each leaving the cathode during an interval dt of the total period τ. These intervals are τ/dt in number. However it must be remembered that of each group leaving the cathode a fraction β_1 makes only one half a revolution.

Hence, while $dN/(1-\alpha)$ electrons travel from cathode to plate, only $(1-\beta_1)dN/(1-\alpha)$ travel back from plate to cathode. The average number making the entire trip is

$$\frac{1}{2}\left(\frac{dN}{1-\alpha}+(1-\beta_1)\frac{dN}{1-\alpha}\right)=\frac{2-\beta_1}{2}\;\frac{dN}{(1-\alpha)},$$

and the total number N in the interelectrode space at any instant is τ/dt times this, or

$$N=\frac{2-\beta_1}{2}\cdot\frac{\tau}{1-\alpha}\cdot\frac{dN}{dt}. \tag{2}$$

Some special cases are of interest. (a) If no electrons are collected by the plate and all are collected by the filament, then $\beta_1=\alpha=0$. In this case, (2) reduces to (1). (b) If all are collected by the plate, i.e., $\beta_1=1$, $\alpha=0$, then

$$N=\frac{\tau}{2}\,\frac{dN}{dt}.$$

This is just one half the value given by (1), since all electrons make only one half a revolution. (c) As $\alpha\rightarrow 1$, N becomes very large, since only a small fraction of the electrons are collected by either plate or cathode. This means that a very small filament emission may cause a large space charge by virtue of the electrons making many oscillations before being captured.

It is evident from (2) that $\tau/(1-\alpha)$ represents the total average time D that an electron remains in the interelectrode space, if $\beta_1=0$. Since τ is the time required for one radial oscillation, $1/(1-\alpha)$ is the number of radial oscillations. This is valid regardless of the path shape. Hence we have

$$D=R\tau=\frac{\tau}{1-\alpha} \tag{3}$$

where R is the total number of radial oscillations.

Multiplying (2) by e and dividing by D, we may write the following relation between the various currents:

$$I_f=I_r+I_p=\frac{Ne}{D}, \tag{4}$$

for the case $\beta_1=0$.

Unfortunately a simple tube such as is shown in Fig. 1 is of little use experimentally since it does not permit the measurement of either I_f or I_r. In most of the work described below a modified design was employed in which the single filament C was replaced by two identical tungsten wires C_1 and C_2 close together near the center of the tube, as in Fig. 2. Only one of these was heated and served as an electron source. The other served as a probe electrode. The distance between them was small in comparison to the plate diameter so that the electrostatic field was not greatly different from that in the tube of Fig. 1. Two tubes of this type were employed. They will be referred to as numbers I and II. They were of Pyrex 16.5 inches long and 1.5 inches in diameter. The plate, which was 10 inches long, consisted of a silver coating painted and baked on the inside of the glass. Electrodes C_1 and C_2 were pure tungsten wires of 0.0125-centimeter diameter, held taut by spiral tungsten springs. The tube had also disk-shaped tantalum end plates positioned near the ends of the plate, but these played no part in the measurements except when specifically mentioned. The magnetic field was supplied by a solenoid, which was built in sections, permitting the field to be applied only to the middle five inches of the tube, or to the entire tube, as was desired. By applying the field to only the central section, cyclic orbits were produced only in that section. However, current flowing radially from cathode to plate in the end sections produced potential distributions there not greatly different from that in the middle section, and thus errors due to end effects were reduced.

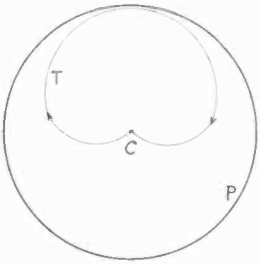

Fig. 1—Trajectory of an undisturbed electron in a magnetron, for the case when the magnetic field slightly exceeds cutoff value.

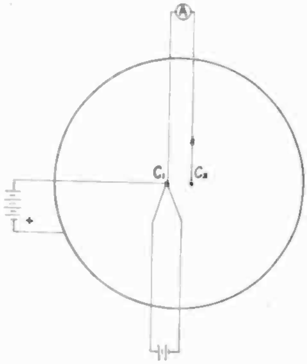

Fig. 2—Schematic diagram of the circuit for tubes I and II.

With this type of tube, measurements of the returning current I_r could be made. If C_1 be taken as the emitting electrode, electrons leave it, traverse cyclic orbits, then are collected by either C_1, C_2, or the plate. The probability of collection is assumed equal for both of the filaments if at the same potential, because of their proximity and identical form, and also, as will be shown later, because the electrons are subjected to disturbances during their motion. The current collected by C_2 is indicated by meter A and is equal to one half of the total returning current.

The circuit was essentially as shown in Fig. 2. In order to eliminate the effect of the potential drop along the filament, a commutator was used with tubes I and II so that current collected by C_2 was measured only during intervals when no heating current was flowing through C_1. With tubes III and IV, which were of a different type, to be described later, no commutator was used since the filament drop was only about 0.2 per cent of the plate potential.

In Fig. 3 data are plotted illustrating the occurrence of space-charge limitation of current in tube I for small filament-emission currents with the magnetic field exceeding the cutoff value. I_s is the saturated emission from the filament, measured by applying about 1000 volts to the plate in the absence of a magnetic field. The current collected by the probe electrode C_2 is indicated by $I_g/2$. Each curve is labeled with the corresponding plate potential in volts. All of these curves show space-charge limitation except the 400-volt one. A dashed line has been drawn approximately through the upper bend of each so that the region under this line represents the condition of space-charge limitation. Another set of similar data for tube II is shown in Fig. 4. This tube was identical with the first, but the magnetic field was applied to the entire length of the plate, and the end-plate current also was measured. Both plate

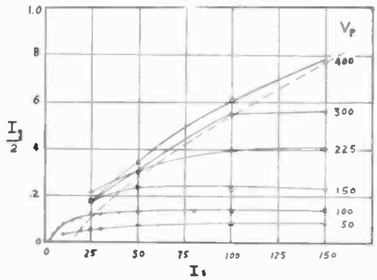

Fig. 3—Variation of probe current (milliamperes) with temperature-limited emission (milliamperes) and plate potential (volts). $I_g/2$ is the current actually indicated by meter A, Fig. 2, because of the use of a commutator it must be multiplied by two to get the total probe current. Tube I.

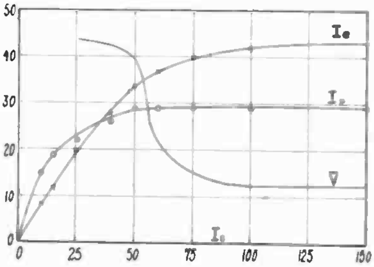

Fig. 4—Variation of end-plate current (milliamperes), plate current (microamperes) and mean random electron energy (electron volts), with temperature-limited filament emission (milliamperes). $V_p = V_e = 400$. Tube II.

current I_p and end-plate current I_e are shown. As should be expected these limit at substantially the same value of I_s. I_e limits somewhat indefinitely since the end plates draw current from portions of the filament, which are at varying distances from them.

In this case practically all the current flowed to the end plates. The plate current (microamperes in the figure) was comparatively small. The current I_g to the probe was of the order of one milliampere. Therefore it is seen that space-charge limitation occurs for a filament emission of approximately 45 milliamperes, whereas emission of about 1500 milliamperes would be required in the absence of a magnetic field, as calculated from the Langmuir-Childs law.

The effect is more striking in the previous case of Fig. 3. Here all currents are negligibly small except I_g. Space-charge limitation occurs at $I_g = 0.25$ milliampere, i.e., $I_f = I_r = 0.5$ milliampere, for a plate voltage of 100. Without the magnetic field a current of about $I_f = 98$ milliamperes would be required. This typical numerical case will be referred to repeatedly in the following pages.

The distributions of potential and charge which produce space-charge limitation in the presence of a magnetic field greater than the cutoff value are not the same as those in the absence of a magnetic field. However the difference is not very great,[13] except close to the cathode. It follows that a fair approximation to N can be obtained from the Langmuir-Childs law. Using as an example the above-mentioned case of Fig. 3, in which I_p is negligible, so that we may put $\beta_1 = 0$, we obtain $N = 15 \times 10^8$ and from (4) $D = N_e/I_f = 4.8 \times 10^{-7}$ seconds.

The time required for an undisturbed electron to execute a complete cycle is given by $\tau_0 = 6.5 \times 10^{-8} r/\sqrt{V}$, which yields in the present case 6×10^{-9} seconds. Thus if the electron paths resemble those of undisturbed electrons, the number of cycles per electron is D/τ_0 or 80. This result is typical for tubes such as I or II.

The relation between D and the plate voltage V_p may be determined from (4), and the experimental data of Fig. 3. From the latter it is evident that I_g, i.e., I_f, varies as the first power of V_p in the space-charge-limited region. Since N also changes as V_p for space-charge limitation, it follows from (4) that D must remain constant as V_p is changed. This conclusion can be drawn only for the case in which H is varied so as to maintain an electron swarm of constant size, as was done experimentally.

[13] H. G. Möller, "Electronenbahnen und Mechanismus der Schwingungserregung im Schlitzanodenmagnetron," *Hochfrequenz. und Elektroackustic*, vol. 47, p. 115; April, (1936).

ACTION OF A CYLINDRICAL COLLECTOR ELECTRODE IN AN ELECTRON SWARM IN WHICH SCATTERING OCCURS

The theory will be developed for a probe in an electron swarm in which energy exchanges between electrons occur. The resulting equations will then be applied to the experimental data.

If a fraction of the orbital energy of an electron is converted into energy of random motion, the electron will, in general, not be able to return to the cathode surface. For the present no hypothesis will be made regarding the mechanism of this energy conversion, but it will be assumed that a mean amount of energy of $\overline{V}$ electron volts per electron is changed from the orbital to the random type, the total average energy per electron remaining constant. On the average then, electrons will be able to travel towards the cathode only up to a limiting distance at which the potential is $\overline{V}$. Electrons approaching the cathode will thus have zero orbital energy upon reaching an equipotential cylindrical surface S surrounding the cathode, the potential of this surface being $\overline{V}$, and its distance from the cathode $\bar{r}$, see Fig. 5. Electrons on this surface retain their random motion, which, due to the assumed random nature of the energy exchanges, is Maxwellian in nature.

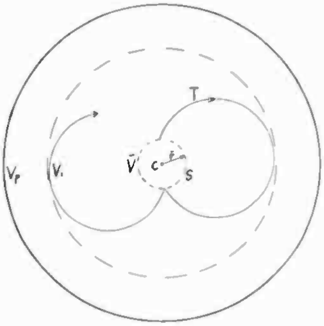

Fig. 5—Schematic diagram showing virtual cathode S and type of electron orbit outside virtual cathode.

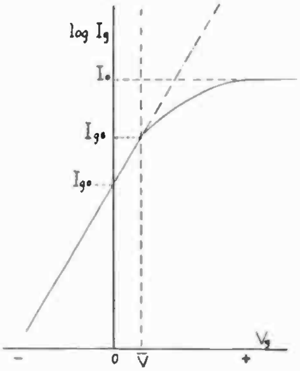

Fig. 6—Theoretical collector characteristic according to (10).

