VOLUME 20 JUNE, 1932 NUMBER 6

Walter J Malone
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PROCEEDINGS
of
The Institute of Radio Engineers

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Institute of Radio Engineers Forthcoming Meetings

ATLANTA SECTION
June 9, 1932

DETROIT SECTION
June 17, 1932

LOS ANGELES SECTION
June 21, 1932

NEW YORK MEETINGS
June 1, 1932

SAN FRANCISCO SECTION
June 15, 1932

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 20 June, 1932 Number 6

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Technical Papers

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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 of Boston, Massachusetts, and the Wireless Institute of America of New York City. Its headquarters were established in New York City and the membership has grown from less than fifty members at the start to almost seven thousand by the end of 1931.

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 need 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.

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33 West 39th Street, New York, N. Y.

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GEOGRAPHICAL LOCATION OF MEMBERS ELECTED MAY 4, 1932

Transferred to the Member Grade

Massachusetts	Arlington, 27 Howard St.	Shea, R. F.
Michigan	Ann Arbor, 270 W. Engineering Bldg., University of Michigan	Holland, L. N.
Ohio	Cleveland, Radio Air Service Corp., 1311 Terminal Tower Bldg.	Gove, E. L.
Washington	Seattle, 615 Boren Ave.	Tolmie, J. R.
England	Dorchester, Dorset, 41 South St.	Dawes, R. M.

Elected to the Member Grade

England	12 St. Michaels Ave., Westoe, S. Shields, Co. Durham	Bloxam, R. W. H.
Scotland	Glasgow, 112 Beechwood Dr., Broomhill	Thomson, D. R.
Straits Settlements	Singapore, Wireless Station Paya Lebar	Dupree, F. H.

Elected to the Associate Grade

Arkansas	Helena, c/o Dixie Furniture Company	Young, R. L.
California	Los Angeles, P. O. Box 804	Hurt, L. J.
	Los Angeles, 1835 W. 25th St.	Lewis, V. F.
	Los Angeles, 765½ E. Vernon Ave.	Mestas, R.
	Oakland, 2415-23rd Ave.	Carlson, E. J.
	San Francisco, 928 Broderick St.	Gray, K. B.
	San Francisco, 2242 Anza St.	Hood, L.
Connecticut	Hamden, 38 Concord St.	Reader, W. A.
Delaware	Seaford, P. O. Box 185	Ellis, E. T.
Dist. of Columbia	Washington, Office of Chief Signal Officer	Guest, W. T.
	Washington, 1337 Girard St.	Hurvitz, H.
	Washington, 1201-16th St., N.W.	Tyler, T. F.
Georgia	Atlanta, Georgia School of Technology	Gerks, I. H.
Idaho	American Falls, 723 Stevens St.	Fields, W. B.
Illinois	Chicago, 1133 S. Whipple St.	Hartman, A. M.
	Chicago, 6139 Michigan Ave.	McCleary, B. J.
Massachusetts	Allston, 209 Warren St.	Pelissier, C. A.
	South Hadley, Mt. Holyoke College	Fletcher, H. M.
Missouri	St. Louis, 819 Telephone Bldg.	Wardell, W. L. C.
	University City, 7410 Liberty Ave.	Ramey, P. A.
New Jersey	Camden, 2115 S. Berwick St.	Neville, J. A.
	Camden, 539 Vine St.	Rogers, W. H.
	Camden, 220 Cooper St.	Townsley, F. W.
	Haddon Heights, 1940 Bryn Mawr Ave.	Owsley, O. M.
	Oaklyn, 16 Ormond Ave.	Robins, B. W.
	Pensauken, 3423 Pennsylvania Ave.	Sweeney, J. A.
	Westmont, 16 Virginia Ave.	Russell, J. F.
New York	Brooklyn, 1663-76th St.	Chasin, G.
	Long Island City, 31-31-29th St.	Reiskind, H. I.
	New York City, Bell Tel. Labs., 463 West St.	Borden, C. C.
	New York City, Tropical Radio, Pier 3, N.R.	Monaghan, P. E.
	New York City, S.S. Margaret, c/o A. H. Bull & Co., 115 Broad St.	Strobel, C. J.
	New York City, 457 W. 47th St.	Von Baudissin, J.
	New York City, 51 W. 76th St.	Wolters, B. J.
	Woodside, 5411-32nd Ave.	Gamble, W. T.
Ohio	Canton, 1220 Louisianna Ave., N.W.	Phillips, W. M.
Oregon	Albany, 1537 Salem Rd.	Hoffman, C. A.
	Salem, 1418 Lana Ave.	Ramage, W. W.
Pennsylvania	Philadelphia, 6829 N. 9th St.	Whitney, A.
Washington	Port Angeles, U.S.C.S. Snohomish	Davis, H. P.
	Seattle, U.S.C.G., S.S. Surveyor, 202 Burke Bldg.	Throndsen, T.
	Seattle, 4230 University Way, Apt. L.	Young, J. L.
Australia	Melbourne, c/o Amalgamated Wireless (A/sia), Ltd.	Baird, W. R.
England	Barnoldswick, Via Colne, Lancs., Church St.	Slater-Tomlinson, R.
	Chelmsford, Essex, 54 New St.	Konteschweller, M.
	Chipstead, Surrey, "South", Pine Walk	Mordaunt, N. C.
	Lincoln, Magpie Sq. P. O., 1, 1a, & 3 Melville St.	Harrison, P. L.
	London, Rotherhithe, S.E. 16, 40 Old Rd.	Davis, J. G.
	Sutton, Surrey, 74 Egmont Rd.	Bridgewater, T. H.
	Swanage, Dorset, 2 Grosvenor Rd.	Hardy, R. V.
	York, 69 Thorpe St.	Budden, G. F.
Federated Malay States	Selangor, Glenmarie Estate, Batu Tiga	Salt, G. W.
Italy	Milano, Via S. Andrea 18	Corbellini, G, P.
Japan	Hiroshima-Hosokyoku, c/o Hara-Hososho	Tamagawa, S.
	Ibarakiken, Hiraiso Radio Lab., Hiraiso-Musen	Tukada, T.
	Kochi City, Kochi Broadcasting Station	Matsui, S.

Geographical Location of Members Elected May 4, 1932

North Wales	Cefn, "Plaskynaston", Wrexham	Ellis, R. F.
South Africa	Natal, c/o J. S. Ramsay (Pty.) Ltd., 3 Carlyle Arcade, P. M. Burg	Purefoy, H. B.

Elected to the Junior Grade

Indiana	Angola, 407 W. South St	Gibbs, W. C.
North Carolina	Raleigh, 715 S. Boylan Ave	Browning, W. P.
Australia	Ashfield, N.S.W., 1 Julia St	Maynard, F. S.

Elected to the Student Grade

Arkansas	Fayetteville, 513 Highland Ave	Jamison, D. B.
California	Berkeley, 2533 Chilton Way	Atkinson, E. B.
	Berkeley, 1001 Heinz Ave	Carlsen, G. H.
	Berkeley, 2574 Bancroft Way	Cassidy, J. J., Jr.
	Berkeley, 2226 Roosevelt Ave	Miller, G. R.
	Berkeley, 2620 Bancroft Way	Moody, W. S.
	Berkeley, 2511 Regent St	Selby, E. R.
	Berkeley, 2428 Bancroft Way	Sparks, N. R.
	Oakland, 265 Vernon St	Jones, M. R., Jr.
	Oakland, 567-63rd St	McLeod, W. J.
	Palo Alto, 383 College Ave	Freeman, R. L.
	Palo Alto, 1033 Guinda St	Starner, C. J.
	San Francisco, 469-25th Ave	Kruger, H. C.
Maine	Bath, 28 Court St	McCole, J. E.
Massachusetts	Tufts College	Nute, P. R.
Washington	Vancouver, 3324 L St	Grant, H. H., Jr.
Canada	Galt, Ont., 41 Lansdowne Rd. N	Jansen, A. A.
	Toronto, Ont., Suite 9, Westview Apts., 33 Christie St	Bayley, A. K.
	Toronto, Ont., 784 A St. Clair Ave. W	Falconer, J. L.
	Toronto, Ont., 158 St. George St	Lindsay, J.
	Toronto, Ont., 60 Greenville St	Lochead, W. J.
	Toronto, Ont., 8 Maitland Pl	McCaughrin, W. O.
	Toronto, Ont., 526 Windermere Ave	Patterson, M. C.
	Toronto, 12, Ont., 63 Broadway Ave	Peddie, L. W.
	Toronto, Ont., 403 Huron St	Reid, J. E.
	Toronto, Ont., 36 Ashland Ave	Whalley, W. B.
	Toronto, Ont., 46 Westmount Ave	Wilson, A. L.

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before July 5, 1932. Final action on these applications will be taken on July 6, 1932.

For Election to the Associate Grade

California	Berkeley, 1731 Allston Way	Dhami, B. S.
	Oakland, U.S.C.G. Cutter Tahoe	Kelly, R. P.
Dist. of Columbia	Washington, Rm. 2534 Navy Department Bldg.	Brown, T. H.
Illinois	Chicago, 6602 S. Troy St.	Hermanny, W.
	Highland Park, 417 McDaniels Ave.	Salyards, W. E.
Massachusetts	Pittsfield, 22 First St.	Robie, E. B.
Missouri	St. Louis, 1010 Pine St.	Houck, L. J.
New Hampshire	Lancaster, 84 Middle St.	Eilenberger, S. D.
New Jersey	Haddon Heights, 1001 Sycamore St.	St. Clair, E. L.
	Livingston, Northfield Ave.	Fund, S. R.
	Oceanport, 15th Signal Service Co., Ft. Monmouth	Kane, G. C.
New York	Brooklyn, 29 Jefferson St.	Davis, H. E.
	New York City, c/o J. A. Ewing & McDonald, Inc., 8-10 Bridge St.	Bottner, M. E.
	New York City, 180 Varick St.	Krauth, E. A.
	Poughkeepsie, 182 S. Grand Ave.	Mahler, R. J.
	Rocky Point	Thornton, J. P.
Ohio	East Cleveland, 15621 Terrace Rd.	Bennett, M. T.
	Mansfield, Radio Station WJW	Myers, M. L.
Oregon	Portland, 9611-58th Ave. S.E.	Anderson, H. C.
Pennsylvania	Lancaster, 132 E. Lemon St.	Rettig, A. C.
	Oxford, 418 E. Market St.	Jones, T. J.
	Philadelphia, 1321 Arch St., 2nd Fl.	Leitch, J. G.
	Pittsburgh, Carnegie Tech., Schenley Park	Gabler, R. T.
Texas	Brooks Field, 22nd Observation Squadron A.C.	Allday, C. L.
Vermont	Winooski, 18 Leclair St.	Bigwood, R. F.
Washington	Palouse, Box 314	Bockmier, C. F.
Wisconsin	Madison, Radio Dept., Northwest Airways, Inc.	Benson, G. A.
Australia	Adelaide, St. Peters, 68-8th Ave.	Wicks, J. J.
Canada	Saint John, N.B., 38 Cranston Ave.	Ruthen, A. S. R.
	Toronto, Ont., 291 Huron St.	Armstrong, A. T.
	Toronto, Ont., 683 Soudan Ave.	Banton, K.
	Toronto, Ont., 26 Tichester Rd., Apt. 407	Cockburn, N. A.
	Toronto 8, Ont., 425 Ashdale Ave.	Corless, C. J.
	Toronto 3, Ont., 86 Morningside Ave.	Nesbit, W. D.
	Toronto, Ont., 35 Nasmith Ave.	Sachs, M.
	Toronto, Ont., 497 Whitmore Ave.	Sparkes, P.
Canal Zone	Balboa, U.S.S. Sciota	Potter, G. E.
England	Bishopston, Bristol, 9 Salthrop Rd.	Stephen, D. A.
	Chelmsford, Essex, Marconi College	Rifaat, T.
	Chelmsford, Essex, Marconi College	Zayoona, J. H.
	Plymouth, Devon, 26 Carlisle Terrace, The Hoe	D'Hesse-Chubb, K.
	Westcliff-on-Sea, Essex, 99 Eastwood Blvd.	Cowley, R. I.
Hawaii	Kauai, Kealia	Wada, J. C.
Italy	Naples, Via Ludorico Bianchini 25	Demedici, L.
Japan	Hiroshimaken, J.O.F.K. Hara Sending Station, Haramura, Asagun	Mizuno, T.
	Nagoya City, Okehazama Hosojyo, Arimatu-cho	Nakamura, H.
	Tokio, 3394 Oi-machi	Enomoto, I.
Sweden	Goteborg, Kungsgatan 8	Lundwall, B. H.

For Election to the Junior Grade

Michigan	Petosky, P.O. Box 165	Schaaf, R. H.
Ohio	North Lima	Goodwin, W. J.

For Election to the Student Grade

California	Berkeley, 2740 Mabel St.	Pape, K. R.
	Berkeley, 2515A Piedmont Ave.	Roy, W. H.
	Hollywood, 1644 Winona Blvd.	Gallagher, W. S.
Kentucky	Winchester, 335 S. Maple	Friel, F. J., Jr.
Minnesota	Minneapolis, 531 Walnut St., S.E.	Clements, L. R.
North Dakota	Grand Forks, Box 307, University Station	Becken, E. D.
	Grand Forks, Box 487, University Station	Denk, W. E.
	Grand Forks, 1102 Reeves Dr.	Moore, R.
	Grand Forks, Box 113, University Station	Stratmoen, A.

Ohio	Camp Chase	Sloan, C. B.
	Columbus, 2256 Neil Ave.	Mueller, W. P.
	Columbus, 51 W. Frambes Ave.	Pelikan, B. Z.
	Columbus, 2163 Neil Ave.	Ross, A. J.
	Columbus, 231 16th Ave.	Smart, P. H.
	Columbus, 90 E. 12th Ave.	Welker, J. W.
	Franklin, 744 S. Front St.	Bryant, V. D.
	Sandusky, 532 Decatur St.	Winkler, L.
	Troy, 29 S. Walnut St.	Thomas, S. O.
Washington	Seattle, 4524 20th Ave., N.E.	Mendenhall, G. G.
	Seattle, 2621 41st Ave., S.W.	Scott, E. D.
	Seattle, Route 8, Box 428	Taylor, R. L.
Wisconsin	Milwaukee, 1929 W. Meinecke Ave.	Plautz, A.

OFFICERS AND BOARD OF DIRECTORS, 1932

(Terms expire January 1, 1933, except as otherwise noted)

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Vice President
E. V. Appleton

Treasurer
Melville Eastham

Secretary
Harold P. Westman

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H. W. Houck
R. H. Marriott
William Wilson

Serving until January 1, 1934

L. M. Hull
R. H. Manson, *Junior Past President*
A. F. Van Dyck

Serving until January 1, 1935

O. H. Caldwell
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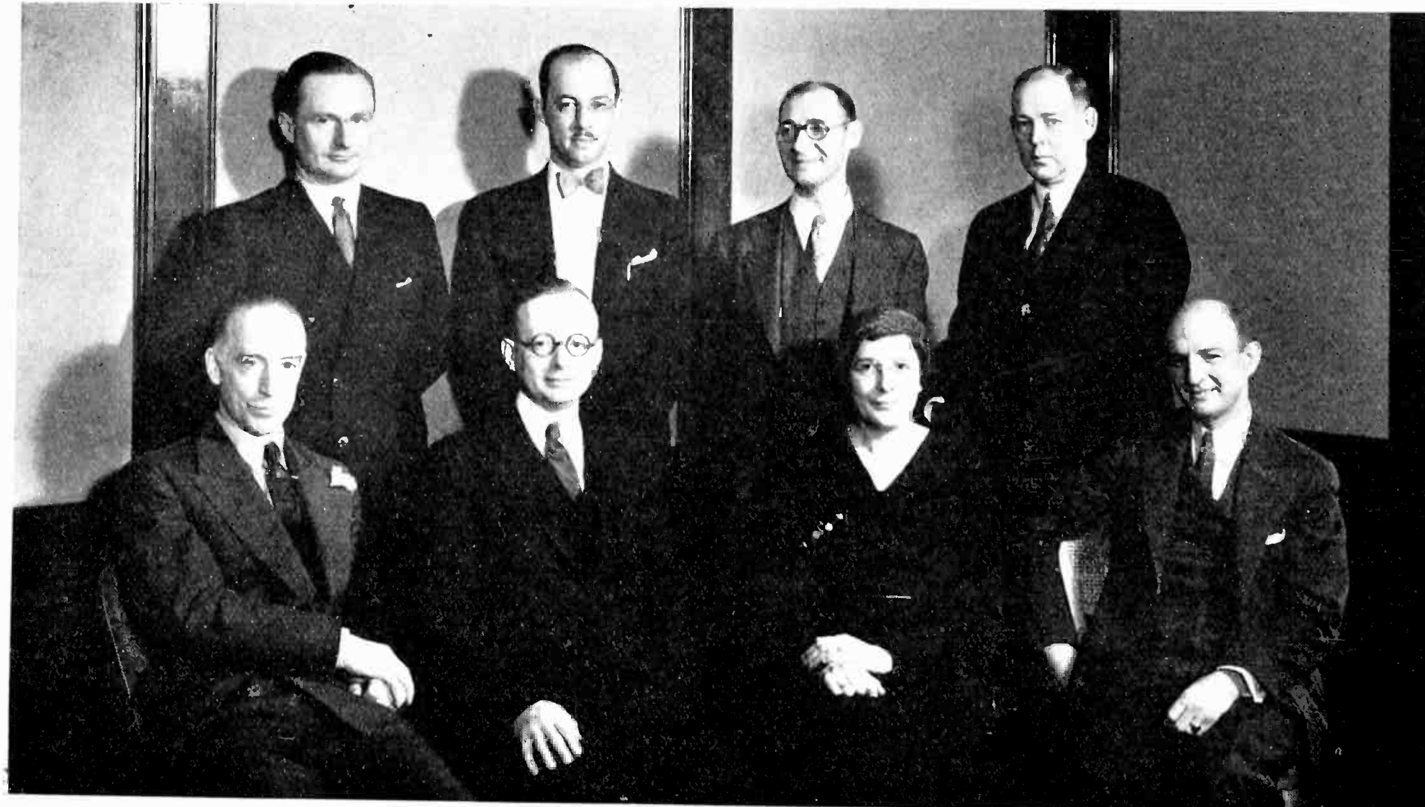

1932 CONVENTION COMMITTEE

The above group are members of the committee responsible for arrangements for the Twentieth Anniversary Convention of the Institute held in Pittsburgh on April 7, 8, and 9, 1932.

Seated from left to right are F. G. Rogers, J. G. Allen, chairman; Miss E. L. Gardner, K. F. Treschow, and standing from left to right are W. C. Evans, R. T. Griffith, L. A. Terven, and L. W. Chubb. Three other members of the committee who are not in the above group are W. C. Bowan, Paul Caldwell, and J. M. Froelich.

INSTITUTE NOTES

Nomination and Election of Officers

In accordance with the Constitution of the Institute, there is printed below Article 7 of the Constitution concerning nomination and election of officers. In addition there is published Section 3 of Article 5 of the Constitution which provides for the election of two additional directors at this first election to be held under the new Constitution.

ARTICLE VII

NOMINATION AND ELECTION OF PRESIDENT, VICE PRESIDENT, AND THREE DIRECTORS AND APPOINTMENT OF SECRETARY, TREASURER, AND FIVE DIRECTORS

SEC. 1—On or before July 1st of each year the Board of Directors shall call for nominations by petition and shall at the same time submit to qualified voters a list of the Board's nominations containing at least two names for each elective office, together with a copy of this article.

Nomination by petition shall be made by letter to the Board of Directors setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acceptance a letter of petition must reach the executive office before August 15th of any year, and shall be signed by at least thirty-five Fellows, Members, or Associates.

Each proposed nominee shall be consulted and if he so requests his name shall be withdrawn. The names of proposed nominees who are not eligible under the Constitution, as to grade of membership or otherwise, shall be withdrawn by the Board.

On or before September 15th, the Board of Directors shall submit to the Fellows, Members, and Associates in good standing as of September 1st, a list of nominees for the offices of President, Vice President, and three Directors. This list shall comprise at least two names for each office, the names being arranged in alphabetical order and shall be without indication as to whether the nominees were proposed by the Board or by petition. The ballot shall carry a statement to the effect that the order of the names is alphabetical for convenience only and indicates no preference.

Fellows, Members, and Associates shall vote for the officers whose names appear on the list of nominees, by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's written signature. No ballots within unsigned outer envelopes shall be counted. No votes by proxy shall be counted. Only ballots arriving at the executive office prior to October 25th shall be counted. Ballots shall be checked, opened, and counted under the supervision of a Committee of Tellers, between October 25th and the first Wednesday of November. The result of the count shall be reported to the Board of Directors at its first meeting in November and the nominees for President and Vice President and the three nominees for Directors receiving the greatest number of votes shall be declared elected. In the event of a tie vote the Board shall choose by lot between the nominees involved.

SEC. 2—The Treasurer, Secretary, and five appointive Directors shall be appointed by the Board of Directors at its annual meeting for a term of one year or until their successors be appointed.

ARTICLE V

SEC. 3—Three Directors shall be elected by the membership annually and shall serve for three years each. At the first election under this Constitution, additional Directors shall be elected, one for one year and one for two years.

The following candidates have been nominated by the Board of Directors for these various offices, and the names are given below together with brief sketches covering their participation in Institute affairs. In cases where committee work is indicated, the figures cover only the last five years, 1928 to 1932, inclusive. Dates and grades of membership are indicated in parenthesis after the name, the grades being abbreviated to the initial letter.

FOR PRESIDENT

Hooper, S. C. (F'28), Director, Naval Communications, Navy Department, Washington, D. C.

Hull, Lewis M. (J'17–A'19–M'27–F'28), Vice President, Radio Frequency Laboratories, Boonton, N. J. Member, Board of Directors, 1929–1932. Admissions Committee, 1928; chairman, Broadcast Committee, 1929–1931; member, Broadcast Committee, 1932; New York Program Committee, 1931; Nominations Committee, 1931; Papers Committee, 1928, 1929, 1931; Standards Committee, 1928.

FOR VICE PRESIDENT

Poulson, Valdemar (F'15), Consulting Engineer, Gentofte, Denmark.

Zenneck, Jonathan (M'13–F'15), Professor, Technische Hochschule, Muenchen, Germany. Recipient, Institute Medal of Honor, 1928.

DIRECTORS

Batsel, M. C. (A'21–F'27), Chief Engineer, RCA Photophone, Inc., New York. Member, Bibliography Committee, 1930–1932; New York Program Committee, 1931–1932; Papers Committee, 1928–1929; Standards Committee, 1928–1930.

Finch, W. G. H. (J'16–A'18–M'25), Secretary and Chief Engineer, American Radio News Corporation, New York. Member, Constitution and Laws Committee, 1928–1931; Papers Committee, 1928; chairman, Publicity Committee, 1928–1930, member, 1931–1932.

Heising, R. A. (A'20–F'23), Engineer, Technical Staff, Bell Telephone Laboratories, New York. Member, Board of Directors, 1927–1930. Chairman, Admissions Committee, 1928–1930, vice chairman, 1931; Constitution and Laws Committee, 1930–1932.

Holland, W. E. (M'25), Chief Engineer, Philadelphia Storage Battery Company, Philadelphia, Pa. Member, Standards Committee, 1928–1930.

Horn, C. W. (A'14–M'28–F'30), General Engineer, National Broadcasting Company, New York. Broadcast Committee, 1929–1932; New York Program Committee, 1932; Sections Committee, 1930, chairman, 1931–1932.

Kolster, F. A. (A'12–M'13–F'16), Research Engineer, International Communications, Inc., New York.

Pratt, Haraden (A'14–M'17–F'29), Vice President and Chief Engineer, Mackay Radio and Telegraph Co., New York. Standards Committee, 1929–1932.

Shute, E. R. (M'25), General Superintendent of Traffic, Western Union Telegraph Company, New York. Admissions Committee, 1929–1932. Bibliography Committee, 1930–1931; New York Program Committee, 1930–1931, chairman, 1932; Sections Committee, 1928, chairman, 1929.

Turner, H. M. (A'14–M'20), Associate Professor of Electrical Engineering, Yale University, New Haven. Bibliography Committee, 1930–1932; Papers Committee, 1929–1932; Standards Committee, 1928–1932.

Wheeler, H. A. (A'27–M'28), Engineer, Hazeltine Corporation, Bayside, L. I., N. Y. Bibliography Committee, 1930–1932; New York Program Committee, 1931; Papers Committee, 1929–1932; Standards Committee, 1931–1932.

May Meeting of the Board of Directors

The May meeting of the Board of Directors was held on the 4th at the Institute office, and those in attendance were W. G. Cady, president; Melville Eastham, treasurer; Arthur Batcheller, O. H. Caldwell, J. V. L. Hogan, H. W. Houck, R. H. Marriott, E. L. Nelson, A. F. Van Dyck, William Wilson, and H. P. Westman, secretary.

Three applications for admission to the grade of Member in the names of R. W. H. Bloxam, F. H. Dupree, and D. R. Thomson were approved as were applications for transfer to the grade of Member in the names of R. M. Dawes, E. L. Gove, L. N. Holland, R. F. Shea, and J. R. Tolmie.

In addition, approval was granted to fifty-eight applications for the Associate grade, three for the Junior grade, and twenty-seven for the Student grade of membership.

An account of the Emergency Employment Committee's activities to date was submitted and follows this report.

The candidates nominated for office for the ensuing year are also listed elsewhere.

It was agreed that papers for presentation at future conventions of the Institute would not be preprinted in view of the negligible effect they have upon discussions presented at meetings and the very substantial expense which they involve. A small committee of Messrs. Goldsmith, Nelson, Wilson, and Westman was appointed to make a study of the subject of convention technical programs.

After considering a request for the use of the Institute membership mailing list for circularization purposes, the Board outlined a specific policy to the effect that such use of the Institute membership list would not be authorized.

A letter from the Standing Committee on Communications from the American Bar Association indicating the interest of that group in the suggestions and proposals which the Institute might care to make on pending and proposed legislation was given favorable consideration.

In view of the substantial reduction in Institute income it was felt that it would be necessary to reduce by about ten per cent the number of editorial pages published in the PROCEEDINGS during 1932 as compared with 1931. This means that approximately 2000 pages of material will be published rather than 2200. This reduction together with a policy of printing fewer copies of each issue for storage in anticipation of future demands will result in a worth while conservation of funds. In an endeavor to make those papers published of maximum value, it was agreed that no papers which were readily available in publications in English would be printed in the PROCEEDINGS, and that a more critical scrutiny would be given to papers published in some other language which are also submitted for publication in the PROCEEDINGS. It is anticipated that these changes will permit the publication of as many original manuscripts as have appeared in past issues of the PROCEEDINGS, and the reduction in the number of pages published will be at the expense of those papers which have appeared elsewhere in English or some foreign language.

Twentieth Anniversary Convention

Inasmuch as the days of April 7, 8, and 9 of 1932 have passed, it is possible to write a report on the Twentieth Anniversary Convention of the Institute which was held in Pittsburgh on those dates. This was the seventh annual convention which the Institute has held.

Those in attendance at the convention were almost exclusively from the United States and Canada and totaled approximately 460, of whom 60 were ladies.

The twenty-three technical papers were presented at five sessions which were well attended. In addition, most of those registered took advantage of the various inspection trips provided.

The two Institute awards which are made annually were presented to their recipients during the Birthday Party which was held on the evening of April 8. They were presented by President Cady who in bestowing upon Dr. Kennelly the Institute Medal of Honor for 1932 made the following presentation address:

"The Medal of Honor of the Institute is awarded each year, according to the phraseology of the rule adopted by the Board of Directors, 'to that person who has made public the greatest advance in the science or art of radio communication regardless of the time of performance or publication of the work on which the award is based.'

"Further along in the official statement is this sentence which is particularly significant in the case of the present award: 'The advance may also be a scientific analysis or explanation of hitherto unexplained phenomena of distinct importance to the radio art.' What words could better express the nature of Professor Kennelly's epochal work on the ionized layer in the atmosphere?

"The first recipient of the Medal of Honor was E. H. Armstrong in 1918. In the intervening years it has been awarded to Messrs. Alexanderson, Marconi, Fessenden, deForest, Stone, Pupin, Pickard, Austin, Zenneck, Pierce, Pedersen, and the latest recipient, General Ferrié, whose recent death has caused widespread grief throughout the scientific world.

"For the year 1932 the Medal of Honor is awarded, upon recommendation of the Awards Committee and by vote of the Board of Directors, to Dr. Arthur Edwin Kennelly, Professor Emeritus of Electrical Engineering at Harvard University and at Massachusetts Institute of Technology.

"Dr. Kennelly, as in the case of certain other men of scientific eminence, so it appears to have been true in your case also that it was a telegraph key that in your early years proved to be the key to the stairway of high achievement. Since the beginning of your scientific career in this country you have occupied an enviable position in the respect and personal regard of your professional associates. The long list of honors that have already been accorded to you bears witness to this. Not only radio engineers, but workers in all fields of oscillating phenomena, including acoustics, are indebted to you for the elegance and utility afforded by the employment of complex numbers and hyperbolic functions as introduced by you. Your studies of the telephone receiver and of vibrating systems in general have proved to be of fundamental importance. Most pertinent of all to the field of radio are your researches in that portion of our mundane sphere which has justly been named for yourself. At least the light side, and therefore the more brilliant side, of the ionized layer as contrasted with the Heaviside, bears your name.

"It is a privilege that I value highly to bestow upon you, sir, the Medal of honor of the Institute of Radio Engineers."

In accepting this award, Dr. Kennelly made the following response:

"Mr. President: It is a great honor that you confer upon me with this medal which has been awarded, in the past, to so famous an array of recipients, whom it has been my privilege personally to know and esteem. The last recipient of this honor, General Ferrié, of beloved leadership and international fame in world radio, has, unhappily for us all, been taken from us by death only a few weeks ago.

"As you have pointed out, sir, it was through the keys that I first came into contact, in 1876, with the great conducting world of wire electrical engineering. It would be keys rather than key, in my case, because submarine telegraphy uses both the international Morse key and the twin pair of cable-code keys.

"Of all the many branches of engineering in the service of mankind, it seems to me that there is no branch more fascinating than communication engineering, on account of its international pervasiveness and its intimate connection with sociology and world psychology, Moreover, in the tree of communication engineering, the youngest branch, radio communication, is the most fascinating and wonder-compelling of all. You gentlemen of the Institute of Radio Engineers belong to a fraternity that has abolished isolation from our planet; minimized the danger of ocean travel; made news travel with the speed of light; converted the heterogeneous pulses of the circumambient ether into meaningful discourse; carried music into the majority of households; and you are now engaged in crystallizing the public opinion of the world. So long as your fraternity is allowed to function, through uncensored channels of radio communication, there will be peace on our planet."

After Dr. Kennelly's response, President Cady presented the Morris Liebmann Memorial Prize to Edmond Bruce with the following words:

"The Morris Liebmann Memorial Prize was established through the generosity of Emil J. Simon, a Fellow of the Institute. It is given in memory of the late Colonel Morris N. Liebmann, and consists of the sum of five hundred dollars.

"The award is made annually by a special committee, appointed by the Board of Directors, to that member of the Institute, who, in the opinion of this committee, shall have made the most important contribution to the radio art during the preceding calendar year.

"The first recipient of this prize was L. F. Fuller, in 1919. Since then, the prize has been awarded to Messrs. Weagant, Heising, Franklin, Beverage, Carson, Conrad, Bown, Taylor, Cady, Appleton, A. W. Hull, and Ballantine.

"By vote of the Awards Committee, consisting of William Wilson, chairman, and Messrs. A. N. Goldsmith, J. V. L. Hogan, J. W. Horton, and R. H. Manson, the prize for 1932 is awarded to Edmond Bruce, Research Engineer of the Bell Telephone Laboratories, in recognition of his researches in directive antenna systems for short-wave communications.

"Mr. Bruce, your brilliant work in field strength measurement, and in the design of antennas combining high directivity, simple construction and effectiveness over a broad, continuous range of frequencies, constitutes a notable contribution to the radio art. It is a great pleasure to hand you this prize, together with all the rights and privileges that inhere thereto, including the privileges of converting it into cash, provided that the checks of the Institute are still honored at the bank, as I trust you will find to be the case."

Mr. Bruce then replied:

"It is hardly necessary for me to say that I am delighted to receive the Liebmann Memorial Award for 1932 from the Institute of Radio Engineers. I wish to thank the Institute membership and their Awards Committee for this honor.

"Since receiving notification of this prize I have taken the occasion to reëxamine the various Institute papers of the period involved. After realizing their very high merit I am particularly flattered that my work should have been selected.

"I think that it is quite a coincidence that I should receive this award at the same time that Dr. Kennelly is being honored by the Institute. I am a former student of Dr. Kennelly. It was in his classes that I received the foundation theory of wires that are electrically long. Throughout all my directive antenna work I have employed Dr. Kennelly's hyperbolic notation, and text books written by him have been my constant bible. I shall feel very happy indeed if he will feel that he played a most important part in my receiving this award."

Emergency Employment Committee Report

The Board of Directors on May 4 directed that I submit a formal report on the Emergency Employment Committee and its activities in the printed pages of the PROCEEDINGS, in addition to other reports. A report is submitted as follows.

At the Directors' meeting on January 6, 1932, O. H. Caldwell brought up the matter of unemployment and what was being done for professional engineers in New York City. As a result, the Board decided, through a series of motions made and seconded by Messrs. Goldsmith, Hogan, Eastham, and Van Dyck, that something should be done to help our members immediately, and I was directed to head a committee to do what we could as quickly as possible, and a drawing account of $1000.00 was appropriated to supply immediate funds. Plans were formulated that evening and the work was started the next morning. At the February 3 Board meeting, President Cady added Dr. Goldsmith and Mr. Hogan to the committee, who with the undersigned have constituted the Emergency Employment Committee to date.

On January 15 a form letter was sent to all members asking those who could do so to contribute, and those who needed help to advise us. Those who replied that they needed help were sent two forms, one is a short confidential questionnaire about their financial condition and dependents; the other is a long questionnaire about their training and experience. Those forms went into use on January 13 for some members who came in before we had said publicly that we would do this work. Other forms were sent to the references given by the members. The first member was employed on January 14. Letters stating the need for help were numerous at first, decreasing gradually to about five per week. On January 19 several hundred form letters were sent to firms who might be expected to employ radio men or use the results of a broadcast survey. Very few replied and no person was placed immediately from that letter. However, one of its results was some publicity in magazines and it may have caused some later inquiries for men.

From March 3 to 10 and from April 29 to May 9 additional circular letters were sent to the membership asking for contributions. So far we have received about $3600 and have spent about $3800.

The abilities of members were brought out under various subjects by the numerous questions in the training and experience questionnaire. That was done to help us get jobs for men under present hard conditions. For example, to produce and sell a product some drafting, some microphone and tube experience, a reading knowledge of German, and some letter writing may be needed. A few years ago five people might have been employed to fill those needs, but now if more than one is employed to fill these needs the product may cost more than it will sell for.

The following classifications were made from the answers to 216 questionnaires. For example in this classification of a group of 216 members who are radio men listed with this committee, 12 could do some drafting, several come under subjects relating to microphones and tubes, 43 can read some German, 67 can do some typing and 8 can do some stenographic and typing work. File numbers appear under these subjects on our cards. If one or more numbers appear under all the subjects then one or more of the members may fill the requirements sufficiently to get a job.

Advertising, publicity, sales promotion	65
Aeronautical radio	
Design	4
Installation	3
Operation	4
Announcer	
Broadcast	4
Automobile driver	199
Aviator (pilot)	3
Bibliographies, have prepared	25
Bookkeeping and clerical	90
Broadcast reception, study of	127
Broadcast surveys, house canvass	68
Building	
Construction, design	2
Battery	
Design, maintenance	2
Canvassing	63
Chiropractic (Dr.)	1
Collecting data	128
College graduates	58
Commercial research	65
Consultant	2

Crystals	
Research, cut	1
Designer	
Broadcast receivers	10
Commercial radio receivers	2
Direction finding	
Design and operation	2
Draughtsman	12
Estimating	94
Executive	4
Explorer (Arctic and Africa)	1
Field strength measurements	47
Geophysical	
Research, experiment	4
Interviewing	76
Laboratory and test	84
Language—read, write, or speak	
Arabic	1
Armenian	2
Danish	2
French	39
Finnish	1
German	43
Italian	6
Jewish	1
Lithuanian	1
Norwegian	5
Polish	1
Russian	5
Spanish	29
Swedish	3
Locomotive	
Mechanic	1
Loud speaker	
Design and manufacturing	5
Machinist	9
Measuring instruments	
Common	179
Advanced	44
Mill operator	2
Music	
Appreciation	8
Training	81
Photographer	2
Operator, radio	
Amateur	98
Broadcast	43
Commercial	60
Power service	1

Production and manufacture	
Radio	121
Nonradio	21
Projectionist	
(Sound and silent pictures)	2
Public speaking	77
Public address systems	
Design and operate	16
Recording	
For pictures	5
For phonograph records	3
Refrigeration	1
Research or development	128
Selling	118
Servicing	191
Sound and acoustics	160
Statistical accountant	2
Stenographer	8
Story and newspaper writing	56
Surveying	
Land	4
Teaching	90
Technical papers and reports	123
Telegrapher	
Commercial and Railroad	3
Telephone engineer	5
Television	
Manufacturing, installation, or design	3
Operating and research	2
Translator	1
Transmitters	
Radio broadcast (design and erection)	6
Commercial, Government (design and erection)	7
Typist	67
Vacuum tubes, electron	
Design and manufacture	8
Uses other than usual radio	
Bridge	1
Burglar protection	28
Calipering	4
Cathode ray and oscillograph	2
Chemical	10
Current devices	62
Dynamo electric machine	15
Fire protection	20
Grading, counting, sorting	12
Highway traffic	11
Home movies	26

Light control	32
Metallurgy	6
Phonograph	49
Photo-electric	13
Railway signals	9
Sonic, supersonic	25
Surgical, medical	16
Synchronizing devices	31
Talkies	72
Temperature control	2
Voltage devices	82
Weighing	2
X-ray	17

According to our records 26 have directly or indirectly obtained jobs through our efforts and still hold those or other jobs. At least they have not come back to ask us to try again. We often send one man after successive possibilities and often send many men after one possibility, only to fail. Sometimes the supposed employer does not hire anybody.

Trying to get a man a job is doing the same thing that others are doing. The man himself, his friends, employment agencies, fraternities, churches, unions, civic organizations, humanitarians, charitable organizations, political organizations, and others are all trying to do the same thing without much success.

However, part of our system differs from what others do in trying to combat unemployment. We offer a man a broadcast survey job that he can do wherever he lives and that will not interfere with odd jobs, looking for a job, or taking a permanent job and that may enable him to pick up temporary jobs or a permanent job. Those who stick to it will probably pick up something else sooner or later, some have already. Also they will probably cash in on the experience in future years. It requires nerve, tact, persistence, judgment, and is different.

We think the product from the survey work of these men is better than surveys that have sold and some that have been praised in print. However, nothing new is selling much now and we suspect that those we thought should be customers are losing money or are afraid they will lose money. When we arrive at the point where we can sell the surveys for what will make them self-supporting then that much depression will be filled up and we will not have to ask members of the Institute to contribute.

We send the surveyor 57 questions. He interviews the listener in the listener's home, uses the listener's receiver and writes the answers to the questions. The questions in the list are numbered. The surveyors write the question numbers and the answers they obtain. The answers identify the question list, the date and time, the surveyor, the address and name of the listener, characteristics of the house, probable financial circumstances, nationality and education of the listener, the receiver and its operating characteristics, stations that can be heard at different times and how well, interferences, the listener's and other members of the family's likes and dislikes, and the listener's opinion of educational broadcasts, European broadcasts, advertising, television, electrical transcriptions, etc.

We did not try to ask a question about the effect of suggestions. We inserted questions with suggestive words attached to them for a period of time and then removed the suggestive words.

Generally the persons interviewed have never written to a broadcast station or advertiser or answered a mail survey. The answers collected in quiet friendly interviews by men who have nothing to sell or advocate, average up to be quite wholesome and normal. They should be of value to the broadcast industry and the listening public.

The payment schedule has gone through some experimentation. First all were paid $15 per week. Then the men on survey work were paid 25 cents for each complete acceptable list of answers. Now the men in the office get $3 for each full day they work and the men on survey get 50 cents for each list of answers. The office uses one or more men every day but Sunday. The Institute Board room and adjacent hall provide office space and the Institute donates the office equipment. Except for paper, postage, and the rent of one typewriter all the money goes to the members either for surveys or for placing men in other jobs.

The broadcast survey work was started with one surveyor on January 26, 11:00 A.M., in Brooklyn. Since then 67 other men have been employed on this work and about 6000 listeners have been interviewed.

The following is a list of localities in which surveys have been made. In some places several men did survey work, Brooklyn for example. In other cases one man did survey work in more than one town. The places covered are in Alabama, Tuscallosa; California, Alamenda, Berkeley, Brea, Burlingame, Folsom City, Fullerton, Kerman, La Habra, Los Angeles, Los Banos, Oakland, Palo Alto, Piedmont, San Francisco, San Leandro, San Mateo, Saratoga, Stockton, Sunnyvale, Venice, Whittier; Colorado, Colorado Springs; Connecticut, Naugatuck, Waterbury; Illinois, Chicago, Palatine; Iowa, Des Moines, De Witt; Kentucky, Silver Grove; Massachusetts, Dórchester, North Andover, Northfield; Michigan, Birmingham, Fenton, Scottville; Mississippi, Cleveland; Nebraska, Falls City; New Hampshire, Hollis, Nashua, Northwood, Northwood Center, East Northwood; New Jersey, Barrinton Park, Elizabeth, Jersey City, Paterson; New York, Brooklyn, Kenmore, New York City; North Carolina, Tarboro; North Dakota, Fargo; Ohio, Canton, Centerburg, Cleveland, Hamilton; Oklahoma, Coalgate; Pennsylvania, Altoona, Berwyn, Connellsville, Johnstown, Keiser, Philadelphia; Rhode Island, Pawtucket; Tennessee, Knoxville; Texas, Dallas, Giddings; Vermont, Brattleboro; Washington, Seattle, Wenatchee; Wisconsin, Whitewater.

We need more money. There are some on our lists in our A and B division classifications who should be helped but we have run so close to our cash limits that we have not helped them yet. In the A division, people need help very badly. The need for help decreases from A through to E. All a man in the E division needs is something to do; he has enough money to take care of anything he needs. Not only do we need more money to help those we have not helped but to continue with those we have helped.

Those who have been helped say in frequent letters how grateful they are and the committee wishes to add its gratitude to all who have contributed.

Respectfully submitted,
(*Signed*) R. H. Marriott, *Chairman*
Emergency Employment Committee

Radio Transmissions of Standard Frequency

The Bureau of Standards transmits standard frequencies from its station WWV, Washington, D. C., every Tuesday. The transmissions are on 5000 kilocycles, and are given continuously from 2:00 to 4:00 P.M., and from 10:00 P.M. to 12:00 midnight, Eastern Standard Time. (From October, 1931, to March, 1932, inclusive, the evening schedule was two hours earlier.) This service may be used by transmitting stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards and transmitting and receiving apparatus. The transmissions can be heard and utilized by stations equipped for continuous-wave reception throughout the United States although not with certainty in some places. The accuracy of the frequency is at all times better than one cycle (one in five million).

From the 5000 kilocycles any frequency may be checked by the method of harmonics. Information on how to receive and utilize the signals is given in pamphlets obtainable on request addressed to the Bureau of Standards, Washington, D. C.

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the phones when received with an oscillatory receiving set. For the first five minutes there are transmitted the general call (CQ de WWV) and announcement of the frequency. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Supplementary experimental transmissions are made at other times. Some of these are made with modulated waves, at various modulation frequencies, Information regarding proposed supplementary transmissions is given by radio during the regular transmissions, and also announced in the newspapers.

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

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

Committee Work

Admissions Committee

A meeting of the Admissions Committee was held at the Institute office on May 4, those in attendance being A. F. Van Dyck, chairman; Arthur Batcheller, H. C. Gawler, E. R. Shute, and H. P. Westman, secretary.

Of seven applications for transfer to the grade of Member, three were approved, three rejected, and one was tabled pending the arrival of additional information. Five applications for admission to the grade of Member were approved and one was rejected.

Membership Committee

The Membership Committee held its regular monthly meeting at 5:30 p.m. on May 4 at the office of the Institute, H. C. Gawler, chairman; A. F. Murray, C. R. Rowe, and A. M. Trogner being in attendance.

New York Program Committee

The New York Program Committee held a meeting at 4 P.M. in the Institute office on May 6. Those in attendance were E. R. Shute, chairman; H. H. Beverage, C. N. Anderson, Austin Bailey, and H. P. Westman, secretary.

STANDARDIZATION

Technical Committee on Electro-Acoustic Devices—I.R.E.

Two meetings of the Technical Committee on Electro-Acoustic Devices were held since the last report. The first of these on April 15 at 10 A.M. was attended by E. D. Cook, chairman; L. G. Bostwick, E. W. Kellogg, L. J. Sivian (nonmember), and B. Dudley, secretary.

The second meeting was held at 10 A.M. on May 6 and those present were E. D. Cook, chairman; L. G. Bostwick, L. J. Sivian, and B. Dudley, secretary.

Technical Committee on Electro-Visual Devices—I.R.E.

The newly established Technical Committee on Electro-Visual devices held its first meeting at 7:30 P.M. on May 3 with the following in attendance: J. V. L. Hogan, chairman; H. S. Baird, H. W. Houck, W. J. Jarrard, R. H. Marriott, and B. Dudley, secretary.

Technical Committee on Radio Receivers

A meeting of the Technical Committee on Radio Receivers was held at 10 A.M. on April 21 at the office of the Institute, those in attendance being H. A. Wheeler, chairman; H. H. Beverage, E. T. Dickey, Virgil M. Graham, David Grimes, F. A. Hinners, W. E. Holland, H. O. Peterson, F. A. Polkinghorn, L. P. Tuckerman (representing C. E. Brigham), Lincoln Walsh, W. T. Wintringham (representing Lloyd Espenschied), and B. Dudley, secretary.

Institute Meetings

Boston Section

A meeting of the Boston Section was held on April 22 at Harvard University, G. W. Pierce, chairman, presiding. A paper on "Recent Developments in Receiving Tubes" was presented by Paul Weeks, chief engineer of the Raytheon Production Corporation.