It is evident that S possesses the properties of a virtual cathode. To determine its temperature, it is only necessary to equate the random energy to the kinetic energy of a gas in terms of temperature; i.e.,

$$ne\overline{V} = \frac{3}{2} nkT$$

or,

$$T = \frac{2}{3}\frac{e\overline{V}}{k}. \tag{5}$$

The surface S and the cathode C form a diode, in which a current I_f flows from C to S, and a current I_r flows from S to C. Under the condition that the plate current is negligible, $I_f = I_r$.

To compute I_r we use the expression developed by I. Langmuir and H. M. Mott-Smith,[14] for the current from a cylindrical cathode at temperature T_0 to an internal cylindrical collector against a retarding field. This is

$$I_r = 2\pi r_0 l I \epsilon^{-e\overline{V}/kT_0} \tag{6}$$

where r_0 is the radius of the collector and l its length, I the saturated current density at S, e the electronic charge, k Boltzmann's constant, and T_0 the electron temperature due to the cathode heat.

If I_0 is the space-charge-limited current we have in the present instance $I = I_0/2\pi\bar{r}l$. Also the temperature of S is given by (5) plus that due to the real cathode. Hence,

$$I_r = \frac{r_0 I_0}{\bar{r}} \epsilon^{-e\overline{V}/k(T+T_0)}. \tag{7}$$

When a probe is inserted near the cathode, the returning current I_r divides between cathode and probe, and sheaths S_1 and S_2 form about each respectively. For simplicity these sheaths will be assumed to have circular cross section. The currents to each will be in the same ratio as their sheath areas, hence the probe current I_g is, from (7)

$$I_g = \frac{\bar{r}_2}{\bar{r}_1 + \bar{r}_2} I_r = \frac{r_0 I_0}{\bar{r}_1 + \bar{r}_2} \epsilon^{-e\overline{V}/k(T+T_0)} \tag{8}$$

where r_1 and r_2 are the sheath radii about cathode and probe, respectively. This expression must be further modified if the probe potential V_g differs from that of the cathode. In that case we must substitute for $\overline{V}$ the term $V_g - \overline{V}$ since that is the actual potential difference.

The radius of the sheath about the probe may vary with probe potential, the sheath being forced farther away as the probe becomes more negative. If probe and cathode are of the same size, and both at zero potential, $\bar{r}_1 = \bar{r}_2$, but as the probe becomes negative $\bar{r}_2$ increases by an amount Δr. Hence in place of $\bar{r}_1 + \bar{r}_2$ we may write $2\bar{r}_1 + \Delta r$.

Reflections of electrons from the collector also must be considered. No distinction will be made between reflected and secondary electrons,

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[14] H. M. Mott-Smith, and I. Langmuir, "The theory of collectors in gaseous discharges," *Phys. Rev.*, vol. 28, p. 727; October, (1926).

and only the case will be considered in which the ratio of secondaries to primaries is low, i.e., less than unity. Thus the only effect of reflections or secondary emission will be to increase the number of oscillations. In case reflections occur, the factor $(1-f)$, where f is the coefficient of reflection, must be introduced. Hence the final expression for probe current is

$$I_g = \frac{(1-f)r_0 I_0}{2\bar{r}_1 + \Delta r} \epsilon^{e(V_g - \bar{V})/k(T+T_0)}, \tag{9}$$

or,

$$\log I_g = \log \frac{(1-f)r_0 I_0}{2\bar{r}_1 + \Delta r} + \frac{e(V_g - \bar{V})}{k(T+T_0)} \cdot \tag{10}$$

The Langmuir—Mott-Smith relation (6) used in deriving (9) is applicable in the presence of a magnetic field, providing the proper expression for the saturation current be introduced. The method used above of expressing this current in terms of I_0, is applicable for all values of magnetic field, and gives the proper value of the saturation current.

If (10) be applied to space-charge-limited cases, I_0 will be constant, if V_p is constant. As V_g is varied Δr will change, but not greatly, and the logarithm of the term containing Δr will be but slightly affected. The reflection coefficient is in general a function of the incident electron energy, i.e., temperature. However, changes of V_g do not affect this, hence f is constant. It follows that (10) gives a nearly linear relation between $\log I_g$ and V_g.

The slope of the line obtained by plotting $\log I_g$ against V_g is $e/k(T+T_0)$. Hence the electron temperature may be determined. In the experimental work T is so much greater than T_0 that the latter may usually be neglected.

Fig. 6 gives the collector characteristic according to (10), $\log I_g$ being plotted against V_g. It is linear only for $V_g < \bar{V}$. For $V_g = \bar{V}$, $\Delta r = -\bar{r}_1 + r_0$, and $I_g = [(1-f)r_0 I_0]/(\bar{r}_1 + r_0)$. As V_g increases above $\bar{V}$ the current approaches the limiting value, I_0. This is the limiting value only if the filament temperature is sufficiently high to maintain a space-charge-limited condition; otherwise the limiting value will be lower. For very high positive probe potentials I_0 will depart considerably from the value for low probe potentials since the potential distribution in the tube will be considerably distorted, and secondary emission may become important. For these reasons (10) probably is not valid unless V_g is small compared to V_p, and also sufficiently small that secondary emission may be neglected. The actual characteristic would therefore likely differ considerably from that of Fig. 6 for large positive values of V_g.

The potential distribution near the probe or cathode for retarding potentials may be obtained by making use of Poisson's equation for cylinders

$$\frac{1}{r}\frac{d}{dr}\left(r\frac{dV}{dr}\right) = 4\pi ne, \tag{11}$$

and Boltzmann's law,

$$n = n_0\epsilon^{Ve/kT}, \tag{12}$$

which governs the charge distribution between the electrode and the virtual cathode. Inserting (12) in (11) and expanding gives

$$\frac{d^2V}{dr^2} + \frac{1}{r}\frac{dV}{dr} = 4\pi n_0 e\epsilon^{Ve/kT}. \tag{13}$$

The solution of this for $V=0$, and $dV/dr=0$, when $r=0$, is

$$V = -\frac{4}{3}\bar{V}\log\left[1-\left(\frac{r}{4\lambda}\right)^2\right], \tag{14}$$

where λ, the Debye distance for the electron swarm near the collector where the density is n_0, is given by

$$\lambda^2 = \frac{kT}{8\pi n_0 e^2}. \tag{15}$$

The electron density distribution is obtained by substituting (14) in (12), which gives

$$n = n_0\left[1-\left(\frac{r}{4\lambda}\right)^2\right]^{-2}. \tag{16}$$

The radius of the virtual cathode is found by putting $V=\bar{V}$ in (14). Thus,

$$\bar{r} = \sqrt{1-\epsilon^{-3/4}}\cdot 4\lambda = 2.9\lambda. \tag{17}$$

Similarly,

$$\bar{n} = 4.48n_0. \tag{18}$$

In applying these equations to the numerical case mentioned previously it is necessary to compute n_0. This may be done by use of the expression[15]

$$n_0 = 2\times 10^{13}I_1T_0^{-1/2}$$

[15] I. Langmuir and K. T. Compton, "Electrical discharges in gases," *Rev. Mod. Phys.*, vol. 3, p. 242; April, (1931).

where I_1 is the emission current density in amperes per square centimeter, and T_0 the cathode temperature. This yields $n_0 = 5 \times 10^8$, whence

$$\lambda = 0.049 \text{ centimeter},$$

and

$$\bar{r} = 0.14 \text{ centimeter}.$$

Expanding (14) in a power series we have

$$V = \frac{4}{3}\bar{V}\left[\left(\frac{r}{4\lambda}\right)^2 + \frac{1}{2}\left(\frac{r}{4\lambda}\right)^4 + \frac{1}{3}\left(\frac{r}{4\lambda}\right)^6 + \cdots\right],$$

whence it is evident that near the cathode V varies as r^2, and as an increasingly higher power as the virtual cathode is approached. Beyond the virtual cathode the variation must approach the logarithmic-law characteristic of concentric cylinders, it being remembered that although the current from the real cathode is space-charge limited, that from the virtual cathode is not.

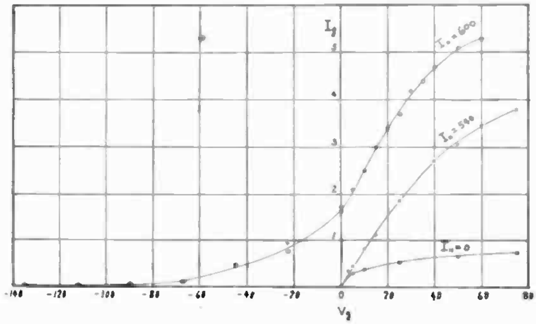

Fig. 7—Probe-current (milliamperes) curves for several values of magnetic field, versus probe potential (volts). Tube III.

Fig. 7 illustrates the typical behavior of a magnetron under various magnetic field strengths, and shows the existence of excess-energy electrons. The tube used here was smaller than those previously described, having a cylindrical tantalum plate of 2 millimeters radius, and 8 millimeters length. Two tungsten wires 0.0125 centimeter in diameter and 0.05 centimeter apart were positioned near the central axis and served as cathode and probe. This will be referred to as tube III. Its behavior was qualitatively the same as that of the larger tubes I and II.

In the figure, probe current I_g is plotted against probe potential V_g, and curves are labeled with their corresponding magnet current I_H. If the magnetic field is zero, the probe collects no current when it is at negative or zero potential, and a small, slowly increasing current as it becomes more positive. For a field a little below cutoff ($I_H = 540$) the behavior is unchanged qualitatively, but the current collected is larger. As the magnetic field passes through the cutoff value there is a sudden change in that the probe begins to collect electrons when it is negative, as is shown by the curve for $I_H = 600$.

As the probe becomes increasingly negative the current collected approaches zero. If positive ions were present in appreciable numbers a point would eventually be reached where the electron current would be negligible and the positive-ion current comparatively large. The curve would cross the horizontal axis, the actual crossing taking place when the electron and positive-ion currents were equal. This effect was observed in only a few cases when the plate voltage and emission current were both high. However the amount of positive-ion current was always too small to play any important part in the tube behavior.

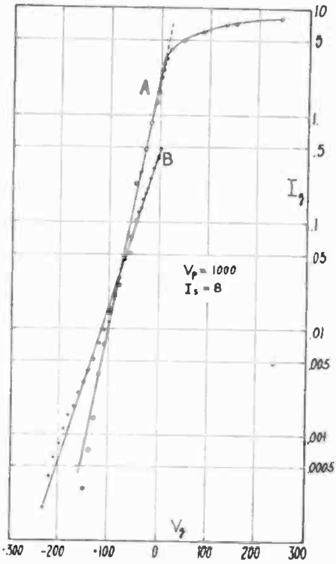

Fig. 8—Probe current characteristics. *A*, axial probe. *B*, end-plate probes with greater tilt. Tube III.

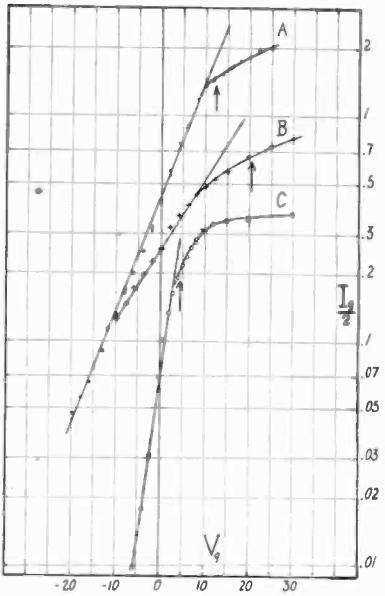

Fig. 9—Collector characteristics showing extension of linear portion into region of positive potentials. Curve *A*, space-charge limited, $V_p = 300$. Curve *B*, not space-charge limited, $V_p = 300$. Curve *C*, space-charge limited, $V_p = 150$, I_o divided by 2.45 before plotting. Tube II.