Dr. Weeks described the constructional details of several new tubes which have been recently announced. Characteristics of the tubes were outlined and their uses discussed.

At this meeting the section officers were changed. Professor E. L. Chaffee of Cruft Laboratory, Harvard University, and Professor G. W. Kenrick of Tufts College are the new chairman and secretary-treasurer, respectively.

The meeting was attended by 105 members and guests.

Buffalo-Niagara Section

A meeting of the Buffalo-Niagara Section was held on April 18 at the University of Buffalo, L. Grant Hector, chairman, presiding.

R. H. Langley, consulting engineer, presented a paper on "The Application of Permeability Tuning to Broadcast Receivers."

The author outlined the development of tuning methods employed in radio receivers and pointed out that the capacity variation method of tuning had the disadvantage of the selectivity varying with frequency over the broadcast range. Inductance tuning does not have this disadvantage and various methods of accomplishing this necessary variation in inductance were described. The author considered a method of changing the permeability of the magnetic circuit of the inductance an effective method of tuning. A magnetic material called Polyiron in which eddy current losses are lower than in other materials is used. Polyiron is made of particles of iron about 10 microns in diameter coated with an insulating material about 1 micron thick. The coated particles are molded into bakelite resulting in a material about 92 per cent iron by weight. The useful permeability is about 8 and the hysteresis loss is negligible at radio frequencies. For present purposes it is not useful above 2000 kc and for the broadcast band coils are preferably wound with litzendraht wire. Adjustments are accomplished by moving the core in and out of the coil and by switching capacity steps. A sample unit permitted the core nearly to surround the coil. At the 1500-kc setting, the inductance is about 65 microhenries with a capacitance of approximately 160 micromicrofarads.

The paper was discussed by Messrs. Crom, Hector, Huntsinger, Manson, MacNabb, Waud, and others of the 65 members and guests in attendance.

Cleveland Section

The March 19 meeting of the Cleveland Section was held in the studios of WHK, E. L. Gove, chairman, presiding.

R. N. White, chief engineer of the Macoustic Engineering Company, Cleveland, presented a paper on "Acoustics and Sound Pressure Measurements."

The author pointed out that sound may be controlled by three basic methods; at the source, by absorption at room boundaries known as sound treatment, and by prevention of sound transmission, which is know as soundproofing.

The author outlined the work done by Sabine, Eyring, Watson, and Knudson in the development of practical formulas for predicting reverberation time in rooms.

He pointed out that sound may be reflected in much the same way as light and can be focused as evidenced by whispering galleries, echoes, and similar occurances. The shape of the auditorium should therefore be free from such obstructions as produce undesirable reflection. Curved walls will make echoes more pronounced near the center of their curvatures and accordingly dome-shaped ceilings are acoustical hazards. If curved walls or ceilings are necessary they should be broken up by deep coffers, pilasters, or similar structures.

In soundproofing, double walls with air space between are considered good. The filling of the space between the walls with loose or porous material often is of doubtful value since it tends to establish a connection between the walls and thus transmits in sound.

Using in general the method outlined by P. E. Sabine, the absorption coefficients of various materials were determined by an intensity reflection test. A microphone and an audio oscillator were so placed that the angle of sound source to the material was equal to that of the microphone. The latter device was in a soundproof box, highly absorbent, having a small aperture facing the material to be tested. An output meter connected to the microphone and an amplifier then gave visual readings of the amount of reflection obtained. A number of different materials were so tested, and the ranges of reflection were noticeably wide. The coefficient of absorption was affected by the angular incidence of the sound and varied also with the frequency. It was noted that the apparent coefficient of an absorbing substance was increased by leaving an air space between it and a hard backing. Other factors were thickness and porosity.

The author concluded his paper and experiment with a demonstration by means of special recordings of the garbling effect of echo upon speech and music.

The meeting was attended by 85 members and guests.

Chicago Section

A meeting of the Chicago Section was held on March 21 in the Engineering Building, R. M. Arnold, vice chairman, presiding.

A paper on "Recent Developments in Radio Receiving Tubes" was presented by E. W. Ritter of the RCA Radiotron Company.

The paper covered technical details of several new receiving tubes which have recently been announced to the public.

The meeting was held jointly with the Radio and Electrical Sections of the Western Society of Engineers and of those in attendance, eighty-five were Institute members.

Detroit Section

The April meeting of the Detroit Section was held on the 15th in the Detroit News Conference Room, H. L. Byerlay, chairman, presiding.

A paper on "Acoustical Design of Broadcast Studios" was presented by J. S. Parkinson, staff engineer of the Acoustic Division, Research Department of the Johns-Manville Company.

The speaker outlined the importance of acoustic consideration in broadcast studio design and pointed out that the studio is but one link in the long chain which makes up the broadcast system. Variations and defects in this link are just as damaging as though occurring in other parts of the system.

As a further introduction to his paper, the speaker presented an interesting discussion of the subject of reverberation and its effect upon programs of various types.

In discussing the most desirable shapes in auditoriums, or studios, it was pointed out that most uniform sound distribution and the greatest reduction in echoes was obtained by proportioning the room in the ratio of 2:3:4 or 2:3:5. Approximately 750 cubic feet of space should be allowed per auditor.

The speaker then presented an interesting discussion of frequency characteristics, the theory of sound absorption, loudness distribution, location of treatment for echoes, and factors governing the choice of treatment. By means of suitable apparatus it was demonstrated that hair felt or similar substances one inch thick absorbed more high frequency sound than low frequency. The effect of echoes on speech and music was also demonstrated.

The paper was discussed by a number of the 65 members and guests in attendance.

Los Angeles Section

A meeting of the Los Angeles Section was held on March 29 at the Mayfair Hotel, E. H. Schreiber, chairman, presiding.

The first paper of the evening which was a "Discussion of the Power Output of Vacuum Tubes at Audio Frequencies" was presented by H. G. McWilliams of the Pacific Telephone and Telegraph Company. The paper covered the derivation of formulas for determining the load necessary to obtain maximum undistorted output from triodes. The speaker also compared the merits and disadvantages of the pentode versus the triode.

The second paper of the evening by R. M. Moore, also of the Pacific Telephone and Telegraph Company, was on "Electrical and Thermal Characteristics of Piezo-Electric Oscillators," in which the conditions necessary for the high order of accuracy required in broadcast transmission was pointed out. Methods of obtaining this essential accuracy of frequency control were outlined. The requirements of a crystal oven having extremely accurate temperature control were discussed and compared to analogous electrical filter circuits.

The meeting was attended by ninety-three members and guests and thirty of these were present at the informal dinner which preceded it.

The April meeting of the Los Angeles Section was held on the 19th at the Mayfair Hotel in Los Angeles, Chairman E. H. Schreiber presiding.

After an introduction by Inspector F. P. Hawtry, Sergeant J. G. Rosso of the Los Angeles Police Department presented a paper on "How Radio Serves the Police Department."

Inspector Hawtry explained how the city was divided into districts to facilitate the handling of calls to the radio cars and outlined how complaints were handled at the central station. He pointed out the speed with which calls are answered, and that for the past three months the average time of answering a call was two minutes and 42 seconds. Sergeant Rosso, who is in charge of the equipment, then discussed some of the problems encountered in completing the installation of the equipment and getting it into satisfactory operation. Specially designed transmitters and receivers are employed and a sample receiver chassis was on display.

Several of the 63 members and guests in attendance entered into the discussion which followed the presentation of the paper. The informal dinner which preceded the meeting was attended by 18.

New York Meeting

Two papers were presented at the May 4 New York meeting of the Institute at which President Cady presided. The first paper on "Recent Cathode Ray Tube Developments" by Allen B. DuMont covered developments in the hot cathode type of cathode ray tubes. Improved methods of generating, focusing, and modulating cathode rays were described and demonstrated. A screen luminescence produced by various types of fluorescent materials was demonstrated and a number of recent types of tubes developed for various purposes were shown.

The second paper on "Applications of the Cathode Ray Oscillograph" was presented by R. R. Batcher. The author pointed out that cathode ray tubes are well adapted to scientific measurements and tests. The associated materials for such equipment were described and demonstrated. The production of timing waves, the recording and interpretation of oscillograms, and several representative applications of the tubes were shown. The factors affecting the accuracy of measurements made with these tubes were discussed.

Philadelphia Section

A meeting of the Philadelphia Section was held on March 31 at the Engineers Club, G. W. Carpenter, chairman, presiding.

The paper of the evening on "Application of Class B Amplifiers to A-C Operated Receivers" was presented by L. E. Barton of the RCA Victor Company.

The paper covered the general subject of class B Audio amplifiers and outlined the economy which this method of operation permitted. The author then discussed the characteristics of the new type-40 power output tube which was designed for class B amplification. The tube operates normally with zero grid bias thus avoiding the necessity of providing a bias voltage having extremely low regulation with varying loads. Methods whereby the varying drain upon the power supply equipment would not result in substantial fluctuations in plate voltage to the power stage and the other circuits in the receiver were discussed in detail.

The general discussion which followed the presentation of the paper was entered into by a number of the one hundred and twenty-three members and guests in attendance.

San Francisco Section

R. M. Heintz, chairman, presided at the March 23 meeting of the San Francisco Section held in the Bellevue Hotel.

S. S. Mackeown of the California Institute of Technology presented a paper on "Gas-Filled Thermionic Tubes."

Dr. Mackeown discussed the theory and some of the practical applications of hot cathode mercury vapor tubes, giving particular attention to thyratrons.

A general discussion followed and was participated in by a number of the 60 members and guests in attendance of whom 17 were present at the informal dinner which preceded the meeting.

The April meeting of the San Francisco Section was held on the 20th at the Bellevue Hotel with Secretary F. E. Terman presiding.

"Reminiscences in Radio and Allied Arts" was the title of the paper by C. F. Elwell of British Talking Pictures, Ltd., London.

Mr. Elwell described his work in the founding of the Federal Telegraph Company and the results obtained in the early development of continuous-wave communication using Poulsen arcs. He then outlined his war activities and described the events leading up to the establishment of the Mullard Company for which he was responsible, and concluded with a discussion of sound pictures.

The 35 members and guests in attendance found the paper to be most facinating in view of the speaker's familiarity with the important events and personalities that have been connected with radio since 1908.

Seattle Section

On March 31 a meeting of the Seattle Section was held at the University of Washington, Chairman L. C. Austin presiding.

"Distortion in Double Side Band Radiotelephone Transmission" was the subject of the paper by R. W. Deardorff and T. M. Libby.

A general demonstration of the effect of distortion in radiotelephone transmission was given as part of the paper and the apparatus used for the demonstration was thoroughly explained.

The meeting was attended by 72 members and guests.

Toronto Section

The April meeting of the Toronto Section was held on the 13th at the University of Toronto, F. K. Dalton, chairman, presiding.

A paper on "The Application of Dual Speakers to Receiving Sets," was presented by W. A. Ellmore, Chief Engineer, Utah Radio Products Company, Chicago.

The speaker illustrated by means of several curves of the sound output of an audio amplifier the effect of using one or two loud speakers. The curves indicated the theoretical advantage particularly notable on the low-frequency end of the spectrum. He then pointed out that the chief application of dual speakers would be in conjunction with the extra peak power available from a push-push amplifier employing the new tubes.

The paper was discussed by Messrs. Andre, Bradley, Burrell, Fox, Hackbusch, Leslie, and Price of the 68 members and guests in attendance.

Washington Section

The April meeting of the Washington Section was held on the 14th at the Continental Hotel, H. G. Dorsey presiding.

Gilbert Smiley, Chief Engineer of the Samson Electric Company, presented a paper on "Centralized Sound Systems."

The author demonstrated a public address system representative of the group which he described. He then discussed these systems dividing them into several parts and treating each separately and in detail. The requirements of such systems were then outlined and the necessity of providing precautions for the safety of the operating personnel stressed. General empirical rules for determining the power output required under varying conditions were given and the possibility of designing units which may be combined to supply larger power outputs was discussed.

The meeting was attended by 45 members and guests, 17 of whom were present at the informal dinner which preceded it.

Personal Mention

J. L. Filgate formerly with the General Motors Corporation has joined the radio engineering staff of the United American Bosch Corporation.

K. W. Karvis previously with the U. S. Radio and Television Corporation has become associate chief engineer of the Zenith Radio Corporation of Chicago.

Lieutenant Commander H. W. Kitchin, USN, has been transferred from Annapolis, Md., to Cavite, P. I.

Formerly chief engineer of the State Telegraph and Telephone Works at Warsaw, Poland, Peter Modrak has been appointed director of the Transatlantic Radio Station at Warsaw.

Previously with the DeForest Radio Company, R. J. Orner has become a radio engineer for the U. S. Radio and Television Corporation, Marion, Ind.

J. S. Robb formerly engineer for the Radio Condenser Company of Camden, N. J., has become chief engineer of the Radio Condenser Company, Ltd. of Toronto, Canada.

C. R. Rowe previously with Wired Radio, Inc., is now radio engineer for the International Radio Communications Labs., Newark, N. J.

Proceedings of the Institute of Radio Engineers
Volume 20, Number 6 *June, 1932*

TECHNICAL PAPERS

WESTINGHOUSE RADIO STATION AT SAXONBURG, PA.*

BY

R. L. DAVIS

(Manager, Radio Engineering Department, Westinghouse Electric and Manufacturing Co., Chicopee Falls, Mass.)

AND

V. E. TROUANT

(Engineer in Charge, Radio Development Engineering Department, Westinghouse Electric and Manufacturing Co., East Pittsburgh, Pa.)

Summary—*Westinghouse Radio Station KDKA, at Saxonburg, Pa., was built to provide up-to-date equipment for regular broadcasting and for high power experimental work on either long or short waves.*

Power equipment consists of a 12-phase, 900-kw, 30-kv rectifier using three-anode mercury pool type tubes; a 6-phase, 450-kw, 22-kv rectifier; four 10-kw, 3-kv motor generator sets for bias and intermediate amplifier plate supply; six 40-kw, 40-volt motor generator sets for filament power; a 400-volt storage battery for small tube plate voltage and for substation control; and two 12-volt, 1600-ampere-hour storage batteries for small tube filament supply.

Present transmitter apparatus includes a 300-kw output stage using six Westinghouse type AW-220 tubes; a 5-kw intermediate power amplifier; a modulator for the 5-kw stage, a crystal control and intermediate amplifier unit; a high level modulator with provision for six AW-220 tubes for experiment or modulating the output stage operated class C; and a 50-kw power amplifier for regular broadcasting using six water-cooled tubes plate modulated by a transformer coupled class B push-pull modulator.

The four audio circuits to the studio in Pittsburgh go underground for several thousand feet to prevent r-f pick-up.

The cooling water system employs heat interchanges.

THE Westinghouse Radio Station at Saxonburg was built to provide up-to-date equipment for the regular broadcast activities and to provide facilities for high power experimental work on either long or short waves.

The station is located on a 120-acre site approximately twenty miles north of Pittsburgh. The building is a brick structure 32 feet by 82 feet with a front wing 24 feet by 32 feet. It houses all of the equipment except the rectifier transformers and filter chokes which are ar-

* Decimal Classification: R600. Original manuscript received by the Institute, March 4, 1932. Presented before Twentieth Anniversary Convention, Pittsburgh, Pa., April 9, 1932.

ranged on a platform at the rear of the building. Fig. 1 is a front view of the building.

Power is brought into the building at 2300 volts through under ground cables from the substation on the north side of the property. One panel of the main switchboard in the station contains the operating controls, relays, meters, etc., for the two sources of 25-kv, 3-phase power at the substation.

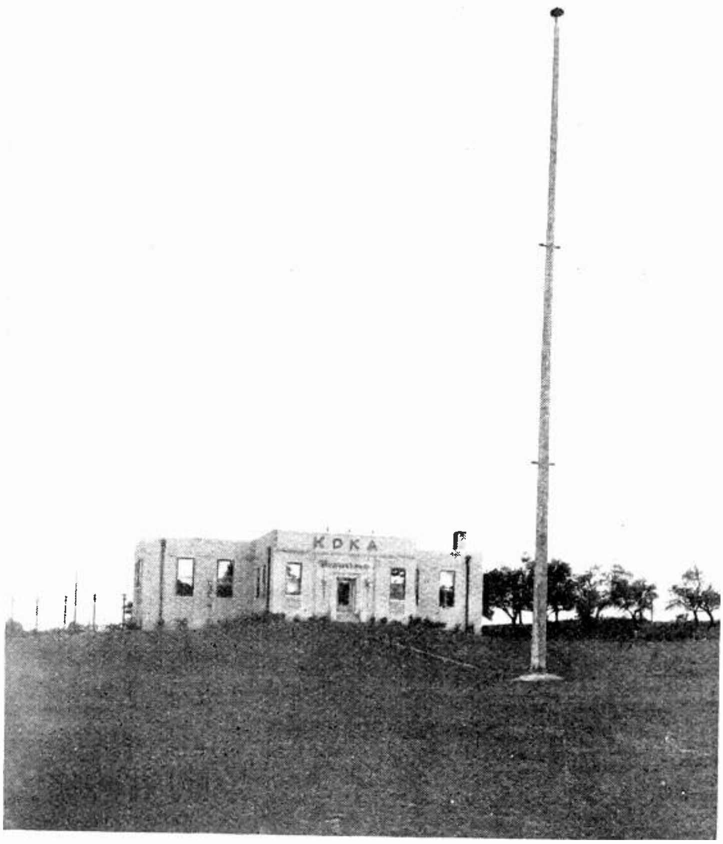

Fig. 1—Front view of Westinghouse radio station at Saxonburg, Pa.

All of the power equipment is located in the basement of the building, leaving the main floor free for the radio-frequency and control apparatus. Fig. 2 shows the layout of the apparatus. The equipment is divided into two general groups—broadcast, and short-wave or experimental. As far as possible the regular broadcast equipment is installed at the north end of the building. The main switchboard is at the center of the apparatus room and all essential controls are brought to this point.

In the belief that the broadcast activities in this country will fol-

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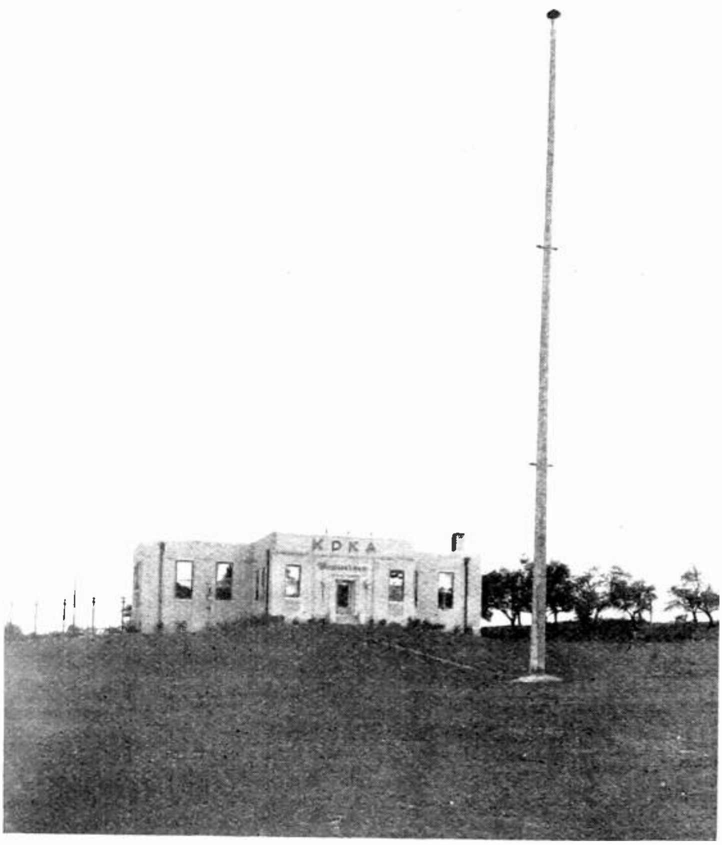

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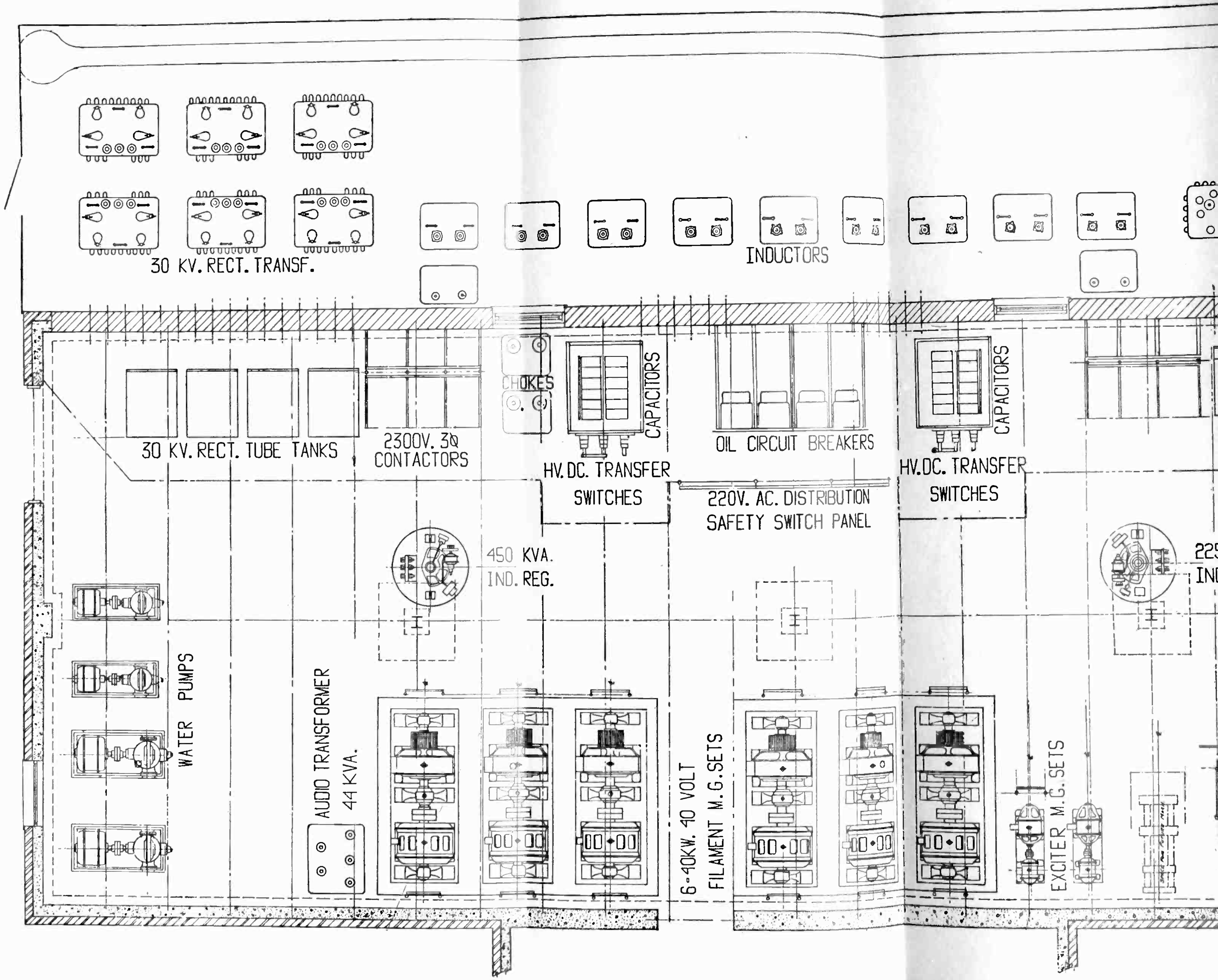

Fig. 2a—Layout of apparatus in basement.