Such curves as those of Fig. 7 should obey the relation (10). Two examples are shown in Fig. 8, in which I_g is plotted versus V_g on a semilog scale, yielding straight lines. These were obtained with tube IV, which was similar to tube III except for having disk-shaped end plates. Curve *A* was obtained with the plate at 1000 volts, the end plates at zero potential, and a temperature-limited filament emission of 8 milliamperes. For curve *B* the end plates were used as probes. In this case the tilt of the tube in the magnetic field was not the same as in case *A*. It will be noted that for curve *A*, an appreciable number of electrons have excess energy equivalent to over 130 volts, while for *B*, energies over 220 volts appear. The mean random energy of the Maxwellian distribution in case *A* is found to be $\overline{V}=27$ equivalent volts, which corresponds to a temperature of about 210,000 degrees centigrade. Although this would be considered a very high temperature for an electron swarm in a plasma, it is not unusually high for a swarm in a high-vacuum magnetron, such as those described here. Cases have been observed in which the temperature exceeded one-half million degrees.

Equation (6) from which (9) was derived is valid only for retarding fields. Hence (9) should hold only for $V_g<\overline{V}$. For $V_g>\overline{V}$ the linear relation between log I_g and V_g should no longer hold. Departures from this linear relation are shown in Fig. 8, curve *A*, and Fig. 9. Curves *A* and *C*, Fig. 9, were made under identical conditions except that the plate voltage and magnetic field were changed, as mentioned elsewhere, to maintain a constant electron swarm size. The cathode was held at a sufficiently high temperature to give space-charge limitation of emission current. The arrows indicate the points at which $V_g=\overline{V}$, the value of $\overline{V}$ being determined from the slope of the line. In curves *A* and *C* the break occurs as near the arrow as could be expected in view of the assumptions made in deriving (10). These results indicate that the energy of random motion is derived at the expense of the orbital motion of the electrons themselves, and not from some external source such as oscillations.

Curve *B* shows the effect of reducing the filament temperature until space-charge limitation does not exist. Except for a lower cathode temperature the conditions were identical with those of curve *A*. The decrease of slope of the linear portion indicates a higher electron random energy. This effect will be discussed later. The arrow indicates the point where $V_g=\overline{V}$. It is evident that the break does not occur at this point if space-charge limitation is not maintained.

In connection with these characteristics it should also be noted here that there is no abrupt increase in the probe current as V_g passes through zero. Such an increase would occur if appreciable numbers of electrons did not undergo scattering, since they would possess sufficient energy just to reach the probe when it was at zero potential. The absence of any break in the curve at that point is evidence that essentially all electrons are scattered.

The change of the quantity Δr is unimportant when $\overline{V}$ is large compared to V_g for then $\bar{r}$ is large compared to Δr. However, if $\overline{V}$ is small, the effect of the change in Δr may become noticeable. This is illustrated in Fig. 10. The decreasing slope with increasing plate potential indicates increasing electron random energy $\overline{V}$ as is evident from (10).

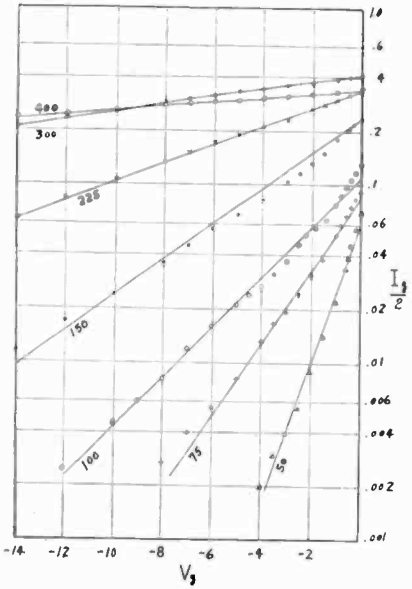

Fig. 10—Probe current (milliamperes) against probe potential (volts) for various plate potentials. Tube I.

It will be noticed that for high random energy (small slope) the points lie closer to straight lines than for low random energy. The plots for plate potentials from 50 to 150 volts show log I_g increasing more rapidly than linearly as V_g approaches zero. This is interpreted as due to the decrease of Δr in (10), which causes the right-hand logarithmic term to increase slightly instead of remaining constant.

To apply (9) to the computation of the current for $V_g=0$, put $\overline{V}=3/2\ kT/e$, then

$$I_{g0} = \frac{(1-f)r_0 I_0 \epsilon^{-3/2}}{2\bar{r}_1}.$$

For the reflection coefficient f use the experimental data of H. E. Farnsworth.[16] The space-charge-limited current I_0 is obtained by means of the Langmuir-Childs law. The virtual-cathode radius $\bar{r}_1$ is calculated from (17), as shown above. Values of I_g thus computed from the data of Fig. 10 are shown as crosses in Fig. 11. Values of f were not available to permit calculation over a larger range. The points lie on a good straight line through the origin, although that such should be the case is not evident from the above equation. The experimental points, indicated by circles, are in very good agreement with the calculated ones in view of the approximations made. The point for $V_p=400$ lies outside the space-charge-limited region (see Figs. 3 and 13) and hence should not follow the same law as the others.

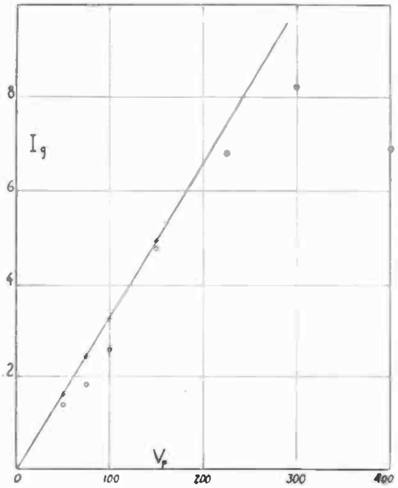

Fig. 11—Probe currents for $V_g=0$. Experimental (0) from data of Fig. 10; computed (+) from (9).

The above theory is therefore in good agreement with the experimental results since it explains (1) the linear relation between log I_g and V_g, (2) the existence of the linear relation for positive values of V_g up to $\overline{V}$, (3) the curvature of the log-I_g-versus-V_g plots for small $\overline{V}$, and (4) the current I_g for $V_g=0$.

RELATION BETWEEN ELECTRON TEMPERATURE AND OTHER VARIABLES

It has been found that the mean random electron energy or temperature is a function of the plate potential, the filament emission, the magnetic field, and the end-plate potential. Graphs showing the varia-

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[16] H. E. Farnsworth, "Electronic bombardment of metal surfaces," *Phys. Rev.*, vol. 25, p. 41; January, (1925).

tion with respect to plate potential are shown in Fig. 10. These were obtained with tube I, applying the magnetic field to the middle section only, so that the end plates played no part. The temperature-limited filament emission was 50 milliamperes. The magnetic field strength was varied with the plate potential in such a way as to confine the electrons (i.e., undisturbed ones) within a cylindrical sheath of constant radius, as is shown in Fig. 12. This diagram represents a cross section of the tube, the probe not being shown. The cross-hatched area indicates the electron swarm in which individual undisturbed electrons execute trajectories outside the virtual cathode approximately as illustrated by curve T. The ratio of the plate radius r_p to the swarm radius r_1 was maintained at the arbitrary value of 2.7. This was done to insure that the changes observed would be due to plate-potential changes alone and not to other factors associated with change of swarm size. The graphs of Fig. 10 are similar to those of Fig. 8 but are taken for a variety of plate potentials, as indicated by the figures on each curve.

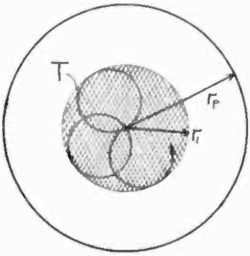

Fig. 12—Schematic diagram of cross section of magnetron showing electron swarm (crosshatched) and undisturbed electron path T.

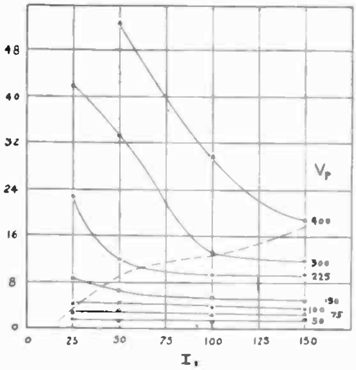

Fig. 13—Variation of electron mean random energy (electron volts) with plate potential (volts) and temperature-limited emission (milliamperes). Tube I.

The electron random energy is inversely proportional to the slope, hence the decreasing slope with increasing plate potential indicates increasing random energy.

A more comprehensive set of data, which shows the variation of random energy with both plate potential and temperature-limited filament emission, is given in Fig. 13. These curves are related to those of Fig. 3, being derived from the same set of data. The dashed lines in the two figures correspond to each other, and divide the space-charge-limited regions from the nonlimited regions. It will be observed that the graphs are essentially horizontal straight lines in the limited regions, indicating that changes in I_s (i.e., filament temperature) have little or no effect upon $\overline{V}$ if space-charge limitation exists. However, if space-charge limitation does not exist, a decrease in I_s results in a rapid rise in $\overline{V}$, within. Hence it appears that the random energy drops as space charge increases, until a limiting value is reached when the current becomes space-charged limited.

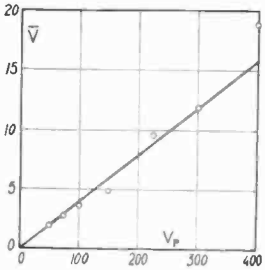

Fig. 14—Linear relation between electron random energy and plate potential when current is space-charge limited.

These same data show that $\overline{V}$ varies directly as the first power of V_p in the space-charge-limited region. Outside that region the variation is as some higher power. This is illustrated in Fig. 14 in which are plotted data from Fig. 13 for $I_s = 150$. It is seen that the points lie fairly well along a straight line except at $V_p = 400$. The latter point, however, lies outside the space-charge-limited region. If we had taken the points for some lower I_s, say 75, they would have departed from the straight line much sooner, in fact at about $V_p = 200$.

The variation with respect to the magnetic field strength H is somewhat more complicated, as is evident from Fig. 15. These curves were made with tube II, which was a duplicate of tube I, except for having a somewhat better vacuum. The plate voltage was 225, the end-plate voltage zero, the temperature-limited filament emission was 25 milliamperes.

To obtain curve *A* the magnetic field was applied to the entire tube. This was done only to determine the cutoff point. (No cutoff is obtained when the field is applied to only a section of the tube, since then electrons merely execute long spirals from the section in the magnetic field to a field-free section where they may reach the plate. Under this condition the plate current changes but slightly as the critical value of magnetic field is passed through.) After curve *A* was obtained, the solenoid was reconnected so as to apply field to the mid-section only, as described above, and curves *B* and *C* were taken with that arrangement.

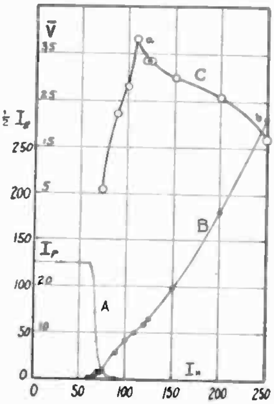

Fig. 15—*A*. Cutoff characteristic of plate current (milliamperes).
B. Probe current (microamperes).
C. Corresponding electron mean random energy (electron volts). Tube II.

Curve *B* indicates the change of probe current with magnetic field, while curve *C* shows the change of electron random energy. These curves will be discussed more fully later, but it is desired to point out here that for values of magnetic field such that the electron sheath is well clear of the plate and yet large compared to the cathode-probe spacing, as section *ab* of *C*, the electron temperature appears to vary as the inverse first power of *H*. This is indicated if section *ab* be plotted on log-log paper. The departure from this relation below $I_H = 120$ may be due to the elimination of the higher-energy electrons by the plate and the consequent reduction of temperature. As the field becomes stronger the sheath shrinks farther away from the plate, fewer high-energy electrons are lost, and the inverse first-power law then becomes apparent.

The variation of the electron random energy with end-plate potential is qualitatively the same as with plate potential. That is, there is an increase of $\bar{V}$ with V_e, but the law of variation is not as simple as in the former case and has not been determined. A less simple law is to be expected since the electrostatic field distribution is complicated by end plates. A similar dependence upon space charge also exists, for it can be shown that if there is space-charge limitation of current, variations of I_s have no effect on $\overline{V}$. However, if space-charge limitation of current does not exist then an increase of I_s causes a decrease of $\overline{V}$.

Experimental data illustrating this are given in Fig. 16. Here $\overline{V}$ is plotted as a function of I_s for different values of V_e. This figure is analogous to Fig. 13 in which the same quantities are plotted for different values of V_p. As in the former case, the graph can be divided into two regions as by the dashed line. Below this line $\overline{V}$ is seen to be substantially independent of I_s, the temperature-limited emission, while above the line there is a marked dependence. It can be shown, as was done in the case of Fig. 13, that the region below the line represents the cases in which the cathode emission is space-charge limited whereas in the region above, space-charge limitation does not occur. The position of the line cannot be sharply determined, of course, since the transition is a gradual one. In the figure it was roughly drawn through those points where the horizontal straight lines first show some upward trend.

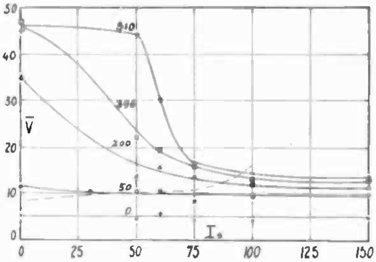

Fig. 16—Variation of electron random energy (electron volts) with respect to end-plate potential (volts) and temperature-limited filament emission (milliamperes). Tube 11.

Evidence that this upward trend of the curve arises from a departure from the space-charge-limited condition is given in Fig. 4. Here a curve of $\overline{V}$ (at $V_e = 400$) is plotted on the same sheet as curves of I_e and I_p against I_s. It is seen that the downward trend of $\overline{V}$ begins as I_e and I_p commence to level off, and that the sharpest drop in $\overline{V}$ occurs approximately at the knee of the other curves, where space-charge limitation occurs.

RELATION BETWEEN ENERGY OF ORBITAL MOTION AND ELECTRON TEMPERATURE

To compute the orbital energy of the undisturbed electrons we refer again to Fig. 12. An undisturbed orbit is represented by T, in which the distance of maximum excursion of the electron from the cathode is r_1. We shall determine the potential at r_1, for the general case when the potential distribution is given by

$$V = V_p\left(\frac{r}{r_p}\right)^{\mu}, \tag{19}$$

where μ is determined by the amount of space charge; e.g., it is equal to two thirds for space-charge limitation.[13,17] This expression is used mainly to give a qualitative idea of the effect of space charge. It is only approximately correct, but is a good approximation especially near the space-charge-limited region in which we are principally interested. Even when the electron swarm does not fill the entire interelectrode space the approximation is sufficiently good.

Making use of Hull's[18] differential equation for electron motion,

$$\left(\frac{dr}{dt}\right)^2 = \frac{2eV(r)}{m} - \left(\frac{He}{2m}\right)^2 r^2,$$

we get the maximum value of r (i.e., r_1) by putting $dr/dt=0$. This yields, after substituting from (19),

$$\frac{r_1}{r_p} = \left(\frac{8mV_p}{H^2 e r_p^2}\right)^{1/(2-\mu)}. \tag{20}$$

The critical cutoff value of H is found by putting $r_1 = r_p$, hence

$$H_c^2 = \frac{8mV_p}{er_p^2},$$

and therefore

$$\frac{r_1}{r_p} = \left(\frac{H_c}{H}\right)^{2/(2-\mu)}. \tag{21}$$

Substituting this in (19) yields

$$V_1 = V_p\left(\frac{H_c}{H}\right)^{2\mu/(2-\mu)}. \tag{22}$$

In the space-charge-limited case $\mu = 2/3$, so that

$$V_1 = V_p\frac{H_c}{H}.$$

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[17] For a discussion of electron paths in magnetrons as a function of space charge, see E. G. Linder, "Description and characteristics of the end-plate magnetron," Proc. I.R.E., vol. 24, pp. 633–653; April, (1936).

[18] A. W. Hull, "The effect of a uniform magnetic field on the motion of electrons between coaxial cylinders," *Phys. Rev.*, vol. 18, p. 31; July, (1921).

Thus it is seen that the maximum orbital energy eV_1 of the undisturbed electrons is directly proportional to V_p and inversely proportional to H as is the electron random energy $\overline{V}$, as determined experimentally. We may therefore write $\overline{V}=\text{constant } V_1$, for space-charge limitation.

For cases in which space-charge limitation is not attained, μ is less than two thirds. The relation (19) then less accurately represents the potential distribution but does so sufficiently well for the present purposes. As V_p is increased, μ decreases, and the factor $(H_c/H)^{2\mu/(2-\mu)}$ increases, instead of remaining constant as in the previous case. Hence V_1 increases at a rate greater than the first power, as was found experimentally for $\overline{V}$ in non-space-charge-limited cases.

It has been found that tilting the tube slightly so that its axis is no longer parallel to the direction of the magnetic field causes an increase in electron temperature. This is due to the resulting decrease in space charge by virtue of electrons reaching the plate by traveling along spirals whose axes parallel the field. The decrease in space charge causes a decrease in μ, resulting as above in an increase of V_1.

POSSIBLE CAUSES OF SCATTERING

In the preceding discussion of electron motion and collector theory it was assumed that electron scattering existed, but no assumptions were made regarding its cause. The above theory is valid regardless of the source of the scattering; nevertheless some consideration of various possible causes is desirable, even though a satisfactory explanation has not been found.

It has been shown that the electron random energy is derived from the orbital energy of the electrons themselves and not from some external source. It has also been shown that the scattering is such as to yield a Maxwellian distribution when the orbital energy is subtracted. Any satisfactory mechanism must meet these conditions.

Oscillations in the external circuits connected to the tube could conceivably yield a Maxwellian distribution; however, the energy would not be supplied by the electrons themselves. Consequently no virtual cathode would be formed, and the law for the current to a probe would differ from that found. However this possibility was carefully investigated since it has been so frequently suggested as an explanation.

Experimental tests for such oscillations were made. With tubes of type III and IV oscillations were searched for down to wavelengths of several centimeters. A conventional radio wavemeter was used for the longer waves, while for the shorter ones a Lecher wire system, coupled to the tube, was employed. Audio-frequency modulation was applied to the magnetron, and a crystal detector in the shorting bridge was connected to an audio-frequency amplifier. Excess-energy electrons were easily observed when no oscillations could be detected with this apparatus. Further tests were made by connecting large condensers across the leads of the tube; no effect whatsoever was observed upon the excess-energy-electron current.

Additional evidence that oscillations are not the cause of this effect lies in the stability and reproducibility of the phenomena, and the smoothness of the curves obtained. If oscillations were present a more erratic behavior would be expected.

Scattering by gas molecules would result in random energy being supplied at the expense of orbital energy. This type of scattering has been studied in detail by Langmuir[1] and Langmuir and Jones[19], who found a relationship between collector current and voltage of a different type from that of (9). Furthermore the number of collisions between electrons and molecules may be computed, and is found to be far too small. If the data of Langmuir and Jones[20] for nitrogen and 75-volt electrons are used, and the pressure be assumed to be 10^{-5} millimeters of mercury, it is found that for an electron path of 90 centimeters the probability of a collision is only about 0.02.

Energy exchanges due to collisions between electrons satisfy all the assumed conditions. An expression for the mean-square angular deflection due to multiple impacts by an electron traversing a swarm of electrons has been derived by H. A. Wilson[21] in connection with β-ray scattering. It has been applied to electron scattering by Langmuir and Jones.[20] The equation is

$$\bar{\phi}^2 = \frac{2\pi e^2 nL}{V^2} \log \frac{P_1}{P_0} \cdot$$

Knowing the angle ϕ, the mean transverse energy for small angles is given by $\bar{V} = \bar{\phi}^2 V$, where V is the energy before impact. Thus $\bar{V} = (2\pi e^2 nL/V) \log (P_1/P_0)$, where n is electron density, L is total path length, and P_1 and P_0 are the maximum and minimum distances of approach between the orbits of colliding electrons which need be considered. Their method of determination is given by Langmuir and Compton.[22] Application of this expression to the numerical example

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[19] I. Langmuir and H. A. Jones, "Collisions between electrons and gas molecules," *Phys. Rev.*, vol. 31, p. 357; March, (1928).

[20] I. Langmuir and H. A. Jones, "Collisions between electrons and gas molecules," *Phys. Rev.*, vol. 31, p. 390; March, (1928).

[21] H. A. Wilson, "On the scattering of β-rays," *Proc. Roy. Soc.*, A102, vol. 9, October, (1923).

[22] I. Langmuir and K. T. Compton, "Electrical discharges in gases," *Rev. Mod. Phys.*, vol. 3, p. 219; April, (1931).

used above gives $\overline{V}=0.055$ volt whereas the experimental value is 4.2 volts.

This same equation applies to scattering by positive ions. However, since the positive-ion density is much smaller than the electron density, the scattering also will be much less.

Electron oscillations similar to plasma electron oscillations[23] may exist in swarms of electrons, since the existence of positive ions is not necessary. There is no direct experimental evidence of their presence, in such swarms, but it is of interest that such oscillations have been suggested as a possible cause of electron scattering in strongly ionized gases,[24] where the free electrons are found to possess a Maxwellian velocity distribution which cannot be accounted for on the basis of ordinary collisions.

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[23] K. T. Compton and I. Langmuir, "Electrical discharges in gases," *Rev. Mod. Phys.*, vol. 2, p. 239; April, (1930).

[24] I. Langmuir, "Oscillations in ionized gases," *Proc. Nat. Acad. Sci.*, vol. 14, p. 627; August, (1928).

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

RELATIONS EXISTING BETWEEN VOLTAGE IMPULSES OF EXPONENTIAL FORM AND THE RESPONSE OF AN OSCILLATING CIRCUIT*

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Summary—*The superposition integral is used to express the voltage produced in the inductance of a tuned circuit in response to a voltage impulse of exponential form. The expression is given in terms of the voltage and time constant of the impulse and the frequency and decrement of the oscillating circuit. This method is more direct and more easily manageable than the conventional method which expresses the relations in terms of the current produced in the secondary or oscillating circuit in terms of the voltage applied to this circuit by the primary or exciting source. The conventional equation,* $Ldi/dt+Ri+q/C=E$ *may be quite troublesome with certain forms of voltage* E.