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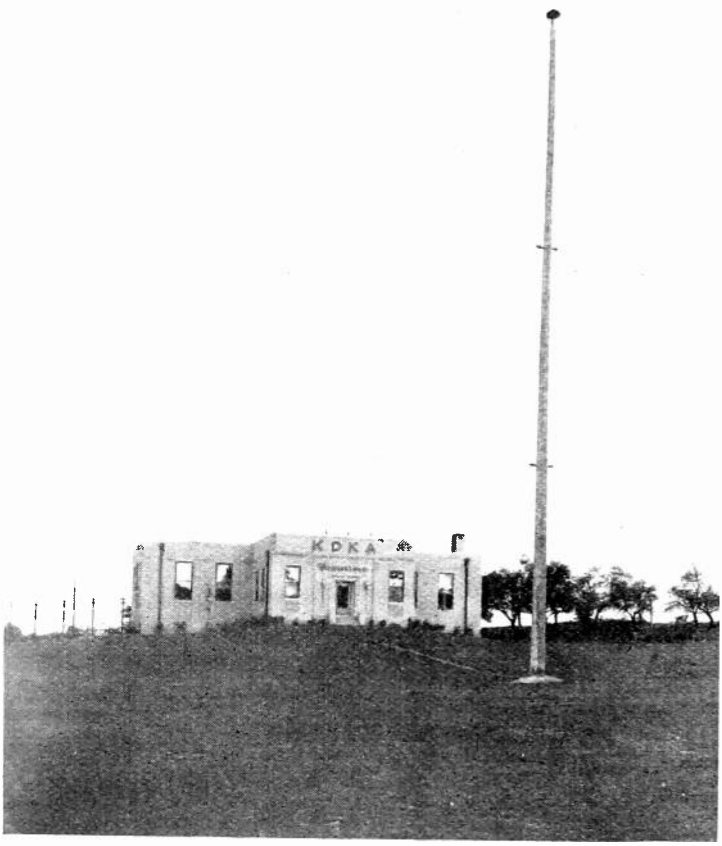

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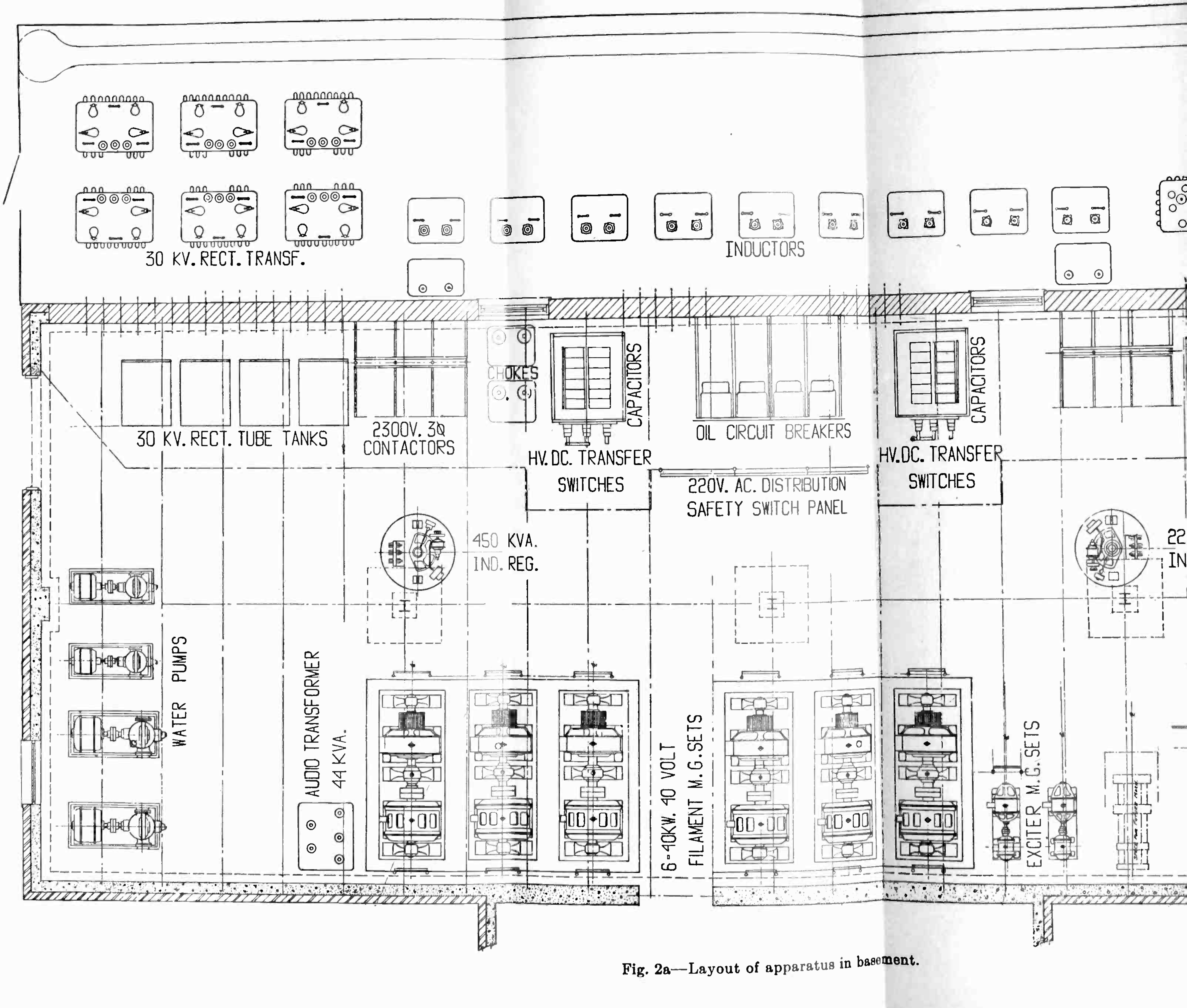

Fig. 2a—Layout of apparatus in basement.

The Institute of Radio Engineers

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INSTITUTE. The Institute of Radio Engineers was formed in 1912 through the amalgamation of the Society of Wireless Telegraph Engineers of Boston, Massachusetts, and the Wireless Institute of America of New York City. Its headquarters were established in New York City and the membership has grown from less than fifty members at the start to almost seven thousand by the end of 1931.

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 need 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.

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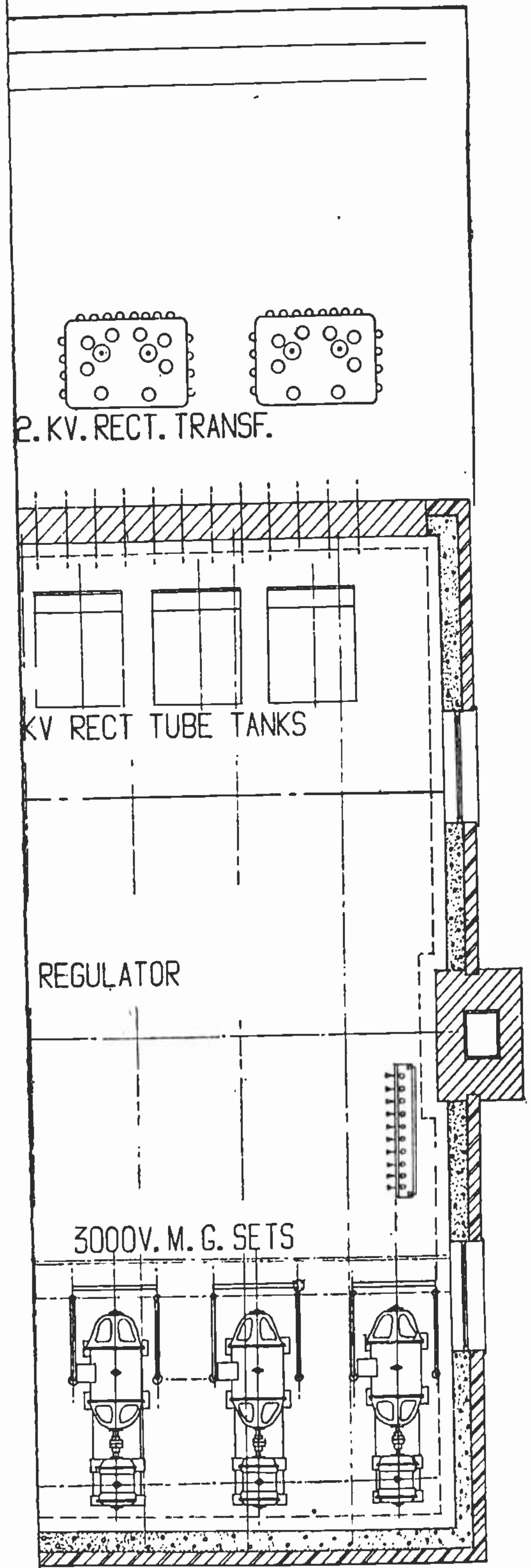


GEOGRAPHICAL LOCATION OF MEMBERS ELECTED MAY 4, 1932

Transferred to the Member Grade

Massachusetts	Arlington, 27 Howard St.	Shea, R. F.
Michigan	Ann Arbor, 270 W. Engineering Bldg., University of Michigan	Holland, L. N.
Ohio	Cleveland, Radio Air Service Corp., 1311 Terminal Tower Bldg.	Gove, E. L.
Washington	Seattle, 615 Boren Ave.	Tolmie, J. R.
England	Dorchester, Dorset, 41 South St.	Dawes, R. M.

Elected to the Member Grade

England	12 St. Michaels Ave., Westoe, S. Shields, Co. Durham	Bloxam, R. W. H.
Scotland	Glasgow, 112 Beechwood Dr., Broomhill	Thomson, D. R.
Straits Settlements	Singapore, Wireless Station Paya Lebar	Dupree, F. H.

Elected to the Associate Grade

Arkansas	Helena, c/o Dixie Furniture Company	Young, R. L.
California	Los Angeles, P. O. Box 804	Hurt, L. J.
	Los Angeles, 1835 W. 25th St.	Lewis, V. F.
	Los Angeles, 765½ E. Vernon Ave.	Mestas, R.
	Oakland, 2415-23rd Ave.	Carlson, E. J.
	San Francisco, 928 Broderick St.	Gray, K. B.
	San Francisco, 2242 Anza St.	Hood, L.
Connecticut	Hamden, 38 Concord St.	Reader, W. A.
Delaware	Seaford, P. O. Box 185	Ellis, E. T.
Dist. of Columbia	Washington, Office of Chief Signal Officer	Guest, W. T.
	Washington, 1337 Girard St.	Hurvitz, H.
	Washington, 1201-16th St., N.W.	Tyler, T. F.
Georgia	Atlanta, Georgia School of Technology	Gerks, I. H.
Idaho	American Falls, 723 Stevens St.	Fields, W. B.
Illinois	Chicago, 1133 S. Whipple St.	Hartman, A. M.
	Chicago, 6139 Michigan Ave.	McCleary, B. J.
Massachusetts	Allston, 209 Warren St.	Pelissier, C. A.
	South Hadley, Mt. Holyoke College	Fletcher, H. M.
Missouri	St. Louis, 819 Telephone Bldg.	Wardell, W. L. C.
	University City, 7410 Liberty Ave.	Ramey, P. A.
New Jersey	Camden, 2115 S. Berwick St.	Neville, J. A.
	Camden, 539 Vine St.	Rogers, W. H.
	Camden, 220 Cooper St.	Townsley, F. W.
	Haddon Heights, 1940 Bryn Mawr Ave.	Owsley, O. M.
	Oaklyn, 16 Ormond Ave.	Robins, B. W.
	Pensauken, 3423 Pennsylvania Ave.	Sweeney, J. A.
	Westmont, 16 Virginia Ave.	Russell, J. F.
New York	Brooklyn, 1663-76th St.	Chasin, G.
	Long Island City, 31-31-29th St.	Reiskind, H. I.
	New York City, Bell Tel. Labs., 463 West St.	Borden, C. C.
	New York City, Tropical Radio, Pier 3, N.R.	Monaghan, P. E.
	New York City, S.S. Margaret, c/o A. H. Bull & Co., 115 Broad St.	Strobel, C. J.
	New York City, 457 W. 47th St.	Von Baudissin, J.
	New York City, 51 W. 76th St.	Wolters, B. J.
	Woodside, 5411-32nd Ave.	Gamble, W. T.
Ohio	Canton, 1220 Louisianna Ave., N.W.	Phillips, W. M.
Oregon	Albany, 1537 Salem Rd.	Hoffman, C. A.
	Salem, 1418 Lana Ave.	Ramage, W. W.
Pennsylvania	Philadelphia, 6829 N. 9th St.	Whitney, A.
Washington	Port Angeles, U.S.C.S. Snohomish	Davis, H. P.
	Seattle, U.S.C.G., S.S. Surveyor, 202 Burke Bldg.	Throndsen, T.
	Seattle, 4230 University Way, Apt. L.	Young, J. L.
Australia	Melbourne, c/o Amalgamated Wireless (A'sia), Ltd	Baird, W. R.
England	Barnoldswick, Via Colne, Lancs., Church St.	Slater-Tomlinson, R.
	Chelmsford, Essex, 54 New St.	Konteschweller, M.
	Chipstead, Surrey, "South", Pine Walk	Mordaunt, N. C.
	Lincoln, Magpie Sq. P. O., 1, 1a, & 3 Melville St.	Harrison, P. L.
	London, Rotherhithe, S.E. 16, 40 Old Rd.	Davis, J. G.
	Sutton, Surrey, 74 Egmont Rd.	Bridgewater, T. H.
	Swanage, Dorset, 2 Grosvenor Rd.	Hardy, R. V.
	York, 69 Thorpe St.	Budden, G. F.
Federated Malay States	Selangor, Glenmarie Estate, Batu Tiga	Salt, G. W.
Italy	Milano, Via S. Andrea 18	Corbellini, G. P.
Japan	Hiroshima-Hosokyoku, c/o Hara-Hososho	Tamagawa, S.
	Ibarakiken, Hiraiso Radio Lab., Hiraiso-Musen	Tukada, T.
	Kochi City, Kochi Broadcasting Station	Matsui, S.

Geographical Location of Members Elected May 4, 1932

North Wales	Cefn, "Plaskynaston", Wrexham	Ellis, R. F.
South Africa	Natal, c/o J. S. Ramsay (Pty.) Ltd., 3 Carlyle Arcade, P. M. Burg	Purefoy, H. B.

Elected to the Junior Grade

Indiana	Angola, 407 W. South St.	Gibbs, W. C.
North Carolina	Raleigh, 715 S. Boylan Ave.	Browning, W. P.
Australia	Ashfield, N.S.W., 1 Julia St.	Maynard, F. S.

Elected to the Student Grade

Arkansas	Fayetteville, 513 Highland Ave.	Jamison, D. B.
California	Berkeley, 2533 Chilton Way	Atkinson, E. B.
	Berkeley, 1001 Heinz Ave.	Carlsen, G. H.
	Berkeley, 2574 Bancroft Way	Cassidy, J. J., Jr.
	Berkeley, 2226 Roosevelt Ave.	Miller, G. R.
	Berkeley, 2620 Bancroft Way	Moody, W. S.
	Berkeley, 2511 Regent St.	Selby, E. R.
	Berkeley, 2428 Bancroft Way	Sparks, N. R.
	Oakland, 265 Vernon St.	Jones, M. R., Jr.
	Oakland, 567-63rd St.	McLeod, W. J.
	Palo Alto, 383 College Ave.	Freeman, R. L.
	Palo Alto, 1033 Guinda St.	Starner, C. J.
	San Francisco, 469-25th Ave.	Kruger, H. C.
Maine	Bath, 28 Court St.	McCole, J. E.
Massachusetts	Tufts College	Nute, P. R.
Washington	Vancouver, 3324 L St.	Grant, H. H., Jr.
Canada	Galt, Ont., 41 Lansdowne Rd. N.	Jansen, A. A.
	Toronto, Ont., Suite 9, Westview Apts., 33 Christie St.	Bayley, A. K.
	Toronto, Ont., 784 A St. Clair Ave. W.	Falconer, J. L.
	Toronto, Ont., 158 St. George St.	Lindsay, J.
	Toronto, Ont., 60 Greenville St.	Lochead, W. J.
	Toronto, Ont., 8 Maitland Pl.	McCaughrin, W. O.
	Toronto, Ont., 526 Windermere Ave.	Patterson, M. C.
	Toronto, 12, Ont., 63 Broadway Ave.	Peddie, L. W.
	Toronto, Ont., 403 Huron St.	Reid, J. E.
	Toronto, Ont., 36 Ashland Ave.	Whalley, W. B.
	Toronto, Ont., 46 Westmount Ave.	Wilson, A. L.

APPLICATIONS FOR MEMBERSHIP

Applications for transfer or election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to transfer or election of any of these applicants should communicate with the Secretary on or before July 5, 1932. Final action on these applications will be taken on July 6, 1932.

For Election to the Associate Grade

California	Berkeley, 1731 Allston Way	Dhami, B. S.
	Oakland, U.S.C.G. Cutter Tahoe	Kelly, R. P.
Dist. of Columbia	Washington, Rm. 2534 Navy Department Bldg.	Brown, T. H.
Illinois	Chicago, 6602 S. Troy St.	Hermanny, W.
	Highland Park, 417 McDaniels Ave.	Salyards, W. E.
Massachusetts	Pittsfield, 22 First St.	Robie, E. B.
Missouri	St. Louis, 1010 Pine St.	Houck, L. J.
New Hampshire	Lancaster, 84 Middle St.	Eilenberger, S. D.
New Jersey	Haddon Heights, 1001 Sycamore St.	St. Clair, E. L.
	Livingston, Northfield Ave.	Fund, S. R.
	Oceanport, 15th Signal Service Co., Ft. Monmouth	Kane, G. C.
New York	Brooklyn, 29 Jefferson St.	Davis, H. E.
	New York City, c/o J. A. Ewing & McDonald, Inc., 8–10 Bridge St.	Bottner, M. E.
	New York City, 180 Varick St.	Krauth, E. A.
	Poughkeepsie, 182 S. Grand Ave.	Mahler, R. J.
	Rocky Point	Thornton, J. P.
Ohio	East Cleveland, 15621 Terrace Rd.	Bennett, M. T.
	Mansfield, Radio Station WJW	Myers, M. L.
Oregon	Portland, 9611-58th Ave. S.E.	Anderson, H. C.
Pennsylvania	Lancaster, 132 E. Lemon St.	Rettig, A. C.
	Oxford, 418 E. Market St.	Jones, T. J.
	Philadelphia, 1321 Arch St., 2nd Fl.	Leitch, J. G.
	Pittsburgh, Carnegie Tech., Schenley Park	Gabler, R. T.
Texas	Brooks Field, 22nd Observation Squadron A.C.	Allday, C. L.
Vermont	Winooski, 18 Leclair St.	Bigwood, R. F.
Washington	Palouse, Box 314	Bocknier, C. F.
Wisconsin	Madison, Radio Dept., Northwest Airways, Inc.	Benson, G. A.
Australia	Adelaide, St. Peters, 68-8th Ave.	Wicks, J. J.
Canada	Saint John, N.B., 38 Cranston Ave.	Ruthen, A. S. R.
	Toronto, Ont., 291 Huron St.	Armstrong, A. T.
	Toronto, Ont., 683 Soudan Ave.	Banton, K.
	Toronto, Ont., 26 Tichester Rd., Apt. 407	Cockburn, N. A.
	Toronto 8, Ont., 425 Ashdale Ave.	Corless, C. J.
	Toronto 3, Ont., 86 Morningside Ave.	Nesbit, W. D.
	Toronto, Ont., 35 Nasmith Ave.	Sachs, M.
	Toronto, Ont., 497 Whitmore Ave.	Sparkes, P.
Canal Zone	Balboa, U.S.S. Sciota	Potter, G. E.
England	Bishopston, Bristol, 9 Salthrop Rd.	Stephen, D. A.
	Chelmsford, Essex, Marconi College	Rifaat, T.
	Chelmsford, Essex, Marconi College	Zayoona, J. H.
	Plymouth, Devon, 26 Carlisle Terrace, The Hoe	D'Hesse-Chubb, K.
	Westcliff-on-Sea, Essex, 99 Eastwood Blvd.	Cowley, R. I.
Hawaii	Kauai, Kealia	Wada, J. C.
Italy	Naples, Via Ludorico Bianchini 25	Demedici, L.
Japan	Hiroshimaken, J.O.F.K. Hara Sending Station, Haramura, Asagun	Mizuno, T.
	Nagoya City, Okehazama Hosojyo, Arimatu-cho	Nakamura, H.
	Tokio, 3394 Oi-machi	Enomoto, I.
Sweden	Goteborg, Kungsgatan 8	Lundwall, B. H.

For Election to the Junior Grade

Michigan	Petosky, P.O. Box 165	Schaaf, R. H.
Ohio	North Lima	Goodwin, W. J.

For Election to the Student Grade

California	Berkeley, 2740 Mabel St.	Pape, K. R.
	Berkeley, 2515A Piedmont Ave.	Roy, W. H.
	Hollywood, 1644 Winona Blvd.	Gallagher, W. S.
Kentucky	Winchester, 335 S. Maple	Friel, F. J., Jr.
Minnesota	Minneapolis, 531 Walnut St., S.E.	Clements, L. R.
North Dakota	Grand Forks, Box 307, University Station	Beeken, E. D.
	Grand Forks, Box 487, University Station	Denk, W. E.
	Grand Forks, 1102 Reeves Dr.	Moore, R.
	Grand Forks, Box 113, University Station	Stratmoen, A.

Ohio	Camp Chase	Sloan, C. B.
	Columbus, 2256 Neil Ave.	Mueller, W. P.
	Columbus, 51 W. Frambes Ave.	Pelikan, B. Z.
	Columbus, 2163 Neil Ave.	Ross, A. J.
	Columbus, 231 16th Ave.	Smart, P. H.
	Columbus, 90 E. 12th Ave.	Welker, J. W.
	Franklin, 744 S. Front St.	Bryant, V. D.
	Sandusky, 532 Decatur St.	Winkler, L.
	Troy, 29 S. Walnut St.	Thomas, S. O.
Washington	Seattle, 4524 20th Ave., N.E.	Mendenhall, G. G.
	Seattle, 2621 41st Ave., S.W.	Scott, E. D.
	Seattle, Route 8, Box 428	Taylor, R. L.
Wisconsin	Milwaukee, 1929 W. Meinecke Ave.	Plautz, A.