Comparisons are made between oscillograms of an experimental circuit and curves calculated from theory.

A simple graphical method is given for determining the constants of an exponential impulse from the response curve and known constants of the oscillating circuit.

General conclusions are drawn which are of interest relative to radio interference.

IT is well known that, if a charge is released suddenly upon the plates of a condenser in an oscillating circuit, voltage oscillation will result which may be given by the expression,

$$E = Ve^{-rt/2L} \cos \omega t, \tag{1}$$

in which $\omega=2\pi f=\sqrt{(1/Lc-r^2/4L^2)}$, L, c, and r having the values of inductance, capacitance, and resistance. In most applications to radio circuits, however, the treatment of impulses as instantaneous is subject to serious error.

The voltage response of a tuned circuit to an impulse may be expressed directly by Duhamel's superposition integral. This theorem was used by J. M. C. Duhamel[1] in problems of heat transmission, by L. Boltzman,[2] by J. Hopkinson[3] in calculating condenser charges, by J.

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* Decimal classification: R141.2. Original manuscript received by the Institute, September 7, 1937.

[1] Duhamel, *Jour. de L'École Royale Polytech.*, 22 cahier, tome 14, p. 20; September, (1833).

[2] Boltzmann, "Zur Theorie der elastischen Nachwirkung," *Wien. Ber.*, vol. 70, p. 275, (1874).

[3] Hopkinson, "Residual charge of the Leyden Jar—Dielectric properties of different gases," *Phil. Trans. Royal Soc.* (London), vol. 167, pp. 599–626, (1877).

R. Carson in transients of electrical networks, and finds applications in modern electrical circuit theory.[4,5,6,7]

Suppose that the impressed voltage $v(t)$ is as shown by the smooth curve of Fig. 1. For the purpose of this discussion imagine this to be divided into a number of steps of sudden voltage increments $v'(t)\Delta t$. Then each of these voltage increments will start a damped cosine wave of the form $v'(t)e^{-rt/2L} \cos \omega t \Delta t$. If the number of these steps is made to increase without limit and the size of each becomes smaller and smaller as the number increases, the sum of all such cosine waves, at a given time, will represent the voltage generated across the inductance of the tuned circuit. Expressing each of these infinitesimal voltages by $v'(t)dt$, each wavelet may be represented by the form $v'(t)e^{-rt/2L} \cos \omega t dt$. But since each of these wavelets does not start when $t=0$ but at a later time, say τ, we shall replace t in the amplitude factor by τ and express the time of succeeding events in the wave train by $(t-\tau)$. This gives the expression $v'(t)e^{-r(t-\tau)/2L} \cos (\omega t - \omega\tau)d\tau$, and the integral of this, from the beginning of the impulse to any time t expresses the voltage

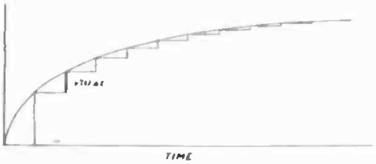

Fig. 1—Analysis of hypothetical voltage impulse.

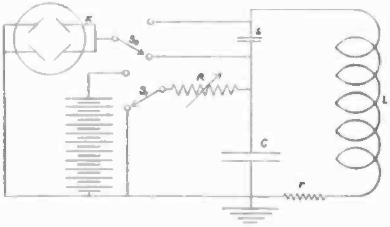

Fig. 2—Circuit for studying the response of a tuned circuit to a voltage impulse of exponential form.

$$E = \int_0^t v'(\tau)e^{-r(t-\tau)/2L} \cos (\omega t - \omega\tau)d\tau. \tag{2}$$

As an application of this integral to a particular oscillating circuit let us take the circuit of Fig. 2. In this diagram, C is very much larger than $\underline{c}$, say 100 times, to provide a loose coupling between the exciting circuit and the oscillating circuit. The effective capacitance in the tuned circuit is $c=\underline{c}C/(\underline{c}+C)$. Suppose that a charge exists on C, S_1 open. Upon closing S_1 downward this charge will leak off through R, releasing

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[4] Carson, "Electric Circuit Theory and the Operational Calculus," p. 16. McGraw-Hill Book Co., (1926).

[5] Berg, "Heaviside's Operational Calculus," p. 67. McGraw-Hill Book Co., (1929).

[6] Bush, "Operational Circuit Analysis," p. 56. John Wiley and Sons, (1929).

[7] Doherty and Keller, "Mathematics of Modern Engineering," vol. 1, pp. 261–276. John Wiley and Sons, (1936).

in a corresponding manner the charge trapped on $\underline{c}$. At the beginning of the operation, $\underline{c}$ is charged to the same voltage as C but in the opposite sense so that the initial voltage across $\underline{c}$ and C in series is zero. If C is previously charged to a voltage V, closing the switch S_1 (Fig. 2) downward allows this condenser to discharge so that the voltage applied to the circuit is the change in voltage across C. This voltage is expressed by the equation,

$$v(t) = V(1 - e^{-t/RC}) \tag{3}$$

and the first time derivative,

$$v'(t) = (V/RC)e^{-t/RC}. \tag{4}$$

Inserting the value of $v'(t)$ of (4) in (2) we have, as the expression for the voltage across the inductance L

$$E = \int_0^t (V/RC)e^{-\tau/RC}e^{-r(t-\tau)/2L} \cos (\omega t - \omega\tau)d\tau \tag{5}$$

$$= (V/RC)e^{-rt/2L} \int_0^t e^{(r/2L-1/RC)\tau} \cos (\omega t - \omega\tau)d\tau$$

$$= (V/RC)e^{-rt/2L} \left[\frac{e^{(r/2L-1/RC)\tau}}{\sqrt{(r/2L - 1/RC)^2 + \omega^2}} \cos\left(\omega t - \omega\tau - \tan^{-1} \frac{-\omega}{r/2L - 1/RC}\right)\right]_0^t$$

$$= (V/RC)e^{-rt/2L} \left[\frac{e^{(r/2L-1/RC)t}(r/2L - 1/RC)}{(r/2L - 1/RC)^2 + \omega^2} + \frac{\cos\left(\omega t - \cos^{-1} \dfrac{(-r/2L + 1/RC)}{\sqrt{(1/RC - r/2L)^2 + \omega^2}}\right)}{\sqrt{(r/2L - 1/RC)^2 + \omega^2}}\right]. \tag{6}$$

The above expression gives the response of the tuned circuit in terms of the voltage induced in it. This view is preferable for this study because the oscillograms are made in terms of voltage and, in most applications to communication circuits, the voltage response of a tuned circuit is of greater significance than is the current. Much the same method may be used, however, to determine the current in such a circuit. First, one must determine the expression for the current that would be induced by the introduction of unit voltage in the circuit. This is Heaviside's indicial admittance. One may proceed as follows:[7]

$$i_1 = 1/2\pi i \int_c e^{\lambda t} d\lambda/(L\lambda^2 + r\lambda + 1/c).$$

This expression has poles at

$$\lambda = -r/2L + j\sqrt{(1/Lc - r^2/4L^2)} = -r/2L + j\omega$$

and,

$$\lambda = -r/2L - j\sqrt{(1/Lc - r^2/4L^2)} = -r/2L - j\omega.$$

Whence,

$$i = (e^{-r/2L}/\omega) \sin \omega t, \text{ the indicial admittance.}$$

Inserting this expression for the indicial admittance in the superposition integral,

$$I = (1/\omega) \int_0^t (V/RC)e^{-\tau/RC}e^{-r(t-\tau)/2L} \sin (\omega t - \omega\tau)d\tau$$

$$= \frac{Ve^{-rt/2L}}{\omega RC}\left[\frac{e^{(r/2L-1/RC)t}\omega}{(r/2L - 1/RC)^2 + \omega^2} + \frac{\sin\left(\omega t - \tan^{-1}\dfrac{-\omega}{(r/2L - 1/RC)}\right)}{\sqrt{(r/2L - 1/RC)^2 + \omega^2}}\right]. \qquad (6a)$$

If $1/RC \gg r/2L$ we may write, for (6),

$$E = -\frac{Ve^{-t/RC}}{1 + \omega^2R^2C^2} + \frac{Ve^{-rt/2L}}{\sqrt{1 + \omega^2R^2C^2}} \cos\left(\omega t - \cos^{-1}\frac{1}{\sqrt{1 + \omega^2R^2C^2}}\right). \qquad (7)$$

An interesting case occurs when $r/2L = 1/RC$. Inserting this condition in (6) we have

$$E = (V/\omega RC)e^{-rt/2L} \sin \omega t.$$

This is a damped sine wave with no phase displacement and with a first maximum value of $Ve^{-\pi r/4\omega L}/\omega RC$.

If $1/RC \ll r/2L$ we may express (6) as

$$E = (V/RC)\left[\frac{2Le^{-t/RC}}{r^2+4L^2\omega^2} + e^{-rt/2L} \cos\left(\omega t - \cos^{-1}\frac{-r}{\sqrt{r^2+4L^2\omega^2}}\right)\right]. \qquad (8)$$

Fig. 3 is a cathode-ray oscillogram showing the record of an exponential impulse superimposed upon the record of the oscillation caused by such an impulse.[8] The frequency shown in this illustration is given by

$$2\pi f = \omega = \sqrt{(1/Lc - r^2/4L^2)}$$
$$= 13{,}600.$$

Other constants, correct within two per cent, are

$$r/2L = 312$$
$$V = 180 \text{ volts, maximum value of the impulse}$$
$$RC = 0.0000663 \text{ second, time constant of the impulse}$$
$$1/RC = 15{,}100.$$

Inserting these constants in (7),

$$E = -99.3e^{-15,100t} + 134e^{-312t}\cos(\omega t - 0.734). \tag{9}$$

It is interesting to compare this expression with voltage curves shown by the oscillograph. The first term of (9) is shown graphically by the dashed line of Fig. 4 and the second term, by the dotted line. These were plotted by inserting values of time from zero to 0.00080 second, in steps of 0.00002 second. The solid curve of Fig. 4 was obtained by adding the ordinates of the curves representing the terms of (9). Figs. 3 and 4 have been reduced to the same scale. A comparison of the oscillating curve of Fig. 3 with the solid line curve of Fig. 4 illustrates the agreement between the theory and the experimental data. Other comparisons, using different time constants of the exciting impulse, were plotted and when compared in the same manner showed similar agreement.

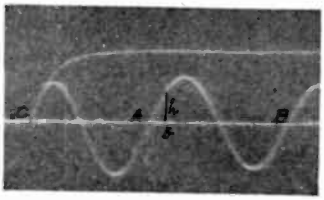

Fig. 3—Oscillogram showing the form of the voltage impulse and the corresponding response of a tuned circuit.

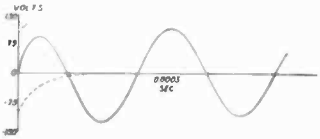

Fig. 4—Voltage-response curve plotted from the mathematical expression showing impulse and circuit constants as in Fig. 3.

The converse problem is to determine the constants of the impulse when the constants of the oscillating circuit and its response curve are known. In the simple case of the single exponential impulse a graphical solution is relatively simple.

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[8] Lambert, "A rotating drum camera for photographing transient phenomena," *Rev. Sci. Instr.*, vol. 8, p. 13; January, (1937).

Find the phase displacement by taking the difference between the distances 0.75 AB and AC (since CA, with an instantaneous impulse, would be three fourths of a period). See Fig. 3. In angular measurement we have the displacement

$$\alpha = 2\pi(AC - 0.75AB)/AB \tag{10}$$

$$\cos^2 \alpha = 1/(1 + \omega^2 R^2 C^2) \tag{11}$$

$$RC = (\tan \alpha)/\omega. \tag{12}$$

On the oscillogram lay off $Ab = \alpha$, the phase displacement, and find the ordinate h of the curve at this point. Then we may say

$$h = \frac{Ve^{-rT/2L(n/2)}}{1 + \omega^2 R^2 C^2}, \tag{13}$$

where T is the period of oscillation and n is the number of half periods of the point b from the origin. This gives

$$V = he^{rnT/4L} \cos^2 \alpha. \tag{14}$$

Combining the results of (12) and (14) in the usual form of an exponential curve representing a condenser discharge,

$$\begin{aligned} v(t) &= V(1 - e^{-t/RC}) \\ &= he^{rnT/4L}(1 - e^{\omega \cot \alpha}) \cos^2 \alpha. \end{aligned} \tag{15}$$

One precaution must be observed in making the measurements indicated. The points of reference, A and b (Fig. 3), must be taken beyond the influence of the first term of (7). For example, if A and B were each moved one period to the right,

$$\alpha = 2\pi[AC - (7/4)AB]/AB.$$

A study of (6) and (7) reveals a number of interesting relations between an exponential impulse and the response of a tuned circuit:

(1) When the time constant of the impulse is zero, that is, if the full value of the charge is released upon the condenser of the circuit instantaneously, the resulting oscillation is in the form of a damped cosine wave without phase displacement (the first maximum occurs at time, $t = 0$) and has the same initial maximum, that of the impulse, for all frequencies of the tuned circuit. Atmospheric disturbances would produce the same maximum voltage in a receiver of high frequency as in one of low frequency if these disturbances were instantaneous.

(2) When the time constant of the impulse is greater than zero, which is true in all practical cases, the response voltage at zero time is zero and the maximum voltage of the response is less than that of the impulse.

(3) With an impulse of given time constant and a circuit of given frequency and decrement, the voltage response is directly proportional to the voltage of the impulse.

(4) It cannot be said, in general, that the voltage response of a tuned circuit to a given impulse is inversely proportional to the frequency of the circuit. This response is governed by the approximate factor, $1/\sqrt{1+\omega^2R^2C^2}$, which we may call the coefficient of maximum unmodified response. It is also the cosine of the phase displacement. If $\omega^2R^2C^2 \gg 1$ the response is approximately inversely proportional to the frequency of the tuned circuit. In the example shown in Fig. 3 this proportionality does not hold for there $\omega^2R^2C^2$ has the value 0.813. Let us say that, approximately, the response is inversely proportional to the frequency if the duration of the impulse variation (up to, say, 90 per cent of the final voltage) exceeds two or three times the period of the oscillating circuit.

(5) It follows from the preceding discussion that, when $1/RC \gg r/2L$, with exponential impulses, the response of the tuned circuit is nearly inversely proportional to the time constant of the impulse if the square of the frequency of the circuit times the square of the time constant of the impulse greatly exceeds unity.

ACKNOWLEDGMENT

The writer wishes to express his appreciation for the special interest and helpfulness of Dr. F. C. Blake and Dr. H. P. Knauss during the pursuance of this study and to Dr. Alva Smith and Dr. W. L. Everitt for helpful criticism offered on the paper.

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(1) Carson, "Theory of the transient oscillations of electrical networks and transmission systems," *Proc. A.I.E.E.*, vol. 38, pp. 407–489; February 21, (1919).

(2) Alexander, "On non-periodic forces, acting on oscillating systems," *Physica*, vol. 2, pp. 273–285; April, (1935).

(3) Osnos, "Eigenschaften eines freischwingenden Kreis es, der Selbstinduktion, Kapazität, und Verlustwiderstand in Reihenschaltung anthält," *Hochfrequenz. und Elektroakustik*, vol. 39, pp. 173–177; May, (1932).

(4) Schilling and Lens, "Der Spannungsverlauf bei der Stossprüfung nach Aufnahmen mit dem Kathodenstrahl-Oszillographen," *Elektrotech. Zeit.*, vol. 52, pp. 107–111; January 22, (1931).

(5) Carson, "Selective circuits and static interference," *Bell Sys. Tech. Jour.*, vol. 4, pp. 265–279; April, (1925).

(6) Morecroft, "Principles of Radio Communication," p. 259–268; John Wiley and Sons, (1921).

(7) Morecroft, "An experiment on impulse excitation," PROC. I.R.E., vol. 8, pp. 75–84; February, (1920).

Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

CHARACTERISTICS OF THE IONOSPHERE AT WASHINGTON, D. C., JANUARY, 1938*

BY

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(National Bureau of Standards, Washington, D. C.)

DATA on the critical frequencies and virtual heights of the ionosphere layers for January, 1938, are given in Fig. 1. Fig. 2 gives the maximum usable frequencies for radio communication in latitudes approximately that of Washington, based on data of Fig. 1.

TABLE I

Date and hour E.S.T.	h_F before sunrise	Min. $f_{F_2}{}^x$ during day kc	Max. $f_{F_2}{}^x$ during day kc	Magnetic character[1] 00–12 G.M.T.	Magnetic character[1] 12–24
{Jan. 25 after 1300	—	below 2,500[2]	8,500 to 10,000	0.6	2.0
{Jan. 26 until 0700	325	below 2,500[2]	—	1.7	1.0
{Jan. 22	407	below 2,500[2]	8,900	2.0	1.9
{Jan. 23 until 0700	326	3,750	—	0.7	0.6
Jan. 17	336	4,800	8,600	1.9	2.0
Jan. 13	330	4,000	10,000 to 13,600	1.4	0.6
Average of undisturbed days	301	4,410	12,770	0.5	0.6

[1] American character figure, compiled by the Department of Terrestrial Magnetism, Carnegie Institution of Washington, from data supplied by its two observatories and five observatories of the United States Coast and Geodetic Survey.

[2] No reflections within range of recorder, 2500 kilocycles and above.

TABLE II

For 441 hours of observations between 1800 and 0900 E.S.T.										
Per cent	−40	−30	−20	−10	−0	+0	+10	+20	+30	+40
Number of hours	3	5	28	115	225	196	98	48	17	5
For 32 hours of observations on Wednesdays between 1000 and 1600 E.S.T.										
Number of hours	0	0	0	2	13	19	0	0	0	0

The average noon and midnight values of *F* critical frequencies in January, 1938, exceeded those for January, 1937, by 400 and 150 kilocycles, respectively. The diurnal minimum f_F at about 0630 local time and the noon f_F for January, 1938, were less than those for January, 1937, by 60 and 160 kilocycles, respectively.

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* Decimal classification: R113.61. Original manuscript received by the Institute, February 9, 1938. This is one of a series of reports on the characteristics of the ionosphere at Washington, D. C. For earlier publications on this subject see PROC. I.R.E., vol. 25, pp. 823–840; July, (1937), and a series of monthly reports beginning in PROC. I.R.E., vol. 25, pp. 1174–1191; September, (1937). Publication Approved by the Director of the National Bureau of Standards of the U. S. Department of Commerce.

Several extremely severe ionosphere storms occurred during January. Data for the storms of January 17 and 22 are shown in Fig. 1. The ionosphere storm of January 25–26 was so severe that either there were no reflections at frequencies above 2500 kilocycles or the reflections were so diffuse and sporadic that critical frequencies and virtual heights could not be determined. This condition obtained from about 1300 E.S.T., January 25 to 0700 E.S.T., January 26. The ionosphere storms for January, 1938, are listed in Table I approximately in the order of their severity.

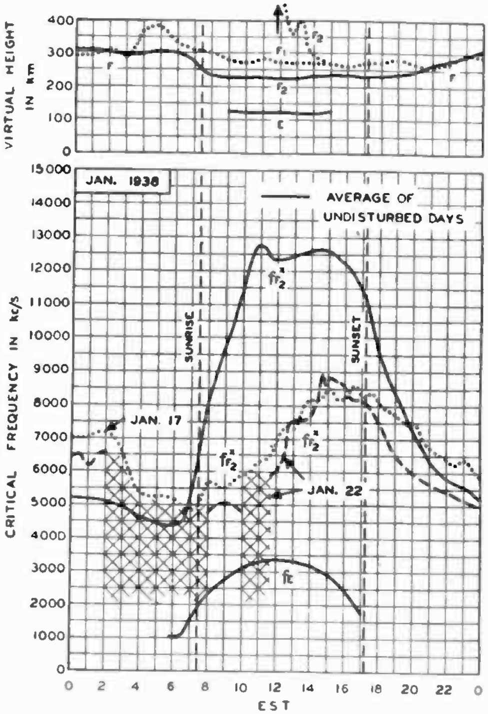

Fig. 1—Virtual heights and critical frequencies of the E, F, and F_2 layers of the ionosphere for January, 1938. The solid curve is the undisturbed average for the month. The dotted and dashed curves are for the days of the very severe ionosphere storms of January 17 and 22, respectively. The cross-hatched portion represents the time on January 22 when no reflections were observed or when the critical frequencies were too poorly defined to measure.

Table II shows the number of hours f_{F^x} differed from the January average of the undisturbed days by more than the given percentages. The usual separation of hours for disturbed and undisturbed days has not been made because of the severity of the ionosphere storms. On most of the hours during these storms either there were no reflections above 2500 kilocycles or the critical frequencies were so poorly defined that they could not be determined. There were 20 such hours during the early morning of January 22, and the night of January 25–26. These hours could not be listed in the percentage variations of Table II but are included in the total of 441 hours of night observations.

The prolonged periods of low-layer daytime absorption described in last month's report continued through January and became extremely pronounced around the time of the severe ionosphere storms, during the latter half of the month. The Bureau has now identified three distinct types of ionosphere irregularities, which, it appears, are associated with sunspot activity. These are ionosphere storms,[1,2,3] fade-outs, and prolonged periods of low-layer absorption. The last two are closely related in the nature of their effects as described last

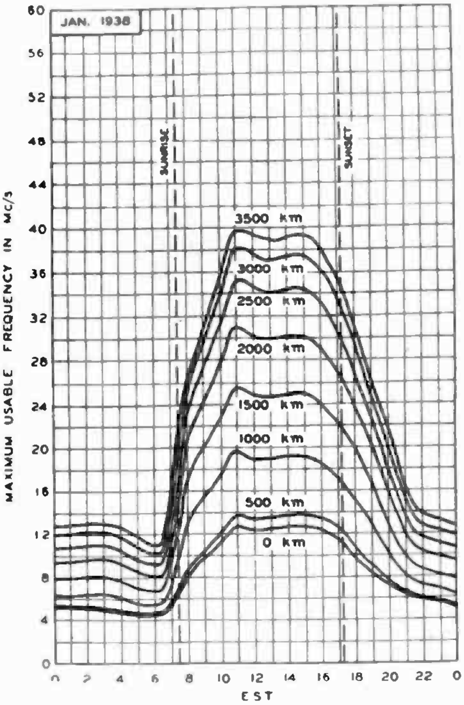

Fig. 2—Maximum usable frequencies for the latitude of Washington; average for January, 1938. The time to be used is local time where the waves are reflected from the ionosphere layer.