OFFICERS AND BOARD OF DIRECTORS, 1932

(Terms expire January 1, 1933, except as otherwise noted)

President

W. G. Cady

Vice President

E. V. Appleton

Treasurer

Melville Eastham

Secretary

Harold P. Westman

Editor

Alfred N. Goldsmith

Directors

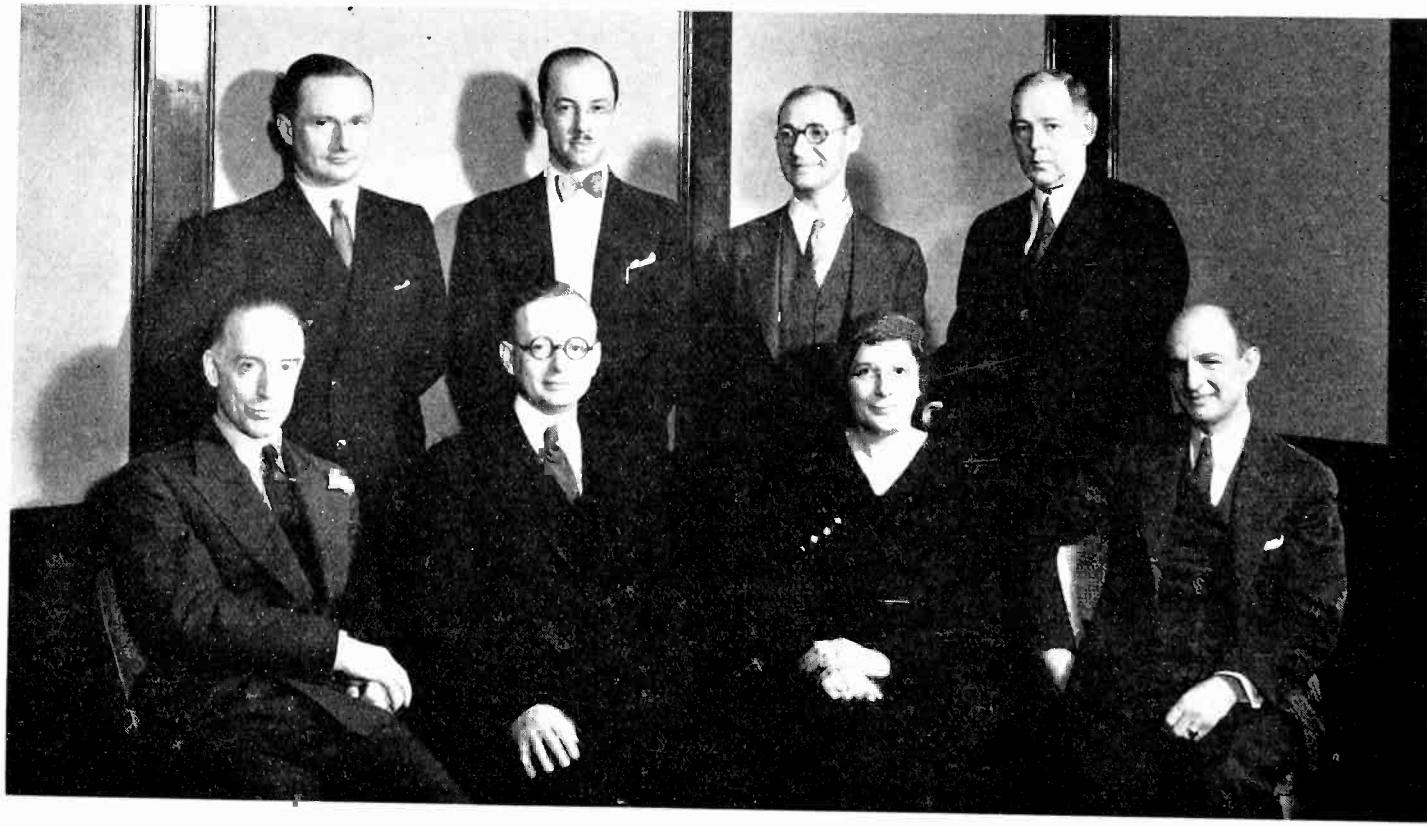
Arthur Batcheller
Lee de Forest, *Junior Past President*
J. V. L. Hogan
C. M. Jansky, Jr.
H. W. Houck
R. H. Marriott
William Wilson

Serving until January 1, 1934

L. M. Hull
R. H. Manson, *Junior Past President*
A. F. Van Dyck

Serving until January 1, 1935

O. H. Caldwell
E. L. Nelson



1932 Convention Committee

The above group are members of the committee responsible for arrangements for the Twentieth Anniversary Convention of the Institute held in Pittsburgh on April 7, 8, and 9, 1932.

Seated from left to right are F. G. Rogers, J. G. Allen, chairman; Miss E. L. Gardner, K. F. Treschow, and standing from left to right are W. C. Evans, R. T. Griffith, L. A. Terven, and L. W. Chubb. Three other members of the committee who are not in the above group are W. C. Bowan, Paul Caldwell, and J. M. Froelich.

INSTITUTE NOTES

Nomination and Election of Officers

In accordance with the Constitution of the Institute, there is printed below Article 7 of the Constitution concerning nomination and election of officers. In addition there is published Section 3 of Article 5 of the Constitution which provides for the election of two additional directors at this first election to be held under the new Constitution.

ARTICLE VII

NOMINATION AND ELECTION OF PRESIDENT, VICE PRESIDENT, AND THREE DIRECTORS AND APPOINTMENT OF SECRETARY, TREASURER, AND FIVE DIRECTORS

SEC. 1—On or before July 1st of each year the Board of Directors shall call for nominations by petition and shall at the same time submit to qualified voters a list of the Board's nominations containing at least two names for each elective office, together with a copy of this article.

Nomination by petition shall be made by letter to the Board of Directors setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acceptance a letter of petition must reach the executive office before August 15th of any year, and shall be signed by at least thirty-five Fellows, Members, or Associates.

Each proposed nominee shall be consulted and if he so requests his name shall be withdrawn. The names of proposed nominees who are not eligible under the Constitution, as to grade of membership or otherwise, shall be withdrawn by the Board.

On or before September 15th, the Board of Directors shall submit to the Fellows, Members, and Associates in good standing as of September 1st, a list of nominees for the offices of President, Vice President, and three Directors. This list shall comprise at least two names for each office, the names being arranged in alphabetical order and shall be without indication as to whether the nominees were proposed by the Board or by petition. The ballot shall carry a statement to the effect that the order of the names is alphabetical for convenience only and indicates no preference.

Fellows, Members, and Associates shall vote for the officers whose names appear on the list of nominees, by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's written signature. No ballots within unsigned outer envelopes shall be counted. No votes by proxy shall be counted. Only ballots arriving at the executive office prior to October 25th shall be counted. Ballots shall be checked, opened, and counted under the supervision of a Committee of Tellers, between October 25th and the first Wednesday of November. The result of the count shall be reported to the Board of Directors at its first meeting in November and the nominees for President and Vice President and the three nominees for Directors receiving the greatest number of votes shall be declared elected. In the event of a tie vote the Board shall choose by lot between the nominees involved.

SEC. 2—The Treasurer, Secretary, and five appointive Directors shall be appointed by the Board of Directors at its annual meeting for a term of one year or until their successors be appointed.

ARTICLE V

SEC. 3—Three Directors shall be elected by the membership annually and shall serve for three years each. At the first election under this Constitution, additional Directors shall be elected, one for one year and one for two years.

The following candidates have been nominated by the Board of Directors for these various offices, and the names are given below together with brief sketches covering their participation in Institute affairs. In cases where committee work is indicated, the figures cover only the last five years, 1928 to 1932, inclusive. Dates and grades of membership are indicated in parenthesis after the name, the grades being abbreviated to the initial letter.

FOR PRESIDENT

Hooper, S. C. (F'28), Director, Naval Communications, Navy Department, Washington, D. C.

Hull, Lewis M. (J'17–A'19–M'27–F'28), Vice President, Radio Frequency Laboratories, Boonton, N. J. Member, Board of Directors, 1929–1932. Admissions Committee, 1928; chairman, Broadcast Committee, 1929–1931; member, Broadcast Committee, 1932; New York Program Committee, 1931; Nominations Committee, 1931; Papers Committee, 1928, 1929, 1931; Standards Committee, 1928.

FOR VICE PRESIDENT

Poulson, Valdemar (F'15), Consulting Engineer, Gentofte, Denmark.

Zenneck, Jonathan (M'13–F'15), Professor, Technische Hochschule, Muenchen, Germany. Recipient, Institute Medal of Honor, 1928.

DIRECTORS

Batsel, M. C. (A'21–F'27), Chief Engineer, RCA Photophone, Inc., New York. Member, Bibliography Committee, 1930–1932; New York Program Committee, 1931–1932; Papers Committee, 1928–1929; Standards Committee, 1928–1930.

Finch, W. G. H. (J'16–A'18–M'25), Secretary and Chief Engineer, American Radio News Corporation, New York. Member, Constitution and Laws Committee, 1928–1931; Papers Committee, 1928; chairman, Publicity Committee, 1928–1930, member, 1931–1932.

Heising, R. A. (A'20–F'23), Engineer, Technical Staff, Bell Telephone Laboratories, New York. Member, Board of Directors, 1927–1930. Chairman, Admissions Committee, 1928–1930, vice chairman, 1931; Constitution and Laws Committee, 1930–1932.

Holland, W. E. (M'25), Chief Engineer, Philadelphia Storage Battery Company, Philadelphia, Pa. Member, Standards Committee, 1928–1930.

Horn, C. W. (A'14–M'28–F'30), General Engineer, National Broadcasting Company, New York. Broadcast Committee, 1929–1932; New York Program Committee, 1932; Sections Committee, 1930, chairman, 1931–1932.

Kolster, F. A. (A'12–M'13–F'16), Research Engineer, International Communications, Inc., New York.

Pratt, Haraden (A'14–M'17–F'29), Vice President and Chief Engineer, Mackay Radio and Telegraph Co., New York. Standards Committee, 1929–1932.

Shute, E. R. (M'25), General Superintendent of Traffic, Western Union Telegraph Company, New York. Admissions Committee, 1929–1932. Bibliography Committee, 1930–1931; New York Program Committee, 1930–1931, chairman, 1932; Sections Committee, 1928, chairman, 1929.

Turner, H. M. (A'14–M'20), Associate Professor of Electrical Engineering, Yale University, New Haven. Bibliography Committee, 1930–1932; Papers Committee, 1929–1932; Standards Committee, 1928–1932.

Wheeler, H. A. (A'27–M'28), Engineer, Hazeltine Corporation, Bayside, L. I., N. Y. Bibliography Committee, 1930–1932; New York Program Committee, 1931; Papers Committee, 1929–1932; Standards Committee, 1931–1932.

May Meeting of the Board of Directors

The May meeting of the Board of Directors was held on the 4th at the Institute office, and those in attendance were W. G. Cady, president; Melville Eastham, treasurer; Arthur Batcheller, O. H. Caldwell, J. V. L. Hogan, H. W. Houck, R. H. Marriott, E. L. Nelson, A. F. Van Dyck, William Wilson, and H. P. Westman, secretary.

Three applications for admission to the grade of Member in the names of R. W. H. Bloxam, F. H. Dupree, and D. R. Thomson were approved as were applications for transfer to the grade of Member in the names of R. M. Dawes, E. L. Gove, L. N. Holland, R. F. Shea, and J. R. Tolmie.

In addition, approval was granted to fifty-eight applications for the Associate grade, three for the Junior grade, and twenty-seven for the Student grade of membership.

An account of the Emergency Employment Committee's activities to date was submitted and follows this report.

The candidates nominated for office for the ensuing year are also listed elsewhere.

It was agreed that papers for presentation at future conventions of the Institute would not be preprinted in view of the negligible effect they have upon discussions presented at meetings and the very substantial expense which they involve. A small committee of Messrs. Goldsmith, Nelson, Wilson, and Westman was appointed to make a study of the subject of convention technical programs.

After considering a request for the use of the Institute membership mailing list for circularization purposes, the Board outlined a specific policy to the effect that such use of the Institute membership list would not be authorized.

A letter from the Standing Committee on Communications from the American Bar Association indicating the interest of that group in the suggestions and proposals which the Institute might care to make on pending and proposed legislation was given favorable consideration.

In view of the substantial reduction in Institute income it was felt that it would be necessary to reduce by about ten per cent the number of editorial pages published in the PROCEEDINGS during 1932 as compared with 1931. This means that approximately 2000 pages of material will be published rather than 2200. This reduction together with a policy of printing fewer copies of each issue for storage in anticipation of future demands will result in a worth while conservation of funds. In an endeavor to make those papers published of maximum value, it was agreed that no papers which were readily available in publications in English would be printed in the PROCEEDINGS, and that a more critical scrutiny would be given to papers published in some other language which are also submitted for publication in the PROCEEDINGS. It is anticipated that these changes will permit the publication of as many original manuscripts as have appeared in past issues of the PROCEEDINGS, and the reduction in the number of pages published will be at the expense of those papers which have appeared elsewhere in English or some foreign language.

Twentieth Anniversary Convention

Inasmuch as the days of April 7, 8, and 9 of 1932 have passed, it is possible to write a report on the Twentieth Anniversary Convention of the Institute which was held in Pittsburgh on those dates. This was the seventh annual convention which the Institute has held.

Those in attendance at the convention were almost exclusively from the United States and Canada and totaled approximately 460, of whom 60 were ladies.

The twenty-three technical papers were presented at five sessions which were well attended. In addition, most of those registered took advantage of the various inspection trips provided.

The two Institute awards which are made annually were presented to their recipients during the Birthday Party which was held on the evening of April 8. They were presented by President Cady who in bestowing upon Dr. Kennelly the Institute Medal of Honor for 1932 made the following presentation address:

"The Medal of Honor of the Institute is awarded each year, according to the phraseology of the rule adopted by the Board of Directors, 'to that person who has made public the greatest advance in the science or art of radio communication regardless of the time of performance or publication of the work on which the award is based.'

"Further along in the official statement is this sentence which is particularly significant in the case of the present award: 'The advance may also be a scientific analysis or explanation of hitherto unexplained phenomena of distinct importance to the radio art.' What words could better express the nature of Professor Kennelly's epochal work on the ionized layer in the atmosphere?

"The first recipient of the Medal of Honor was E. H. Armstrong in 1918. In the intervening years it has been awarded to Messrs. Alexanderson, Marconi, Fessenden, deForest, Stone, Pupin, Pickard, Austin, Zenneck, Pierce, Pedersen, and the latest recipient, General Ferrié, whose recent death has caused widespread grief throughout the scientific world.

"For the year 1932 the Medal of Honor is awarded, upon recommendation of the Awards Committee and by vote of the Board of Directors, to Dr. Arthur Edwin Kennelly, Professor Emeritus of Electrical Engineering at Harvard University and at Massachusetts Institute of Technology.

"Dr. Kennelly, as in the case of certain other men of scientific eminence, so it appears to have been true in your case also that it was a telegraph key that in your early years proved to be the key to the stairway of high achievement. Since the beginning of your scientific career in this country you have occupied an enviable position in the respect and personal regard of your professional associates. The long list of honors that have already been accorded to you bears witness to this. Not only radio engineers, but workers in all fields of oscillating phenomena, including acoustics, are indebted to you for the elegance and utility afforded by the employment of complex numbers and hyperbolic functions as introduced by you. Your studies of the telephone receiver and of vibrating systems in general have proved to be of fundamental importance. Most pertinent of all to the field of radio are your researches in that portion of our mundane sphere which has justly been named for yourself. At least the light side, and therefore the more brilliant side, of the ionized layer as contrasted with the Heaviside, bears your name.

"It is a privilege that I value highly to bestow upon you, sir, the Medal of honor of the Institute of Radio Engineers."

In accepting this award, Dr. Kennelly made the following response:

"Mr. President: It is a great honor that you confer upon me with this medal which has been awarded, in the past, to so famous an array of recipients, whom it has been my privilege personally to know and esteem. The last recipient of this honor, General Ferrié, of beloved leadership and international fame in world radio, has, unhappily for us all, been taken from us by death only a few weeks ago.

"As you have pointed out, sir, it was through the keys that I first came into contact, in 1876, with the great conducting world of wire electrical engineering. It would be keys rather than key, in my case, because submarine telegraphy uses both the international Morse key and the twin pair of cable-code keys.

"Of all the many branches of engineering in the service of mankind, it seems to me that there is no branch more fascinating than communication engineering, on account of its international pervasiveness and its intimate connection with sociology and world psychology, Moreover, in the tree of communication engineering, the youngest branch, radio communication, is the most fascinating and wonder-compelling of all. You gentlemen of the Institute of Radio Engineers belong to a fraternity that has abolished isolation from our planet; minimized the danger of ocean travel; made news travel with the speed of light; converted the heterogeneous pulses of the circumambient ether into meaningful discourse; carried music into the majority of households; and you are now engaged in crystallizing the public opinion of the world. So long as your fraternity is allowed to function, through uncensored channels of radio communication, there will be peace on our planet."

After Dr. Kennelly's response, President Cady presented the Morris Liebmann Memorial Prize to Edmond Bruce with the following words:

"The Morris Liebmann Memorial Prize was established through the generosity of Emil J. Simon, a Fellow of the Institute. It is given in memory of the late Colonel Morris N. Liebmann, and consists of the sum of five hundred dollars.

"The award is made annually by a special committee, appointed by the Board of Directors, to that member of the Institute, who, in the opinion of this committee, shall have made the most important contribution to the radio art during the preceding calendar year.

"The first recipient of this prize was L. F. Fuller, in 1919. Since then, the prize has been awarded to Messrs. Weagant, Heising, Franklin, Beverage, Carson, Conrad, Bown, Taylor, Cady, Appleton, A. W. Hull, and Ballantine.

"By vote of the Awards Committee, consisting of William Wilson, chairman, and Messrs. A. N. Goldsmith, J. V. L. Hogan, J. W. Horton, and R. H. Manson, the prize for 1932 is awarded to Edmond Bruce, Research Engineer of the Bell Telephone Laboratories, in recognition of his researches in directive antenna systems for short-wave communications.

"Mr. Bruce, your brilliant work in field strength measurement, and in the design of antennas combining high directivity, simple construction and effectiveness over a broad, continuous range of frequencies, constitutes a notable contribution to the radio art. It is a great pleasure to hand you this prize, together with all the rights and privileges that inhere thereto, including the privileges of converting it into cash, provided that the checks of the Institute are still honored at the bank, as I trust you will find to be the case."

Mr. Bruce then replied:

"It is hardly necessary for me to say that I am delighted to receive the Liebmann Memorial Award for 1932 from the Institute of Radio Engineers. I wish to thank the Institute membership and their Awards Committee for this honor.

"Since receiving notification of this prize I have taken the occasion to reëxamine the various Institute papers of the period involved. After realizing their very high merit I am particularly flattered that my work should have been selected.

"I think that it is quite a coincidence that I should receive this award at the same time that Dr. Kennelly is being honored by the Institute. I am a former student of Dr. Kennelly. It was in his classes that I received the foundation theory of wires that are electrically long. Throughout all my directive antenna work I have employed Dr. Kennelly's hyperbolic notation, and text books written by him have been my constant bible. I shall feel very happy indeed if he will feel that he played a most important part in my receiving this award."

Emergency Employment Committee Report

The Board of Directors on May 4 directed that I submit a formal report on the Emergency Employment Committee and its activities in the printed pages of the PROCEEDINGS, in addition to other reports. A report is submitted as follows.

At the Directors' meeting on January 6, 1932, O. H. Caldwell brought up the matter of unemployment and what was being done for professional engineers in New York City. As a result, the Board decided, through a series of motions made and seconded by Messrs. Goldsmith, Hogan, Eastham, and Van Dyck, that something should be done to help our members immediately, and I was directed to head a committee to do what we could as quickly as possible, and a drawing account of $1000.00 was appropriated to supply immediate funds. Plans were formulated that evening and the work was started the next morning. At the February 3 Board meeting, President Cady added Dr. Goldsmith and Mr. Hogan to the committee, who with the undersigned have constituted the Emergency Employment Committee to date.

On January 15 a form letter was sent to all members asking those who could do so to contribute, and those who needed help to advise us. Those who replied that they needed help were sent two forms, one is a short confidential questionnaire about their financial condition and dependents; the other is a long questionnaire about their training and experience. Those forms went into use on January 13 for some members who came in before we had said publicly that we would do this work. Other forms were sent to the references given by the members. The first member was employed on January 14. Letters stating the need for help were numerous at first, decreasing gradually to about five per week. On January 19 several hundred form letters were sent to firms who might be expected to employ radio men or use the results of a broadcast survey. Very few replied and no person was placed immediately from that letter. However, one of its results was some publicity in magazines and it may have caused some later inquiries for men.

From March 3 to 10 and from April 29 to May 9 additional circular letters were sent to the membership asking for contributions. So far we have received about $3600 and have spent about $3800.

The abilities of members were brought out under various subjects by the numerous questions in the training and experience questionnaire. That was done to help us get jobs for men under present hard conditions. For example, to produce and sell a product some drafting, some microphone and tube experience, a reading knowledge of German, and some letter writing may be needed. A few years ago five people might have been employed to fill those needs, but now if more than one is employed to fill these needs the product may cost more than it will sell for.

The following classifications were made from the answers to 216 questionnaires. For example in this classification of a group of 216 members who are radio men listed with this committee, 12 could do some drafting, several come under subjects relating to microphones and tubes, 43 can read some German, 67 can do some typing and 8 can do some stenographic and typing work. File numbers appear under these subjects on our cards. If one or more numbers appear under all the subjects then one or more of the members may fill the requirements sufficiently to get a job.

Advertising, publicity, sales promotion	65
Aeronautical radio	
Design	4
Installation	3
Operation	4
Announcer	
Broadcast	4
Automobile driver	199
Aviator (pilot)	3
Bibliographies, have prepared	25
Bookkeeping and clerical	90
Broadcast reception, study of	127
Broadcast surveys, house canvass	68
Building	
Construction, design	2
Battery	
Design, maintenance	2
Canvassing	63
Chiropractic (Dr.)	1
Collecting data	128
College graduates	58
Commercial research	65
Consultant	2

Crystals	
Research, cut	1
Designer	
Broadcast receivers	10
Commercial radio receivers	2
Direction finding	
Design and operation	2
Draughtsman	12
Estimating	94
Executive	4
Explorer (Arctic and Africa)	1
Field strength measurements	47
Geophysical	
Research, experiment	4
Interviewing	76
Laboratory and test	84
Language—read, write, or speak	
Arabic	1
Armenian	2
Danish	2
French	39
Finnish	1
German	43
Italian	6
Jewish	1
Lithuanian	1
Norwegian	5
Polish	1
Russian	5
Spanish	29
Swedish	3
Locomotive	
Mechanic	1
Loud speaker	
Design and manufacturing	5
Machinist	9
Measuring instruments	
Common	179
Advanced	44
Mill operator	2
Music	
Appreciation	8
Training	81
Photographer	2
Operator, radio	
Amateur	98
Broadcast	43
Commercial	60
Power service	1

Production and manufacture	
Radio	121
Nonradio	21
Projectionist	
(Sound and silent pictures)	2
Public speaking	77
Public address systems	
Design and operate	16
Recording	
For pictures	5
For phonograph records	3
Refrigeration	1
Research or development	128
Selling	118
Servicing	191
Sound and acoustics	160
Statistical accountant	2
Stenographer	8
Story and newspaper writing	56
Surveying	
Land	4
Teaching	90
Technical papers and reports	123
Telegrapher	
Commercial and Railroad	3
Telephone engineer	5
Television	
Manufacturing, installation, or design	3
Operating and research	2
Translator	1
Transmitters	
Radio broadcast (design and erection)	6
Commercial, Government (design and erection)	7
Typist	67
Vacuum tubes, electron	
Design and manufacture	8
Uses other than usual radio	
Bridge	1
Burglar protection	28
Calipering	4
Cathode ray and oscillograph	2
Chemical	10
Current devices	62
Dynamo electric machine	15
Fire protection	20
Grading, counting, sorting	12
Highway traffic	11
Home movies	26

Light control	32
Metallurgy	6
Phonograph	49
Photo-electric	13
Railway signals	9
Sonic, supersonic	25
Surgical, medical	16
Synchronizing devices	31
Talkies	72
Temperature control	2
Voltage devices	82
Weighing	2
X-ray	17

According to our records 26 have directly or indirectly obtained jobs through our efforts and still hold those or other jobs. At least they have not come back to ask us to try again. We often send one man after successive possibilities and often send many men after one possibility, only to fail. Sometimes the supposed employer does not hire anybody.