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[1] *Phys. Rev.* vol. 48, p. 849, (1935).
[2] *Phys. Rev.*, vol. 50, p. 258, (1936).
[3] *Phys. Rev.*, vol. 51, p. 992, (1937).

month but are believed to be due to different causes. The fade-out has been shown to be caused by a sudden solar flare.[4] The prolonged periods of low-layer absorption appear to be caused by a radiation more continuous during the day and often on a series of days connected with high sunspot activity. The ionosphere storm seems to be caused by an eruptive type of radiation differing in character from that causing fade-outs and occurring at independent times. However, all three of these irregularities are especially prevalent and severe during periods of high sunspot activity such as began about the middle of January.

TABLE III

Date	Beginning of fade-out	Beginning of recovery	Recovery complete	Location of transmitter	Remarks	Min. intensity
Jan. 11..........	1702	1715	1735	Ohio, Mass.		0.1
Jan. 11..........	1935	1945	1954	Ohio, Mass.	Terr. mag.[1] pulse	0.0
Jan. 13..........	1409	—	1420	Ohio		0.1
Jan. 13..........	1528	1546	1559	Ohio, Mass., D. C.	Terr. mag. pulse	0.0
Jan. 14..........	1629	1651	1835	Ohio, D. C.		0.0
Jan. 14..........	1840	—	1857	Ohio		0.1
Jan. 15..........	1708	1716	1724	Ohio, Mass., D. C.	Terr. mag. pulse	0.0
Jan. 15..........	1838	—	1935	Ohio, D. C.		0.1
Jan. 16..........	1640	2020	—	Ohio		0.0
Jan. 19..........	2238	2245	2312	Ohio, Mass.	Terr. mag. pulse	0.0
Jan. 20..........	1800	1815	1840	Ohio, Mass., D. C.	Terr. mag. pulse	0.0
Jan. 20..........	1902	1954	2040	Ohio, Mass., D. C.		0.0
Jan. 21..........	1640	—	1920	Ohio, Mass.		0.0
Jan. 24..........	1810	1818	1850	Ohio, Mass., D. C.		0.0
Jan. 31..........	1552	1630	1720	Ohio, Mass., D. C.		0.0

[1] Terrestrial magnetic pulse observed on magnetograms from Cheltenham Observatory of the United States Coast and Geodetic Survey.

Sudden disturbances of the ionosphere at Washington during January were marked by the radio fade-outs listed in Table III.[5]

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[4] J. H. Dellinger, "Sudden disturbances of the ionosphere," (and references therein), *Nat. Bur. Stand. Jour. Res.*, vol. 19, p. 111; August, (1937); PROC. I.R.E., vol. 25, pp. 1253–1290; October, (1937).

[5] All times G.M.T. Minimum intensities given in terms of transmissions from W8XAL, 6060 kilocycles, distance 650 kilometers.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

CORRESPONDENCE

High-Fidelity Broadcasting at Ultra-High Frequencies

To the Editor:

In the trend towards higher fidelity in radio broadcasting, one of the factors which is of great importance is the volume range. The recent assignment of a new, and still relatively unused, commercial broadcast band from approximately 41 to 44 megacycles, leads one to wonder whether or not steps are being taken to assure the possibility of obtaining greater volume range at the reproducing end of receivers designed for this band.

There appears to be little which can be done to extend the volume range in the present 0.55- to 1.5-megacycle broadcast band. The present tendency of transmitters in this band is to use automatic compressors of the "limiter" type on much of the lower-quality broadcast material. The "limiter" type of compressor is not well suited for automatic expansion at the receiver since the frequency band allotted to each station is too small to permit the transmission of a "monitor" tone. This is especially true when an undefined and sometimes changeable input-versus-output characteristic is used on the compressor. It would be unfortunate if a similar situation were permitted to arise on the 41- to 44-megacycle band without prior consideration of what means for extending volume range are to be used.

The four most important methods of obtaining an increased volume range are:

1. The use of increased transmitter power with a very low average modulation. This is a "brute force" solution which is uneconomical and is now largely outmoded by improved methods.

2. The use of frequency modulation. The successful application of frequency modulation to an increase in volume range may require a somewhat increased band width but offers excellent possibilities otherwise.

3. Use of automatic compression obeying a definite law at the transmitter and automatic expansion obeying an inverse law at the receiver. This method raises the effective modulation percentage and thus increases the apparent power of the transmitter. It may give unsatisfactory reproduction in receivers not equipped with expansion.[1]

4. Use at the transmitter of a "monitor" tone of (preferably) superaudible frequency which is separated from the sound modulation at the receiver. The tone is then used to control the receiver expansion exactly in an inverse manner to the monitoring at the transmitter. This method permits the use of any form of monitoring at the transmitter and thus does not affect reproduction in receivers not equipped with an expander. Additional side-band room is required and the receiver cost may be increased somewhat by the involved filtering needed for this system.

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[1] Satisfactory application of this method appears to restrict the input-versus-output relationship of expander and compressor to a power law and its inverse. Mathes and Wright, *Elec. Eng.*, vol. 53, p. 860; June, (1934), state that the voice sounds "slightly unnatural" when power-law compression is used without expansion.

In the new 41- to 44-megacycle band, it should be possible to adopt any one of the above methods. With all but the first one, however, it would be desirable to set up standards in order to permit commercial receiver design. If the third method is adopted, the law to be used in the compressor should be defined. In the case of the "monitor tone" system, the frequency of the tone should he standardized.

It might be well if the problem of obtaining extended volume range be studied in detail by a technical committee representing the interests of both the broadcast industry and the public. It should be considerably less difficult to treat the problem of wide-volume-range sound reproduction than the problems involved in setting up standards for the video portion of a television system.

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Proceedings of the Institute of Radio Engineers
Volume 26, Number 3 *March, 1938*

BOOK REVIEW

Dictionary of Radio Terminology in the English, German, French, and Russian Languages, by A. S. Litvinenko, edited by Prof. V. I. Bashenoff. Published by ONTI NKTP, Moscow, 1937, 559 pages. Price $4.00. Distributors for North and South America, Bookniga Corporation, 255 Fifth Ave., New York, N. Y.

This dictionary in the English, German, French, and Russian languages has been prepared to serve, primarily, as an aid to the engineer in making translations from any one of these languages into the other three. A further important end is served by it in providing a comparative survey of the terminology of radio and related subjects found in the current literature of these languages. This should prove useful in further standardization of radio terminology.

The book begins with a preface, repeated in each of the four languages, which deals with the problems which enter into the establishment of a consistent and exact terminology. Illustrations of existing imperfections in terminology follow. Directions for the use of the dictionary and explanation of the abbreviations and symbols used are also repeated in each of the four languages.

The dictionary itself is arranged in four parallel columns, on each page, with equivalents in a single language only in each column. By an ingenious arrangement English words printed in heavy type in the English column follow each other in alphabetical order, and similarly for each of the other columns. To find the equivalents of a given English word, for example, the given word is located, in its proper alphabetical position, among the words in heavy type in the English column, and the German, French, and Russian equivalents appear in ordinary type in their proper columns on the same horizontal line with the English word.

The dictionary includes not only radio terms but other electrical terms and words occurring in acoustics, optics, and fields connected with radio communication. The whole work gives evidence that no pains have been spared to make the work complete and accurate.

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Kirby, S. S.: See PROCEEDINGS for January, 1938.

Lambert, Ray: Received S.B. degree, Mt. Union College, 1915; B.S. degree in education, Kent State University, 1917; M.A. degree in physics, Ohio State University, 1931; additional graduate work, Ohio State University and University of Cincinnati. Engaged in secondary education, Walnut Hills High School, Cincinnati, Ohio. Member, Phi Delta Kappa and Sigma Xi. Nonmember, Institute of Radio Engineers.

Linder, Ernest G.: Born 1902, at Waltham, Massachusetts. Received B.A. degree, 1925; M.S. degree, 1927, University of Iowa. Instructor in physics, State University of Iowa, 1925–1927; instructor, California Institute of Technology, 1927–1928; Detroit Edison Research Fellow, Cornell University, 1928–1932; received Ph.D. degree, Cornell University, 1931. Research division, RCA Victor Company, Inc., 1932–1935; RCA Manufacturing Company, Inc., RCA Victor Division, 1935 to date. Member, American Physical Society. Nonmember, Institute of Radio Engineers.

Pierce, John R.: Born March 27, 1910, at Des Moines, Iowa. Received B.S. degree, 1933; M.S. degree, 1934; Ph.D. degree, 1936, California Institute of Technology. Bell Telephone Laboratories, 1936 to date. Member, Tau Beta Pi; Sigma Xi; American Physical Society. Associate member, Institute of Radio Engineers, 1937.

Reymer, S. E.: See PROCEEDINGS for January, 1938.

Shockley, William: Born February 13, 1910, at London, England. Received B.Sc. degree, 1932, California Institute of Technology; Ph.D. degree, 1936, Massachusetts Institute of Technology. Teaching Fellow, Massachusetts Institute of Technology, 1932–1936. Member of Technical staff, Bell Telephone Laboratories, 1936 to date. Member, Tau Beta Pi; Sigma Xi; American Physical Society. Nonmember, Institute of Radio Engineers.

Smith, Newbern: See PROCEEDINGS for January, 1938.

Ware, Paul: Born 1893, at East Orange, New Jersey. Amateur, 1904 to date; marine operator, 1907–1912. Received M.E. degree, Stevens Institute of Technology, 1917. Developed two-way break-in trench set known as SCR 77 during World War. Head of Ware Radio Corporation, 1923–1926. Radio consulting and development work, 1926 to date. Associate member, Institute of Radio Engineers, 1917.

Woodyard, John R.: Born 1904, at Parkersburg, West Virginia. Received B.S. degree in electrical engineering, University of Washington, 1933; graduate student, 1933–1934. Instructor in electrical engineering, University of Washington, 1935–1936. Graduate student, Stanford University, 1936 to date. Member, Sigma Xi. Student member, Institute of Radio Engineers, 1933; Associate, 1935.

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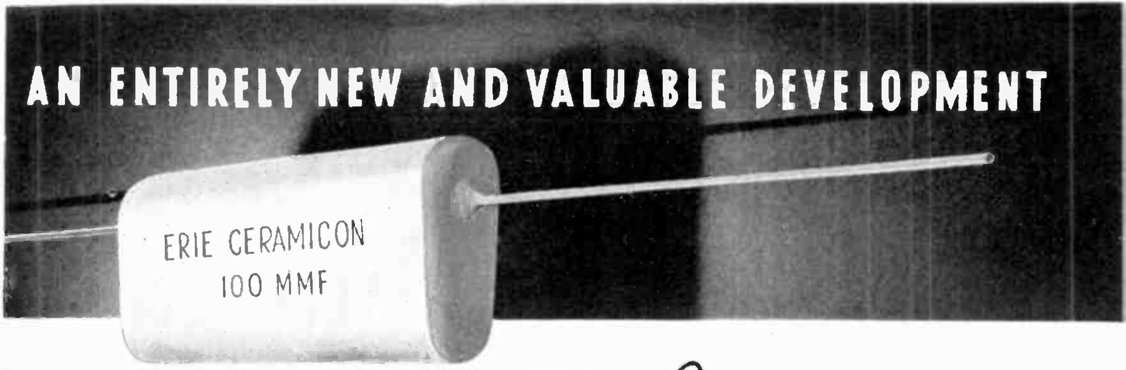

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FOR CONTROLLING REACTANCE DRIFT IN TUNED OSCILLATOR CIRCUITS

ERIE Ceramicons are unusual in that they have a definite, linear and reproducable temperature coefficient of capacity. These small fixed condensers are available as single units with either a positive temperature coefficient of 1.2 x 10^{-4} per °C. or a negative coefficient of 6.5 x 10^{-4} per °C.