Trying to get a man a job is doing the same thing that others are doing. The man himself, his friends, employment agencies, fraternities, churches, unions, civic organizations, humanitarians, charitable organizations, political organizations, and others are all trying to do the same thing without much success.

However, part of our system differs from what others do in trying to combat unemployment. We offer a man a broadcast survey job that he can do wherever he lives and that will not interfere with odd jobs, looking for a job, or taking a permanent job and that may enable him to pick up temporary jobs or a permanent job. Those who stick to it will probably pick up something else sooner or later, some have already. Also they will probably cash in on the experience in future years. It requires nerve, tact, persistence, judgment, and is different.

We think the product from the survey work of these men is better than surveys that have sold and some that have been praised in print. However, nothing new is selling much now and we suspect that those we thought should be customers are losing money or are afraid they will lose money. When we arrive at the point where we can sell the surveys for what will make them self-supporting then that much depression will be filled up and we will not have to ask members of the Institute to contribute.

We send the surveyor 57 questions. He interviews the listener in the listener's home, uses the listener's receiver and writes the answers to the questions. The questions in the list are numbered. The surveyors write the question numbers and the answers they obtain. The answers identify the question list, the date and time, the surveyor, the address and name of the listener, characteristics of the house, probable financial circumstances, nationality and education of the listener, the receiver and its operating characteristics, stations that can be heard at different times and how well, interferences, the listener's and other members of the family's likes and dislikes, and the listener's opinion of educational broadcasts, European broadcasts, advertising, television, electrical transcriptions, etc.

We did not try to ask a question about the effect of suggestions. We inserted questions with suggestive words attached to them for a period of time and then removed the suggestive words.

Generally the persons interviewed have never written to a broadcast station or advertiser or answered a mail survey. The answers collected in quiet friendly interviews by men who have nothing to sell or advocate, average up to be quite wholesome and normal. They should be of value to the broadcast industry and the listening public.

The payment schedule has gone through some experimentation. First all were paid $15 per week. Then the men on survey work were paid 25 cents for each complete acceptable list of answers. Now the men in the office get $3 for each full day they work and the men on survey get 50 cents for each list of answers. The office uses one or more men every day but Sunday. The Institute Board room and adjacent hall provide office space and the Institute donates the office equipment. Except for paper, postage, and the rent of one typewriter all the money goes to the members either for surveys or for placing men in other jobs.

The broadcast survey work was started with one surveyor on January 26, 11:00 A.M., in Brooklyn. Since then 67 other men have been employed on this work and about 6000 listeners have been interviewed.

The following is a list of localities in which surveys have been made. In some places several men did survey work, Brooklyn for example. In other cases one man did survey work in more than one town. The places covered are in Alabama, Tuscallosa; California, Alamenda, Berkeley, Brea, Burlingame, Folsom City, Fullerton, Kerman, La Habra, Los Angeles, Los Banos, Oakland, Palo Alto, Piedmont, San Francisco, San Leandro, San Mateo, Saratoga, Stockton, Sunnyvale, Venice, Whittier; Colorado, Colorado Springs; Connecticut, Naugatuck, Waterbury; Illinois, Chicago, Palatine; Iowa, Des Moines, De Witt; Kentucky, Silver Grove; Massachusetts, Dorchester, North Andover, Northfield; Michigan, Birmingham, Fenton, Scottville; Mississippi, Cleveland; Nebraska, Falls City; New Hampshire, Hollis, Nashua, Northwood, Northwood Center, East Northwood; New Jersey, Barrinton Park, Elizabeth, Jersey City, Paterson; New York, Brooklyn, Kenmore, New York City; North Carolina, Tarboro; North Dakota, Fargo; Ohio, Canton, Centerburg, Cleveland, Hamilton; Oklahoma, Coalgate; Pennsylvania, Altoona, Berwyn, Connellsville, Johnstown, Keiser, Philadelphia; Rhode Island, Pawtucket; Tennessee, Knoxville; Texas, Dallas, Giddings; Vermont, Brattleboro; Washington, Seattle, Wenatchee; Wisconsin, Whitewater.

We need more money. There are some on our lists in our A and B division classifications who should be helped but we have run so close to our cash limits that we have not helped them yet. In the A division, people need help very badly. The need for help decreases from A through to E. All a man in the E division needs is something to do; he has enough money to take care of anything he needs. Not only do we need more money to help those we have not helped but to continue with those we have helped.

Those who have been helped say in frequent letters how grateful they are and the committee wishes to add its gratitude to all who have contributed.

Respectfully submitted,
(*Signed*) R. H. Marriott, *Chairman*
Emergency Employment Committee

Radio Transmissions of Standard Frequency

The Bureau of Standards transmits standard frequencies from its station WWV, Washington, D. C., every Tuesday. The transmissions are on 5000 kilocycles, and are given continuously from 2:00 to 4:00 P.M., and from 10:00 P.M. to 12:00 midnight, Eastern Standard Time. (From October, 1931, to March, 1932, inclusive, the evening schedule was two hours earlier.) This service may be used by transmitting stations in adjusting their transmitters to exact frequency, and by the public in calibrating frequency standards and transmitting and receiving apparatus. The transmissions can be heard and utilized by stations equipped for continuous-wave reception throughout the United States although not with certainty in some places. The accuracy of the frequency is at all times better than one cycle (one in five million).

From the 5000 kilocycles any frequency may be checked by the method of harmonics. Information on how to receive and utilize the signals is given in pamphlets obtainable on request addressed to the Bureau of Standards, Washington, D. C.

The transmissions consist mainly of continuous, unkeyed carrier frequency, giving a continuous whistle in the phones when received with an oscillatory receiving set. For the first five minutes there are transmitted the general call (CQ de WWV) and announcement of the frequency. The frequency and the call letters of the station (WWV) are given every ten minutes thereafter.

Supplementary experimental transmissions are made at other times. Some of these are made with modulated waves, at various modulation frequencies, Information regarding proposed supplementary transmissions is given by radio during the regular transmissions, and also announced in the newspapers.

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

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

Committee Work

Admissions Committee

A meeting of the Admissions Committee was held at the Institute office on May 4, those in attendance being A. F. Van Dyck, chairman; Arthur Batcheller, H. C. Gawler, E. R. Shute, and H. P. Westman, secretary.

Of seven applications for transfer to the grade of Member, three were approved, three rejected, and one was tabled pending the arrival of additional information. Five applications for admission to the grade of Member were approved and one was rejected.

Membership Committee

The Membership Committee held its regular monthly meeting at 5:30 P.M. on May 4 at the office of the Institute, H. C. Gawler, chairman; A. F. Murray, C. R. Rowe, and A. M. Trogner being in attendance.

New York Program Committee

The New York Program Committee held a meeting at 4 P.M. in the Institute office on May 6. Those in attendance were E. R. Shute, chairman; H. H. Beverage, C. N. Anderson, Austin Bailey, and H. P. Westman, secretary.

STANDARDIZATION

Technical Committee on Electro-Acoustic Devices—I.R.E.

Two meetings of the Technical Committee on Electro-Acoustic Devices were held since the last report. The first of these on April 15 at 10 A.M. was attended by E. D. Cook, chairman; L. G. Bostwick, E. W. Kellogg, L. J. Sivian (nonmember), and B. Dudley, secretary.

The second meeting was held at 10 A.M. on May 6 and those present were E. D. Cook, chairman; L. G. Bostwick, L. J. Sivian, and B. Dudley, secretary.

Technical Committee on Electro-Visual Devices—I.R.E.

The newly established Technical Committee on Electro-Visual devices held its first meeting at 7:30 P.M. on May 3 with the following in attendance: J. V. L. Hogan, chairman; H. S. Baird, H. W. Houck, W. J. Jarrard, R. H. Marriott, and B. Dudley, secretary.

Technical Committee on Radio Receivers

A meeting of the Technical Committee on Radio Receivers was held at 10 A.M. on April 21 at the office of the Institute, those in attendance being H. A. Wheeler, chairman; H. H. Beverage, E. T. Dickey, Virgil M. Graham, David Grimes, F. A. Hinners, W. E. Holland, H. O. Peterson, F. A. Polkinghorn, L. P. Tuckerman (representing C. E. Brigham), Lincoln Walsh, W. T. Wintringham (representing Lloyd Espenschied), and B. Dudley, secretary.

Institute Meetings

Boston Section

A meeting of the Boston Section was held on April 22 at Harvard University, G. W. Pierce, chairman, presiding. A paper on "Recent Developments in Receiving Tubes" was presented by Paul Weeks, chief engineer of the Raytheon Production Corporation.

Dr. Weeks described the constructional details of several new tubes which have been recently announced. Characteristics of the tubes were outlined and their uses discussed.

At this meeting the section officers were changed. Professor E. L. Chaffee of Cruft Laboratory, Harvard University, and Professor G. W. Kenrick of Tufts College are the new chairman and secretary-treasurer, respectively.

The meeting was attended by 105 members and guests.

Buffalo-Niagara Section

A meeting of the Buffalo-Niagara Section was held on April 18 at the University of Buffalo, L. Grant Hector, chairman, presiding.

R. H. Langley, consulting engineer, presented a paper on "The Application of Permeability Tuning to Broadcast Receivers."

The author outlined the development of tuning methods employed in radio receivers and pointed out that the capacity variation method of tuning had the disadvantage of the selectivity varying with frequency over the broadcast range. Inductance tuning does not have this disadvantage and various methods of accomplishing this necessary variation in inductance were described. The author considered a method of changing the permeability of the magnetic circuit of the inductance an effective method of tuning. A magnetic material called Polyiron in which eddy current losses are lower than in other materials is used. Polyiron is made of particles of iron about 10 microns in diameter coated with an insulating material about 1 micron thick. The coated particles are molded into bakelite resulting in a material about 92 per cent iron by weight. The useful permeability is about 8 and the hysteresis loss is negligible at radio frequencies. For present purposes it is not useful above 2000 kc and for the broadcast band coils are preferably wound with litzendraht wire. Adjustments are accomplished by moving the core in and out of the coil and by switching capacity steps. A sample unit permitted the core nearly to surround the coil. At the 1500-kc setting, the inductance is about 65 microhenries with a capacitance of approximately 160 micromicrofarads.

The paper was discussed by Messrs. Crom, Hector, Huntsinger, Manson, MacNabb, Waud, and others of the 65 members and guests in attendance.

Cleveland Section

The March 19 meeting of the Cleveland Section was held in the studios of WHK, E. L. Gove, chairman, presiding.

R. N. White, chief engineer of the Macoustic Engineering Company, Cleveland, presented a paper on "Acoustics and Sound Pressure Measurements."

The author pointed out that sound may be controlled by three basic methods; at the source, by absorption at room boundaries known as sound treatment, and by prevention of sound transmission, which is know as soundproofing.

The author outlined the work done by Sabine, Eyring, Watson, and Knudson in the development of practical formulas for predicting reverberation time in rooms.

He pointed out that sound may be reflected in much the same way as light and can be focused as evidenced by whispering galleries, echoes, and similar occurances. The shape of the auditorium should therefore be free from such obstructions as produce undesirable reflection. Curved walls will make echoes more pronounced near the center of their curvatures and accordingly dome-shaped ceilings are acoustical hazards. If curved walls or ceilings are necessary they should be broken up by deep coffers, pilasters, or similar structures.

In soundproofing, double walls with air space between are considered good. The filling of the space between the walls with loose or porous material often is of doubtful value since it tends to establish a connection between the walls and thus transmits in sound.

Using in general the method outlined by P. E. Sabine, the absorption coefficients of various materials were determined by an intensity reflection test. A microphone and an audio oscillator were so placed that the angle of sound source to the material was equal to that of the microphone. The latter device was in a soundproof box, highly absorbent, having a small aperture facing the material to be tested. An output meter connected to the microphone and an amplifier then gave visual readings of the amount of reflection obtained. A number of different materials were so tested, and the ranges of reflection were noticeably wide. The coefficient of absorption was affected by the angular incidence of the sound and varied also with the frequency. It was noted that the apparent coefficient of an absorbing substance was increased by leaving an air space between it and a hard backing. Other factors were thickness and porosity.

The author concluded his paper and experiment with a demonstration by means of special recordings of the garbling effect of echo upon speech and music.

The meeting was attended by 85 members and guests.

Chicago Section

A meeting of the Chicago Section was held on March 21 in the Engineering Building, R. M. Arnold, vice chairman, presiding.

A paper on "Recent Developments in Radio Receiving Tubes" was presented by E. W. Ritter of the RCA Radiotron Company.

The paper covered technical details of several new receiving tubes which have recently been announced to the public.

The meeting was held jointly with the Radio and Electrical Sections of the Western Society of Engineers and of those in attendance, eighty-five were Institute members.

Detroit Section

The April meeting of the Detroit Section was held on the 15th in the Detroit News Conference Room, H. L. Byerlay, chairman, presiding.

A paper on "Acoustical Design of Broadcast Studios" was presented by J. S. Parkinson, staff engineer of the Acoustic Division, Research Department of the Johns-Manville Company.

The speaker outlined the importance of acoustic consideration in broadcast studio design and pointed out that the studio is but one link in the long chain which makes up the broadcast system. Variations and defects in this link are just as damaging as though occurring in other parts of the system.

As a further introduction to his paper, the speaker presented an interesting discussion of the subject of reverberation and its effect upon programs of various types.

In discussing the most desirable shapes in auditoriums, or studios, it was pointed out that most uniform sound distribution and the greatest reduction in echoes was obtained by proportioning the room in the ratio of 2:3:4 or 2:3:5. Approximately 750 cubic feet of space should be allowed per auditor.

The speaker then presented an interesting discussion of frequency characteristics, the theory of sound absorption, loudness distribution, location of treatment for echoes, and factors governing the choice of treatment. By means of suitable apparatus it was demonstrated that hair felt or similar substances one inch thick absorbed more high frequency sound than low frequency. The effect of echoes on speech and music was also demonstrated.

The paper was discussed by a number of the 65 members and guests in attendance.

Los Angeles Section

A meeting of the Los Angeles Section was held on March 29 at the Mayfair Hotel, E. H. Schreiber, chairman, presiding.

The first paper of the evening which was a "Discussion of the Power Output of Vacuum Tubes at Audio Frequencies" was presented by H. G. McWilliams of the Pacific Telephone and Telegraph Company. The paper covered the derivation of formulas for determining the load necessary to obtain maximum undistorted output from triodes. The speaker also compared the merits and disadvantages of the pentode versus the triode.

The second paper of the evening by R. M. Moore, also of the Pacific Telephone and Telegraph Company, was on "Electrical and Thermal Characteristics of Piezo-Electric Oscillators," in which the conditions necessary for the high order of accuracy required in broadcast transmission was pointed out. Methods of obtaining this essential accuracy of frequency control were outlined. The requirements of a crystal oven having extremely accurate temperature control were discussed and compared to analogous electrical filter circuits.

The meeting was attended by ninety-three members and guests and thirty of these were present at the informal dinner which preceded it.

The April meeting of the Los Angeles Section was held on the 19th at the Mayfair Hotel in Los Angeles, Chairman E. H. Schreiber presiding.

After an introduction by Inspector F. P. Hawtry, Sergeant J. G. Rosso of the Los Angeles Police Department presented a paper on "How Radio Serves the Police Department."

Inspector Hawtry explained how the city was divided into districts to facilitate the handling of calls to the radio cars and outlined how complaints were handled at the central station. He pointed out the speed with which calls are answered, and that for the past three months the average time of answering a call was two minutes and 42 seconds. Sergeant Rosso, who is in charge of the equipment, then discussed some of the problems encountered in completing the installation of the equipment and getting it into satisfactory operation. Specially designed transmitters and receivers are employed and a sample receiver chassis was on display.

Several of the 63 members and guests in attendance entered into the discussion which followed the presentation of the paper. The informal dinner which preceded the meeting was attended by 18.

New York Meeting

Two papers were presented at the May 4 New York meeting of the Institute at which President Cady presided. The first paper on "Recent Cathode Ray Tube Developments" by Allen B. DuMont covered developments in the hot cathode type of cathode ray tubes. Improved methods of generating, focusing, and modulating cathode rays were described and demonstrated. A screen luminescence produced by various types of fluorescent materials was demonstrated and a number of recent types of tubes developed for various purposes were shown.

The second paper on "Applications of the Cathode Ray Oscillograph" was presented by R. R. Batcher. The author pointed out that cathode ray tubes are well adapted to scientific measurements and tests. The associated materials for such equipment were described and demonstrated. The production of timing waves, the recording and interpretation of oscillograms, and several representative applications of the tubes were shown. The factors affecting the accuracy of measurements made with these tubes were discussed.

Philadelphia Section

A meeting of the Philadelphia Section was held on March 31 at the Engineers Club, G. W. Carpenter, chairman, presiding.

The paper of the evening on "Application of Class B Amplifiers to A-C Operated Receivers" was presented by L. E. Barton of the RCA Victor Company.

The paper covered the general subject of class B Audio amplifiers and outlined the economy which this method of operation permitted. The author then discussed the characteristics of the new type-40 power output tube which was designed for class B amplification. The tube operates normally with zero grid bias thus avoiding the necessity of providing a bias voltage having extremely low regulation with varying loads. Methods whereby the varying drain upon the power supply equipment would not result in substantial fluctuations in plate voltage to the power stage and the other circuits in the receiver were discussed in detail.

The general discussion which followed the presentation of the paper was entered into by a number of the one hundred and twenty-three members and guests in attendance.

San Francisco Section

R. M. Heintz, chairman, presided at the March 23 meeting of the San Francisco Section held in the Bellevue Hotel.

S. S. Mackeown of the California Institute of Technology presented a paper on "Gas-Filled Thermionic Tubes."

Dr. Mackeown discussed the theory and some of the practical applications of hot cathode mercury vapor tubes, giving particular attention to thyratrons.

A general discussion followed and was participated in by a number of the 60 members and guests in attendance of whom 17 were present at the informal dinner which preceded the meeting.

The April meeting of the San Francisco Section was held on the 20th at the Bellevue Hotel with Secretary F. E. Terman presiding.

"Reminiscences in Radio and Allied Arts" was the title of the paper by C. F. Elwell of British Talking Pictures, Ltd., London.

Mr. Elwell described his work in the founding of the Federal Telegraph Company and the results obtained in the early development of continuous-wave communication using Poulsen arcs. He then outlined his war activities and described the events leading up to the establishment of the Mullard Company for which he was responsible, and concluded with a discussion of sound pictures.

The 35 members and guests in attendance found the paper to be most facinating in view of the speaker's familiarity with the important events and personalities that have been connected with radio since 1908.

Seattle Section

On March 31 a meeting of the Seattle Section was held at the University of Washington, Chairman L. C. Austin presiding.

"Distortion in Double Side Band Radiotelephone Transmission" was the subject of the paper by R. W. Deardorff and T. M. Libby.

A general demonstration of the effect of distortion in radiotelephone transmission was given as part of the paper and the apparatus used for the demonstration was thoroughly explained.

The meeting was attended by 72 members and guests.

Toronto Section

The April meeting of the Toronto Section was held on the 13th at the University of Toronto, F. K. Dalton, chairman, presiding.

A paper on "The Application of Dual Speakers to Receiving Sets," was presented by W. A. Ellmore, Chief Engineer, Utah Radio Products Company, Chicago.

The speaker illustrated by means of several curves of the sound output of an audio amplifier the effect of using one or two loud speakers. The curves indicated the theoretical advantage particularly notable on the low-frequency end of the spectrum. He then pointed out that the chief application of dual speakers would be in conjunction with the extra peak power available from a push-push amplifier employing the new tubes.

The paper was discussed by Messrs. Andre, Bradley, Burrell, Fox, Hackbusch, Leslie, and Price of the 68 members and guests in attendance.

Washington Section

The April meeting of the Washington Section was held on the 14th at the Continental Hotel, H. G. Dorsey presiding.

Gilbert Smiley, Chief Engineer of the Samson Electric Company, presented a paper on "Centralized Sound Systems."

The author demonstrated a public address system representative of the group which he described. He then discussed these systems dividing them into several parts and treating each separately and in detail. The requirements of such systems were then outlined and the necessity of providing precautions for the safety of the operating personnel stressed. General empirical rules for determining the power output required under varying conditions were given and the possibility of designing units which may be combined to supply larger power outputs was discussed.

The meeting was attended by 45 members and guests, 17 of whom were present at the informal dinner which preceded it.

Personal Mention

J. L. Filgate formerly with the General Motors Corporation has joined the radio engineering staff of the United American Bosch Corporation.

K. W. Karvis previously with the U. S. Radio and Television Corporation has become associate chief engineer of the Zenith Radio Corporation of Chicago.

Lieutenant Commander H. W. Kitchin, USN, has been transferred from Annapolis, Md., to Cavite, P. I.

Formerly chief engineer of the State Telegraph and Telephone Works at Warsaw, Poland, Peter Modrak has been appointed director of the Transatlantic Radio Station at Warsaw.

Previously with the DeForest Radio Company, R. J. Orner has become a radio engineer for the U. S. Radio and Television Corporation, Marion, Ind.

J. S. Robb formerly engineer for the Radio Condenser Company of Camden, N. J., has become chief engineer of the Radio Condenser Company, Ltd. of Toronto, Canada.

C. R. Rowe previously with Wired Radio, Inc., is now radio engineer for the International Radio Communications Labs., Newark, N. J.

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TECHNICAL PAPERS

WESTINGHOUSE RADIO STATION AT SAXONBURG, PA.*

By

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and

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Summary—*Westinghouse Radio Station KDKA, at Saxonburg, Pa., was built to provide up-to-date equipment for regular broadcasting and for high power experimental work on either long or short waves.*

Power equipment consists of a 12-phase, 900-kw, 30-kv rectifier using three-anode mercury pool type tubes; a 6-phase, 450-kw, 22-kv rectifier; four 10-kw, 3-kv motor generator sets for bias and intermediate amplifier plate supply; six 40-kw, 40-volt motor generator sets for filament power; a 400-volt storage battery for small tube plate voltage and for substation control; and two 12-volt, 1600-ampere-hour storage batteries for small tube filament supply.

Present transmitter apparatus includes a 300-kw output stage using six Westinghouse type AW-220 tubes; a 5-kw intermediate power amplifier; a modulator for the 5-kw stage, a crystal control and intermediate amplifier unit; a high level modulator with provision for six AW-220 tubes for experiment or modulating the output stage operated class C; and a 50-kw power amplifier for regular broadcasting using six water-cooled tubes plate modulated by a transformer coupled class B push-pull modulator.

The four audio circuits to the studio in Pittsburgh go underground for several thousand feet to prevent r-f pick-up.

The cooling water system employs heat interchanges.

THE Westinghouse Radio Station at Saxonburg was built to provide up-to-date equipment for the regular broadcast activities and to provide facilities for high power experimental work on either long or short waves.