These features have led to the development of Erie Compensating Ceramicons, consisting of two Ceramicons connected in parallel and mounted in a single sealed case. By properly proportioning the capacities between the two units, practically any temperature coefficient within the limits of the single units may be obtained. Where the desired temperature coefficient is identical with that of either unit, only one Ceramicon is used.

Engineers will readily appreciate the particular value of Erie Compensating Ceramicons for controlling reactance drift due to heating in tuned high frequency circuits, such as in receivers designed for push button tuning.

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Total capacity at room temperature. (State temperature)________	NAME________
Tolerance on capacity at room temperature.________	TITLE________
Percent change in capacity from 30° to 60° C. (or other desired range)________	COMPANY________
Tolerance on capacity change.________	STREET________
	CITY________

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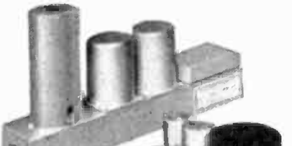
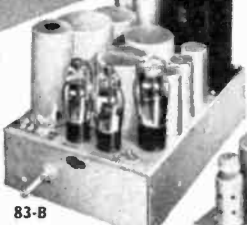
Here they are! A complete new line of high fidelity amplifiers. Designed primarily for stringent broadcasting requirements, they are low in cost, convenient to use. Built in chassis form, they may also be rack mounted.

RCA 85-A Preamplifier
A small single stage unit having a gain of 30 db. Input impedance 30 and 250 ohms. Output impedance 250 ohms. Six of these may be mounted on one 36-A shelf. Dimensions 2½″ wide by 12½″ deep by 6″ high. Plate power obtainable from any RCA Program type Amplifier. One filament transformer will operate six 85-A's.

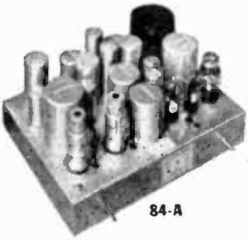


85-A

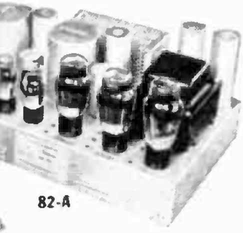
RCA 83-B Isolation Amplifier
A two stage unit for feeding several circuits from one source. Over-all gain 46 db max. Input impedance 500 and 22,000 ohms. Output impedance 500, 250, 125, 62.5 and 10.5 ohms. Max. Output Level plus 10 db for 1% distortion or plus 20 db for 3.5% distortion. Dimensions 8″ x 13½″ x 8″. A. C. operated. Two 83-B's may be mounted on one 36-A shelf.



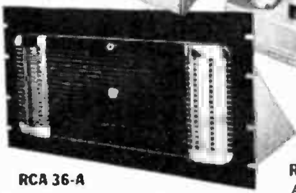
83-B



84-A



82-A



RCA 84-A Program Amplifier
A line or program amplifier having an over-all amplification of 75 db max. Input impedance, 250, 500 or 20,000 ohms. Output impedance 250 and 500 ohms. Supplies plate voltage for one to six 85-A units. Provided with gain control. Dimensions 16″ x 13″ x 7⅜″. A.C. operated.

RCA 36-A
Mounting Shelf and Panel Assembly
For mounting any of these units on a relay rack.

For full details write to the nearest district office.

These amplifiers are designed for use with RCA tubes—dependable, economical.

RCA 82-A Monitoring Amplifier
A low distortion amplifier employing feedback, with 8 watts maximum output for loudspeaker use. Over-all gain 67 db. Input impedance 500 and 20,000 ohms. Output impedances 500, 15, 7½, 5 ohms. External gain control. Dimensions 16″ x 10″ x 7″. A. C. operated.

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RCA Mfg. Co., Inc., Camden, N.J. • A Service of the Radio Corporation of America

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3-38

The Institute of Radio Engineers

Incorporated

330 West 42nd 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 Directors

Gentlemen:

I hereby make application for Associate membership in the Institute of Radio Engineers on the basis of my training and professional experience given herewith, and refer to the members named below who are personally familiar with my work.

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. Furthermore I 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.

(Sign with pen)

(Address for mail)

(Date)

(City and State)

Sponsors:

(Signature of references not required here)

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

Mr. ....

Address ....

City and State ....

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: * * * (c) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold any elective office specified in Article V. * * *

Sec. 4. An Associate shall be not less than twenty-one years of age and shall be a person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION AND EXPULSIONS

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to three Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a full record of the general technical education of the applicant and of his professional career.

ARTICLE IV—ENTRANCE FEE AND DUES

Sec. 1: * * * Entrance fee for the Associate grade of membership is $3.00 and annual dues are $6.00.

ENTRANCE FEE SHOULD ACCOMPANY APPLICATION

(Typewriting preferred in filling in this form) No..................

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

Name ....
(Give full name, last name first)

Present Occupation ....
(Title and name of concern)

Business Address ....

Permanent Home Address ....

Place of Birth .... Date of Birth .... Age ....

Education ....

Degree ....
(College) (Date received)

TRAINING AND PROFESSIONAL EXPERIENCE

DATES	

Record may be continued on other sheets of this size if space is insufficient.

Receipt Acknowledged .... Elected .... Deferred ....
Grade .... Advised of Election .... This Record Filed ....

INDEX TO ADVERTISEMENTS

ENGINEERING POSITIONS OPEN

Graduate Engineer, 27-35 years old, with experience in high-voltage applications and good commercial sense wanted to supervise installation and maintenance of X-ray equipment. The applicant's personal qualities—appearance, intelligence and the ability to handle men—must be of high order. Include a complete list of former employers with positions held, and address Box 183, c/o Institute of Radio Engineers, 330 West 42nd Street, New York, N.Y.

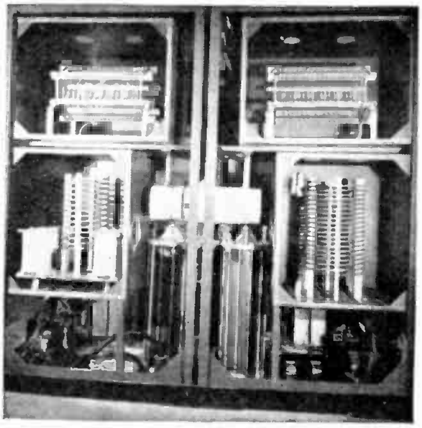
ENGINEERING POSITIONS

Advertisements on this page are accepted from organizations interested in employing Institute members. Information on rates, preparation of material, and closing dates will be mailed on request.

THE INSTITUTE OF RADIO ENGINEERS
330 West 42nd Street
NEW YORK, N.Y.

ENGINEERING DIRECTORY

DOHERTY CIRCUIT INCREASES AMPLIFIER EFFICIENCY BY MORE THAN 100%!



Rear view of the new 50KW amplifier which employs the Doherty high efficiency circuit.

Distributors:
Graybar Electric Company
In Canada:
Northern Electric Co., Ltd.
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Distributed by Graybar

The famous Doherty Circuit—developed by Bell Telephone Laboratories—increases the efficiency of the power amplifier stage from the usual *30% to over 60%.*

In the past, approximately ⅔ of the plate power supplied to radio frequency amplifier tubes was lost by dissipation.

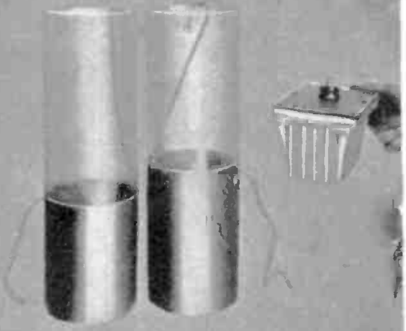
Today, the Doherty Circuit—used in Western Electric's new radio transmitters—greatly reduces plate dissipation, which minimizes tube cooling requirements. It makes possible the use of smaller circuit elements, saving space—gives increased stability and greater ease of adjustment—reduces outlay for auxiliary equipment—results in marked operating economies.

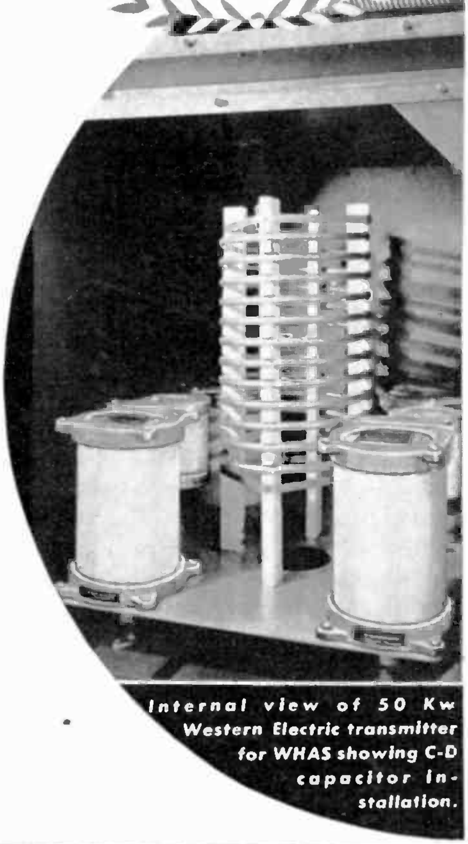
For full details on these pace-setting Western Electric transmitters with the Doherty Circuit, write to Graybar, Graybar Building, New York.

Western Electric

RADIO TELEPHONE BROADCASTING EQUIPMENT

28 YEARS AGO





Internal view of 50 Kw Western Electric transmitter for WHAS showing C-D capacitor installation.

DUBILIER produced the first practical mica condenser for use in wireless transmission! It was tested . . . it worked! The old, clumsy, fragile, unsatisfactory Leyden jar was at last replaced.

That early condenser looks strange today when you compare it to the modern compact C-D capacitors now being used in the majority of leading transmitting stations. Yet one vital factor links the new with the old . . . **DEPENDABILITY**.

Solid DEPENDABILITY was there in that first condenser twenty-eight years ago . . . it is still there today!

Send for Catalog No. 160 listing in detail the entire line of C-D capacitors.

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MICA · DYKANOL · PAPER · WET & DRY ELECTROLYTICS

JUNE 1938

SUN.	MON.	TUE.	WED.	THU	FRI	SAT.
FIRST QR 4TH	FULL MOON 12TH	LAST QR 20TH	1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	NEW MOON 27TH	..

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No matter where in radio or allied engineering your interests lie, this year's annual convention and exhibition will be worth traveling a long way to attend.

There is no other easier way of keeping abreast of technical developments in our rapidly changing art. And there is no better way of broadening your professional outlook than this 3-day meeting with 1000 other engineers having interests like your own.

The program now in preparation will include

- Reading and discussion of technical papers
- Entertainment for the women guests of members
- The exhibition of new instruments, materials, and components—an important feature of I.R.E. Annual Conventions since 1930

Did You Notice . . ?

that the convention will open 4 days earlier than the date announced in last month's Proceedings? A conflict that became evident after the February issue had been mailed caused the change.

Look for full details of the convention program in the June Proceedings.

Address suggestions for technical papers and reservations for exhibition space to

INSTITUTE OF RADIO ENGINEERS
330 WEST 42ND STREET, NEW YORK, N. Y.

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