The station is located on a 120-acre site approximately twenty miles north of Pittsburgh. The building is a brick structure 32 feet by 82 feet with a front wing 24 feet by 32 feet. It houses all of the equipment except the rectifier transformers and filter chokes which are ar-

* Decimal Classification: R600. Original manuscript received by the Institute, March 4, 1932. Presented before Twentieth Anniversary Convention, Pittsburgh, Pa., April 9, 1932.

ranged on a platform at the rear of the building. Fig. 1 is a front view of the building.

Power is brought into the building at 2300 volts through underground cables from the substation on the north side of the property. One panel of the main switchboard in the station contains the operating controls, relays, meters, etc., for the two sources of 25-kv, 3-phase power at the substation.

Fig. 1—Front view of Westinghouse radio station at Saxonburg, Pa.

All of the power equipment is located in the basement of the building, leaving the main floor free for the radio-frequency and control apparatus. Fig. 2 shows the layout of the apparatus. The equipment is divided into two general groups—broadcast, and short-wave or experimental. As far as possible the regular broadcast equipment is installed at the north end of the building. The main switchboard is at the center of the apparatus room and all essential controls are brought to this point.

In the belief that the broadcast activities in this country will fol-

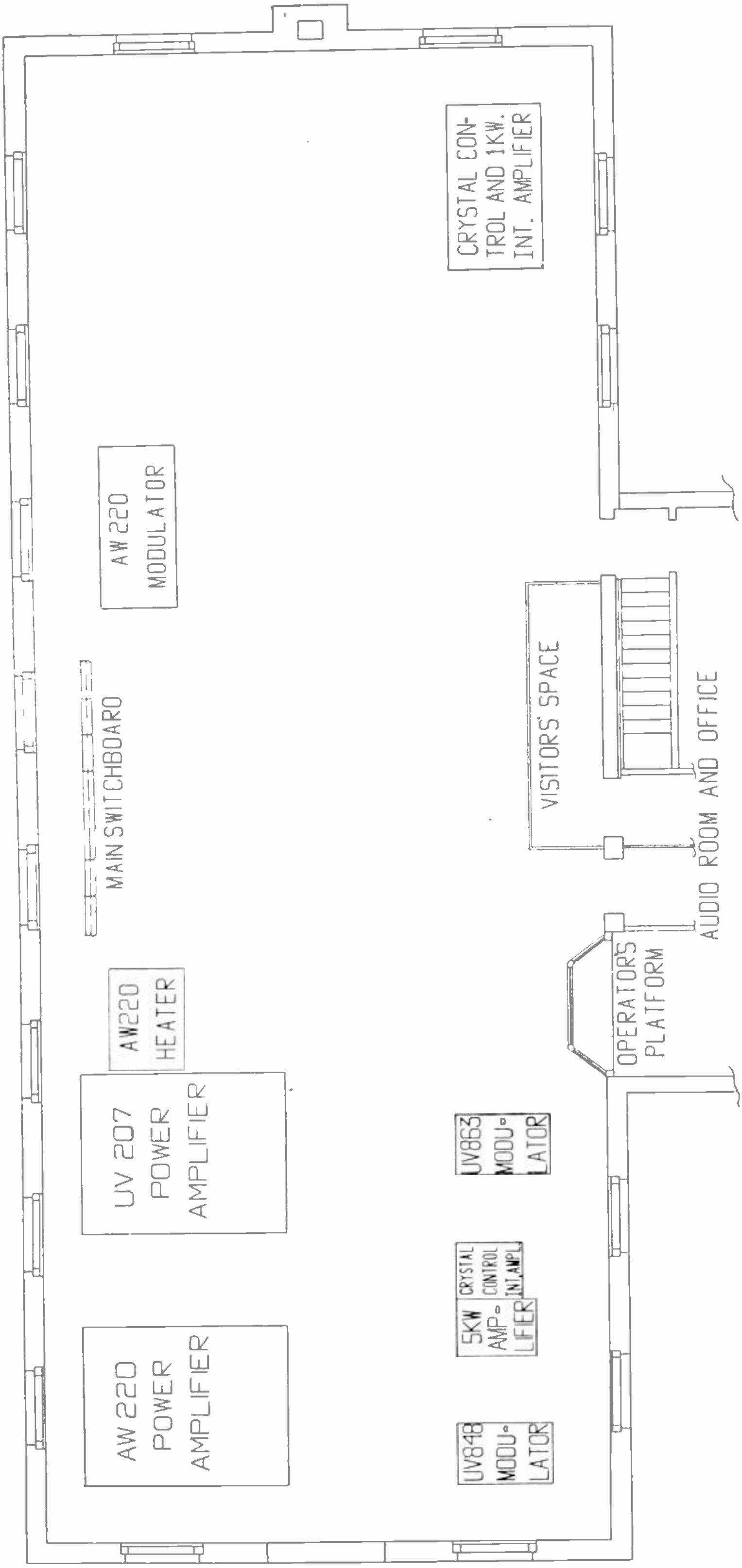

Fig. 2b—Layout of apparatus on main floor.

low the European trend toward higher power, it was decided that a carrier of approximately 300 kw completely modulated was about the limit of possibilities with tubes of the present design. One rectifier capable of delivering 900 kw at 30 kv was therefore included in the equipment. A second rectifier of 450 kw at 22 kv was also included. All necessary auxiliary equipment was provided to facilitate development of methods of modulation and operation of tubes at high power.

Although the original intention was to use the large unit for broadcast operation and the small unit for short-wave or experimental work, the control system is so arranged that almost any combination of units can be used for either broadcast or experimental work without interfering in any way with the automatic control and safety features provided. One panel of the main switchboard is devoted entirely to the control of the motor-driven equipment. From this panel all of the machines can be started up ready for operation. On either side of this panel are two smaller panels which contain the equipment actually to connect the rotating or auxiliary equipment to its load. Two other panels control the operation of the main rectifiers. Each panel is equipped with the necessary meters and rheostats for complete control.

All of the motors start directly on the line to reduce the starting time. Each motor is protected by overload relays, and any machine can be isolated for repairs while the station is in operation. All of the heavier rotating machines are flexibly mounted to reduce the amount of vibration transmitted to the building.

Rectifiers

The two main rectifiers have been described in detail elsewhere[1] and will only be outlined briefly here. Both rectifiers are of the polyphase type and operate directly from the 2300-volt station supply through 3-phase water-cooled induction regulators capable of 100 per cent regulation. The 30-kv rectifier, through an ingenious use of the Scott connection is the equivalent of a 12-phase rectifier, which greatly increases the ripple frequency and consequently reduces the filter required. The connections are so arranged that the four 3-anode mercury pool cathode tubes are effectively in series resulting in a very low inverse voltage per tube. Fig. 3 shows the schematic diagram of the 12-phase rectifier. Each of the tubes is mounted in a sparate oil tank, in a cradle which may be readily removed and replaced by another cradle with a new tube. Automatic starting is provided by the motor-driven tilt mecha-

[1] R. L. Davis, "Power equipment at new KDKA station," presented at A.I.E.E. Meeting, March, 1931, Pittsburgh, Pa.

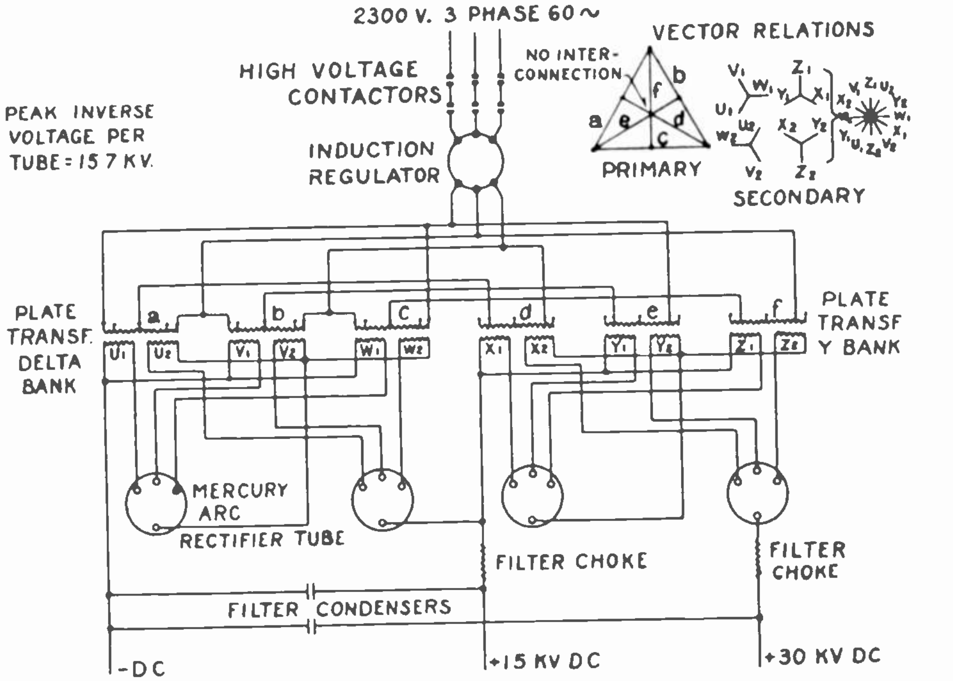

Fig. 3—Schematic diagram of 30-kv, 12-phase rectifier.

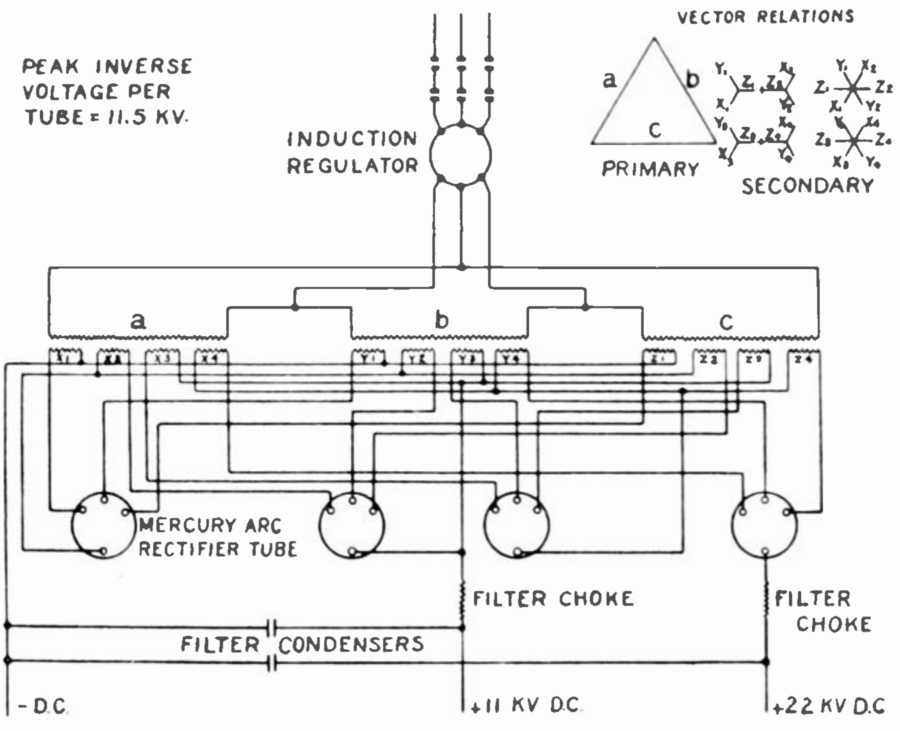

Fig. 4—Schematic diagram of 22-kv, 6-phase rectifier.

nism operated by push button from the main control panel. The 22-kv rectifier is similar except that an ordinary 6-phase transformer connection is used, with four tubes in series. The schematic diagram

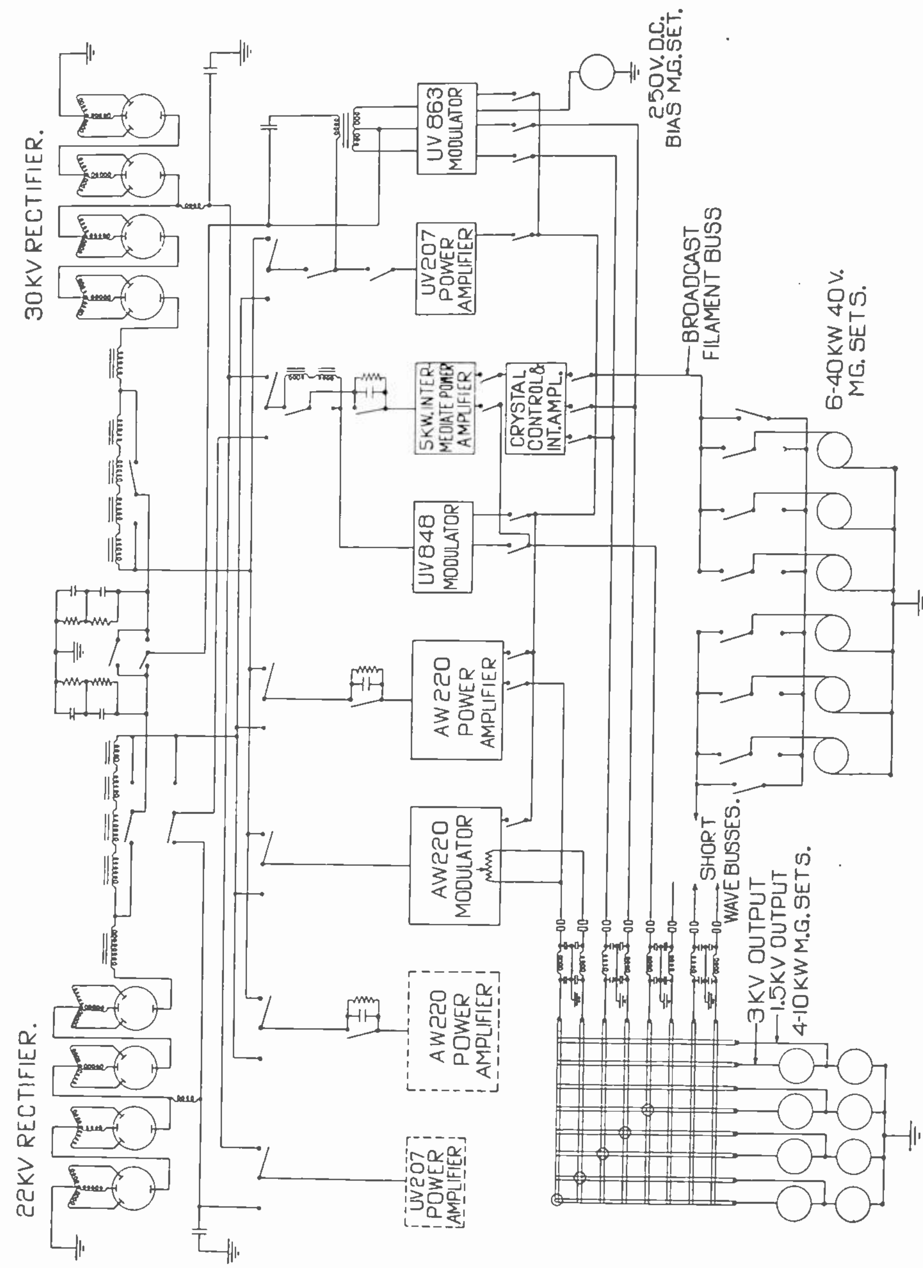

Fig. 5—Schematic circuit diagram.

of this rectifier is shown in Fig. 4. Midtaps are provided on each of the rectifiers to supply plate voltage for intermediate stages. To facilitate the use of the rectifier for experimental use provision has been made to make various combinations of rectifiers, filters, and modulation chokes. Two panels of high voltage switches have been provided in the basement to make this interchangeability possible. Fig. 5 gives some idea of the possible combinations.

Intermediate Plate Supply and Bias Generators

Four 10-kw, 3-kv motor generator sets are provided for plate supply for the intermediate amplifier stages and for bias. Two of these were intended for use with the broadcast equipment, one with the short-wave equipment and one for spare or experimental use. Each

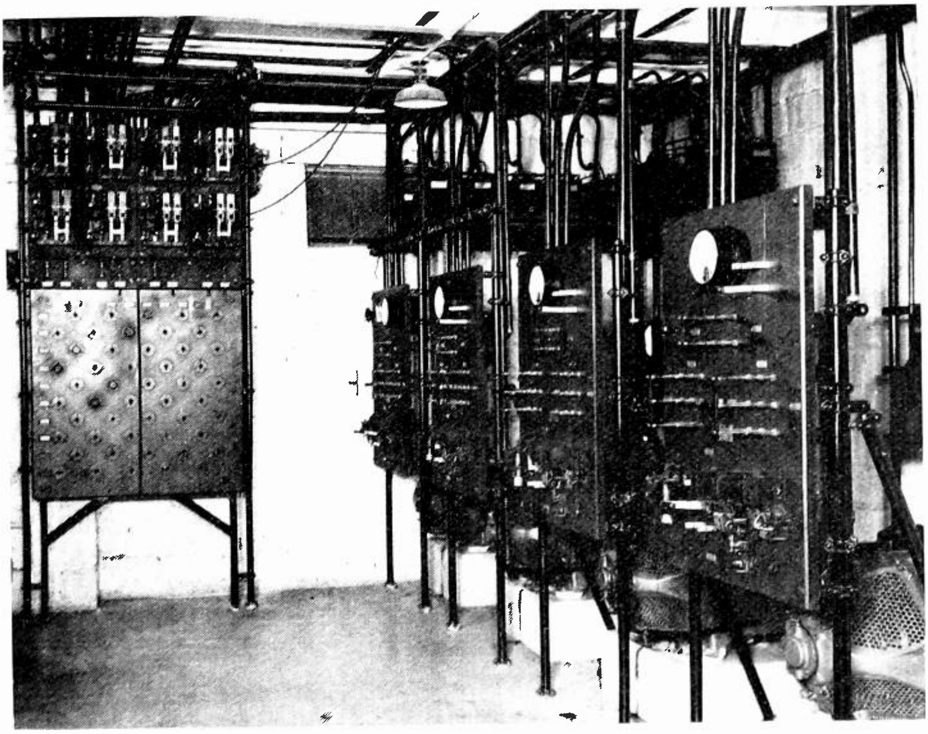

Fig. 6—3000-volt motor generators and plugboard.

machine is equipped with a suitable filter and may be used for either plate or bias supply on any apparatus by means of the "cross-hatch" plugboard shown in Fig. 6. 3000-volt contactors, controlled from the main switchboard, are used to connect these generators to their load. These contactors have two breaks in series with magnetic blow-outs, rapid moving contact arms, and wide opening, to insure utmost reliability. One of them on test interrupted 5 amperes at 3000 volts on an inductive load many thousands of times. The generators were designed for radio applications and have very good regulation and output voltages which are easily filtered.

Filament Supply

To supply the 6000 amperes at 40 volts required for filament supply it was decided to operate several machines in parallel rather than to install one large machine. A total of six 1000-ampere machines were installed, three of which would normally be used for broadcast equipment, two for short-wave, and one for spare or experimental use. The control is so arranged that any number of these machines may be set up to supply the load as one machine. A single push button starts them and a single rheostat on the main switchboard controls the volt-

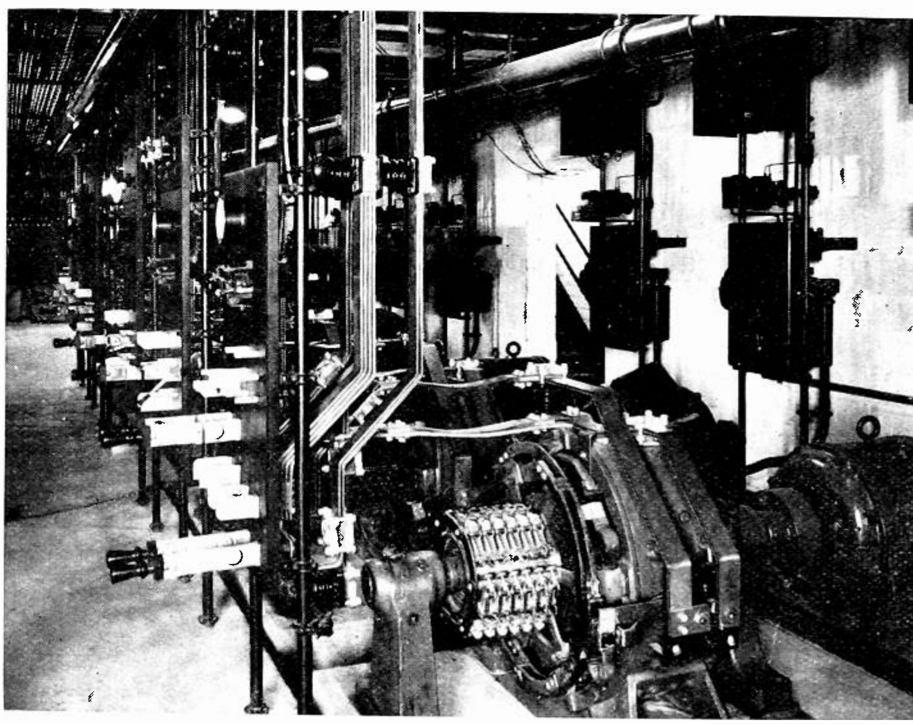

Fig. 7—40-volt, 1000-ampere filament motor generators.

age of all of them. Individual rheostats are used to adjust the machines for an equal division of load. The machines were especially designed for radio applications having large air gaps, skewed slots, and a large number of commutator bars and a symmetrical arrangement of armature coils to reduce the ripple voltage. Fig. 7 shows these machines.

Storage Batteries

A large 400-volt and two 12-volt storage batteries are provided to supply the smaller radio-frequency amplifier tubes and all of the speech input equipment. Motor generators equipped with filters charge these batteries continuously at a low rate.

The 400-volt battery is also used to operate the 25-kv circuit breakers in the substation.

Radio-Frequency Equipment

The original intention was to use this station for higher power than 50 kw. An output stage, shown in Fig. 8, was therefore installed which

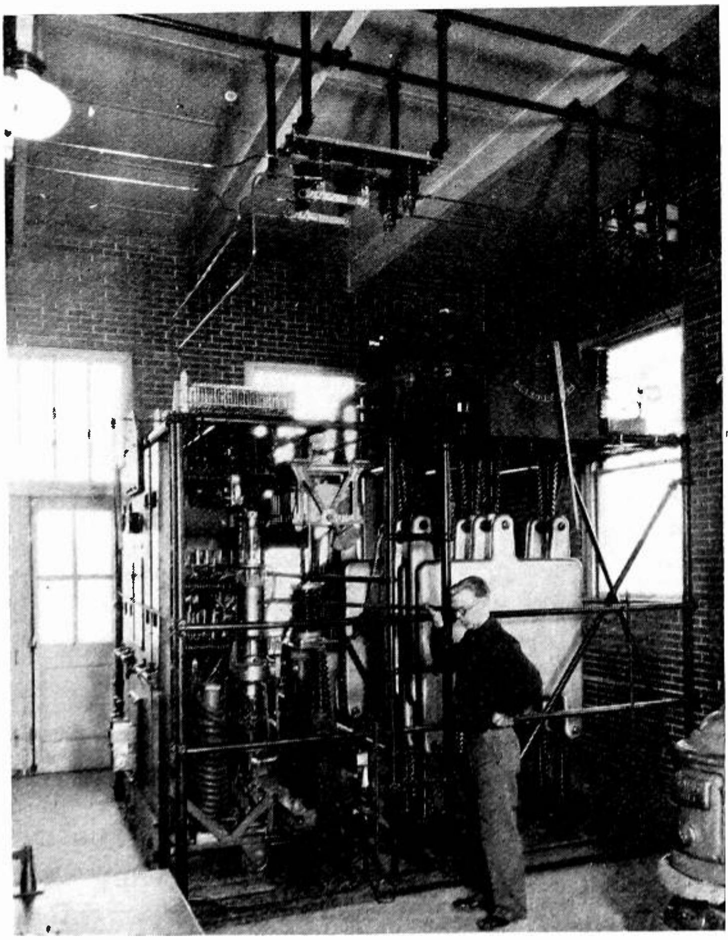

Fig. 8—AW-220 radio-frequency output stage.

was capable of supplying a carrier of approximately 300 kw using six of the AW-220 tubes designed by the Westinghouse Research Department and described by I. E. Mouromtseff.[2]

The crystal control and intermediate amplifier are similar to the corresponding units in the 50-B broadcast transmitter described by

[2] I. E. Mouromtseff, "A new water-cooled vacuum tube," Proc. I.R.E., vol. 20, pp. 783–808; May, (1932); also presented before Twentieth Anniversary Convention, Pittsburgh, Pa., April 9, 1932.

Kaar and Burnside in a previous issue of the PROCEEDINGS.[3] Two crystal oscillators with individual heat boxes and buffer amplifiers are included which are operated entirely from storage batteries to reduce voltage variations which would influence the frequency of the crystal. These precautions make it possible to maintain the transmitter well within the limits specified by the Federal Radio Commission.

The output of the buffer amplifier is amplified by one UX-860 tube and by two UV-849's in parallel before it is impressed on the grids of two water-cooled tubes operating push-pull. The tuned grid circuit on

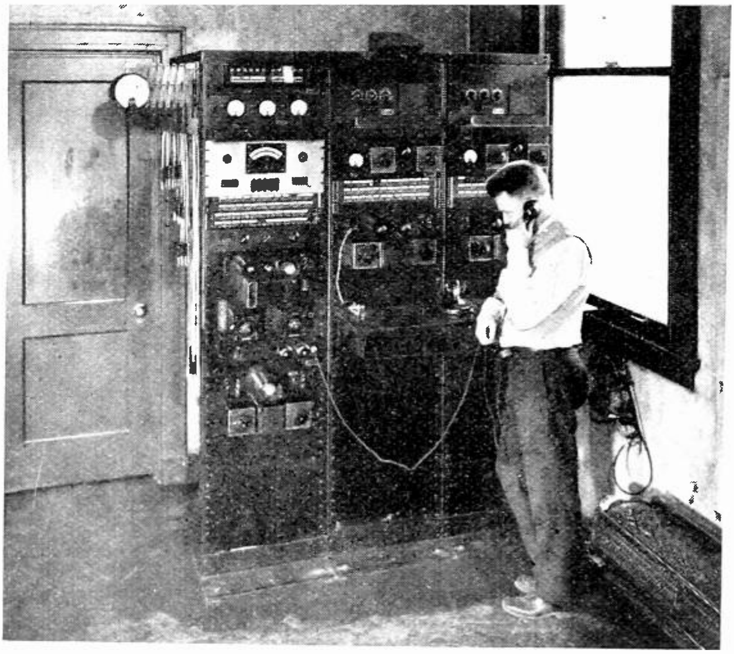

Fig. 9—Line amplifiers and associated equipment.

the AW-220 output stage is inductively coupled to the plate circuit of the water-cooled tubes.

A modulator with positions for four UV-848 tubes, but normally using only two, is used to plate modulate the water-cooled stage through a voltage dropping resistor by-passed by a capacitor, to obtain about 90 per cent modulation. The modulator and oscillator obtain their plate supply from the midtap of the rectifier through suitable filters and modulation chokes.

The modulator frame also contains a three-stage speech amplifier consisting of two 50-watt stages and one stage of two UV-849's in parallel impedance coupled to the modulator tubes. The frequency char-

[3] I. J. Kaar and C. J. Burnside, "Some developments in broadcast transmitters," PROC. I.R.E., vol. 18, p. 1623; October, (1930).

acteristic of this equipment is flat within 2 db from 30 to 10,000 cycles.

A high level modulator with positions for six AW-220 tubes is provided for experimental use or to modulate the output stage when class C operation is used.

A tube heater rack was also installed as it was believed that it would be advantageous to keep the filament hot on two spare tubes as there is quite a mass of metal to be heated up. In practice it was found to be an unnecessary precaution so the frame is not now used.

All of the equipment just described was intended for experimental work and operation at high power. For operation at 50 kw, which is the maximum allowed by the Federal Radio Commission for regular operation, we are installing a power amplifier using six water-cooled tubes which will supply a carrier of 50 kw. This stage will be plate modulated by a transformer coupled class B modulator. The smaller rectifier has been temporarily modified to use six UV-857 tubes in a 6-phase, single-Y circuit for use with the new output stage. This limits the voltage to 19 kv and the current to 20 amperes, which is ample for a 50-kw carrier.

Audio Equipment

Four audio circuits to the KDKA Studios in Pittsburgh are provided. These come in to the station underground for a distance of several thousand feet to prevent radio-frequency pick-up. Fig. 9 shows the audio equipment in the control room. Relays are provided so that lines may be changed from the pulpit. In case of an emergency announcement, it is only necessary to operate one switch, which automatically disconnects all loud speakers and the studio line and puts the microphone amplifier into operation.

Cooling Water System

The tube water-cooling system is unique in that heat interchangers are used. The water circulated through the tubes should be soft, but the well water, the only supply avialable at the station is extremely hard. It was decided to use rain water to cool the tubes. Fig. 10 shows the arrangment of the pumps and heat interchangers.

Pumps, provided in duplicate, circulate the water from the small sump through the tubes and the heat interchangers, and back to the sump. Arrangements are made to collect the roof rain water in this sump. A natural pond on the property was enlarged to provide sufficient water to keep the tube water at a safe temperature. Several filters are provided to prevent foreign matter from clogging the water system. Flow meters and thermometers are generously used throughout the equipment.

The heat interchangers are of standard design and will cool 300 gallons per minute from 140 degrees to 132 degrees F using 270 gallons per minute of pond water at 110 degrees and discharging it at 119 degrees F. With all of the equipment in operation with present efficiencies the water system must dissipate approximately 1000 kw.

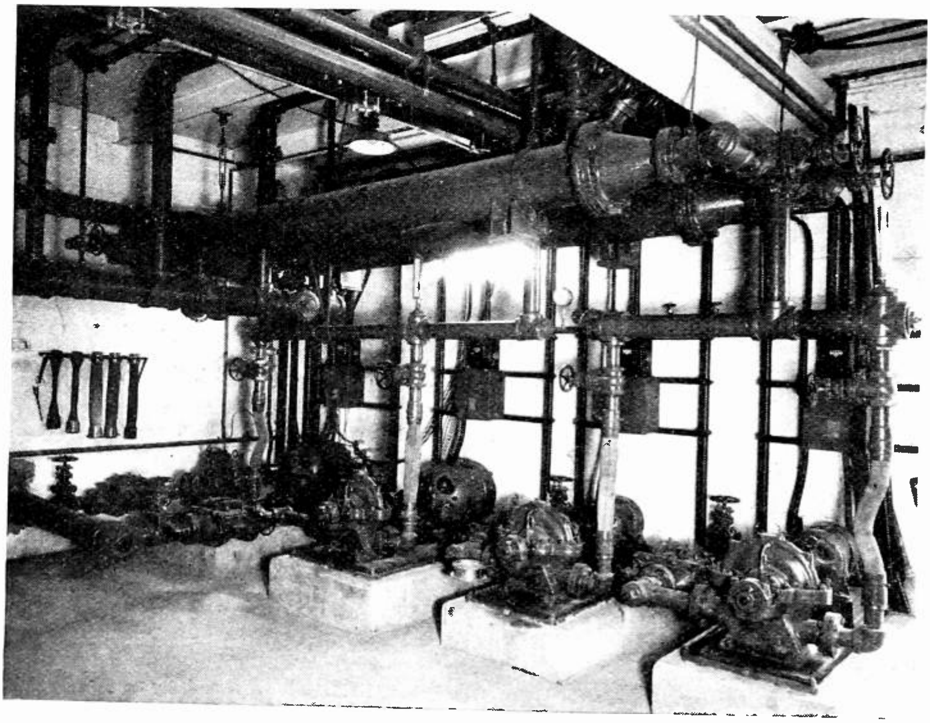

Fig. 10—Water pumps and heat interchangers.

Every precaution has been taken to prevent interruption of service both by the conservative design of apparatus and by provision of duplicate equipment which may readily be switched into operation. All of the equipment is protected by overload relays; and interlocks have been provided wherever necessary.

This paper is intended only as a brief description of the Westinghouse Radio Station at Saxonburg. Some of the more technical phases, such as the design of the rectifiers and tubes, are being covered by other papers.

Proceedings of the Institute of Radio Engineers
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THE TRANSMISSION AND RECEPTION OF ULTRA-SHORT WAVES THAT ARE MODULATED BY SEVERAL MODULATED HIGH FREQUENCIES*

By

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Summary—*In the first part there are mentioned two modulation connections that have been found suitable for modulation with one high frequency or with several high frequencies. It is stated that by careful screening of the parts carrying high frequency, it is possible to prevent direct high-frequency radiation.*

The question of the pro-component for the permissible degree of balance is discussed from the viewpoints that must be considered in the simultaneous modulation with several high frequencies. Further, there is taken up the disturbances that appear in the receiver due to harmonic vibrations and compound oscillations between the modulated high frequencies. Critical combination oscillations and harmonic vibrations do not appear in the receiving range if this is restricted to one frequency octave. Disturbances due to the direct effect of the high-frequency transmitter through couplings are overcome by adding intermediate circuits. A special connection for modulation with the widest frequency bands is given. In the second part of the paper there is discussed the technique of demodulation connections after a comparison of sensitivity. The screening of all parts carrying high frequency is also very important in receivers in order to avoid additional disturbances. A set for receiving ultra-short waves that are modulated with several high frequencies is described. In conclusion, some possibilities are pointed out for increasing the sensitivity with converter sets.

THE problem of the modulation of high frequencies with still higher frequencies is old. Its solution is especially important with ultra-short waves because of their extraordinary capability of modulation. The absence of fading, good freedom from interference, which is theoretically based on the attenuation law of the spectral components for interfering impulses, and finally the range, restricted essentially by the optical field of vision, have permitted combinations whose possibilities in the development of broadcasting[1] were outlined a short time ago by the author. In the course of work that the author has undertaken on this subject over a rather long period of time, connections, dimensions, and viewpoints have been obtained that make possible technically reliable transmission and reception of ultra-short waves modulated with several high frequencies. This work will be summarized in the following.

* Decimal classification: R550×R423.5. Original manuscript received by the Institute, December 3, 1930; translation received by the Institute, May 29, 1931.

[1] "Vielfachrundfunk auf einer Ultrakurzwelle." *E.T.Z.*, No. 47, p. 1619, (1930).

If high frequencies in the region of broadcast waves are used, one is not very restricted in the selection of ultra-short waves by reasons of side band widths. The highest broadcast frequency with the longest ultra-short wave causes a side band of ± 5 per cent. Actually, the frequency ratio in general will be such that side bands of 2 to 3 per cent will be found, which still radiate excellently in the transmitter and cause no inconsiderable demodulation in the short-wave circuits on reception.

Modulation Connections

Very few of the modulation connections applied to telephony are suitable for operation with high frequencies. Generally there are unavoidable capacity shunts, which at high frequencies burden the different circuits of the modulation connections so that normal operation cannot be reached. In the tests, two modulation connections were found to be highly suitable for modulation with one high frequency and

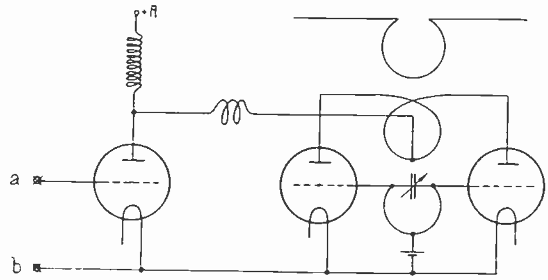

Fig. 1—Heising connection for high-frequency modulation of ultra-short waves.

with several high frequencies. In both cases a normal push-pull transmitter, operating on waves between 4 and 9 meters, was modulated. Modulation was done in one case over the lower curve in the plate current characteristic curve because with suitable operating voltages, the high-frequency e.m.f. between plate and grid oscillating circuit was used. The corresponding connection is shown in the following section. The short-wave choke was found to be suitable in order to avoid the necessity of exact adjustment of the point of symmetry in the grid oscillating circuit. This method of modulation was used almost exclusively in the experiments because comparatively low high-frequency powers are sufficient for control with it, and outside interference with simultaneous supermodulation of several high frequencies could be avoided very easily. The Heising connection shown in Fig. 1 should be very suitable for economical operation as a rule. There is a choke for a region of the supermodulating high-frequency oscillation, corresponding to the sense of this connection, in the plate circuit of the modulation tube, and there is a choke for the ultra-high frequency in the connection between modulation tube and transmitter.

Fundamentally, as with all transmitters in which there is modulation with high frequencies, careful *screening* and *neutralization* make *direct high-frequency radiation impossible*, which would naturally cause disturbances in the vicinity of sensitive receiving stations.

Criteria for Simultaneous Supermodulation of Several High Frequencies

With high-frequency modulation, as contrasted with modulation with low frequencies, the degree of modulation is generally very constant in time. On modulation with one high frequency, its amplitude must be adjusted so that the ultrafrequency with unmodulated high-frequency oscillation is balanced at about 70 to 80 per cent. The residual safety is sufficient to permit sufficiently linear amplitude fluctuations caused by the low-frequency modulation of the high-frequency oscillation. On modulation with several high-frequency oscillations we can assume, in a similar manner, that even in the most unfavorable case, that is, with the addition of all maximum amplitudes, the ultrafrequency is not balanced more than 100 per cent. If the degree of balance of the high frequency is designated by k_H and the number of simultaneously modulating high frequencies is n, the degree of balance of the ultrafrequency which is adjusted to the high-frequency component is as follows:

$$k_u = \frac{100}{n + nk_H}$$

With four high frequencies with a degree of balance of 20 per cent each, we get a maximum permissible degree of balance per component of about 20 per cent. For the sake of economy in the transmitter, this maximum permissible degree of modulation per component is maintained. With a larger number of components the energy per component gets very small. Because of this the suggestions given in this paper may find technical employment only in connection with beam systems.

An important source of disturbance is caused by the formation of overtone and compound oscillations between the supermodulated high frequencies. Naturally the combination tones of the second degree, that is, the sum and difference frequencies and the octaves, are most dangerous. The ratio of these disturbing oscillations to the desired oscillation decreases proportionally with the degree of balance k_u, with a first rectifier that operates according to a quadratic law. Therefore, while the disturbing frequencies appear less in amplitudes that decrease with increasing number of components, their number increases extraordinarily. The decrease in amplitude alone does not guarantee reception of the desired high frequencies without disturbance if the interferences that form lie within the audible range. It can be shown *that all combination oscillations and overtones are dropped from the field*

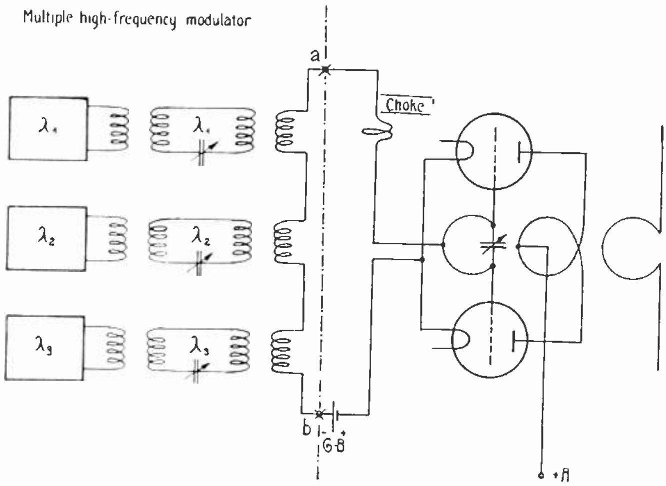

Fig. 2—Diagram for simultaneous modulation of several high frequencies.

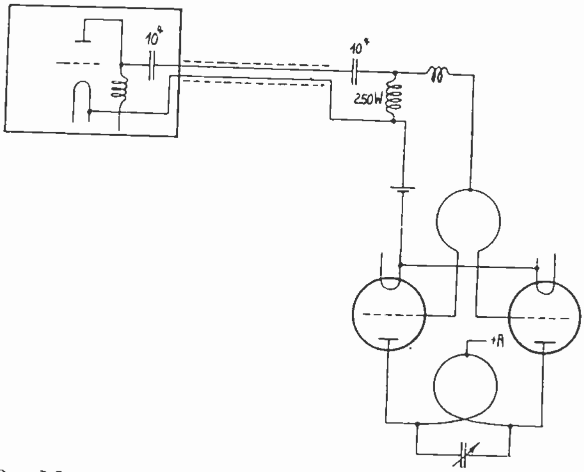

Fig. 3—Modulation diagram for widest frequency bands.

of reception if this is restricted to one frequency octave. With the number of high frequencies that can be transmitted, and which is restricted because of the power, one octave is generally necessary in order to be sure to avoid mutual disturbances. Another disturbance that also may appear with the transmitter with simultaneous modulation with several frequencies, is found when there are direct influences acting on the high-frequency transmitter or on couplings. These influences can be safely avoided with the arrangement with intermediate circuits shown in Fig. 2 at the left. Frequently loose couplings are sufficient. Another modulation connection in which an aperiodic high-frequency power amplifier is used[2] is shown in Fig. 3. This connection permits the *modulation* of the ultra-short-wave transmitter *with the widest high-frequency bands*, such as are necessary in television for example. It is used in places where connections with resonance circuits must fail.

The Receiving Arrangement

The fundamental viewpoints for rectification of ultra-short waves modulated with several high frequencies have already been discussed in the papers cited above. The important point is the relation between the energy requirement of the transmitter and the efficiency of the ultra-short-wave rectifier in the receiver. If a comparison is made to show how much better a direct ultra-short-wave transmitter modulated to k per cent with low frequency is capable of reception than a transmitter of equal strength on which several (n) k per cent modulated high-frequency oscillations are superposed simultaneously, we find the following. Assuming the receiving rectifiers of equal range, the efficiency of the ultra-short-wave rectifier is exactly the same in both cases. In the cases of multiple modulation only, the oscillation amplitude obtained is $1/n$ of the amplitude with low-frequency modulation. Therefore steps must be taken to balance out this disadvantage, and at the same time also, the losses that appear in the second rectifier. On modulation by four high frequencies, this disadvantage is completely balanced out for a high-frequency double-tube is used for demodulation, in whose second stage there is an effective high-frequency amplification. On operation with such an apparatus, with the sole use of the low-frequency amplification properties of a series connected unit (broadcast set) the same receiving loudness is obtained. Almost all tube arrangements have high-frequency amplifiers, or at least regeneration. Only by using regeneration can there be obtained easily a voltage amplification of 20, which gives us a considerable excess of sensitivity as compared to the system with pure low-frequency modulation. The excess sensitivity is so great that the increased input in the converter set is profitable for these reasons. *The special advantage of multiple modulation as compared with low-frequency modulation lies in the fact that the selectivity properties of the present broadcast apparatus can be used for separating several programs, and at the same time there is extremely simple operation of the entire apparatus.*

[2] *See* M. v. Ardenne: "Eine Methode zur Schaffung guter Empfangungsverhältnisse für den Rundfunk in der Grosstadt," *E.N.T.*, No. 12, (1930).

A number of sets for stage rectification, for connection in series with normal high-frequency receivers, have been made with detectors, single tubes, and multiple tubes. Fig. 4 shows the diagram of a converter working with a double tube. The line circuit of the converter is

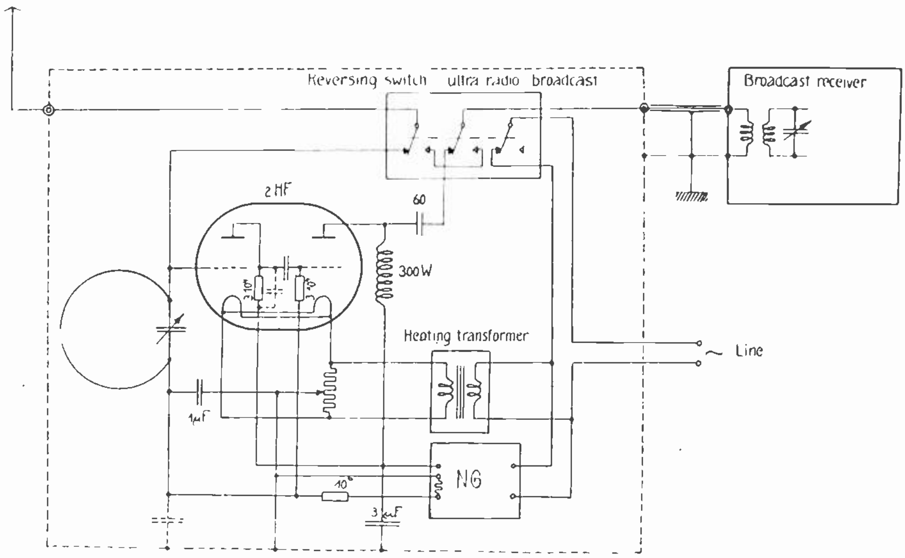

Fig. 4—Diagram of converter set for broadcast receiver.

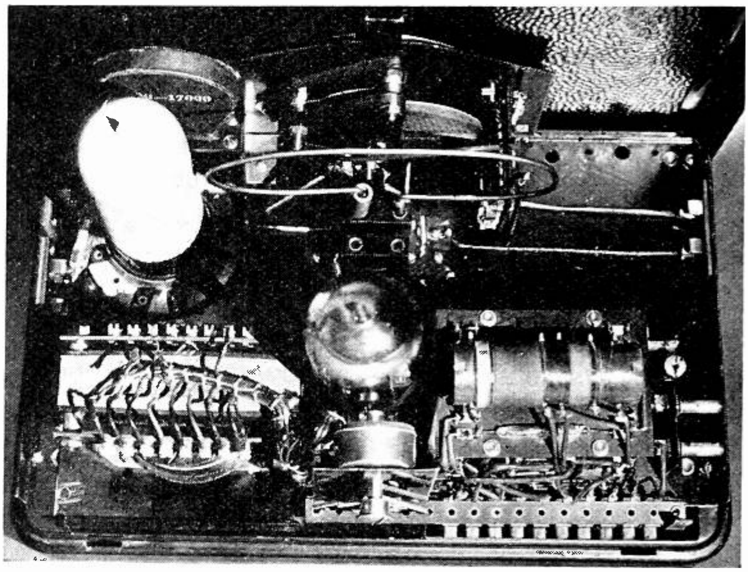

Fig. 5—Inside view of converter set.

controlled by a reversing switch, and at the same time the ultra-short-wave antenna is connected, while in the other position of the switch the line current is opened and the antenna or broadcast antenna is directly connected with the radio receiver. By screening all parts of the set carrying high frequency, the penetration of long-wave disturbances is prevented in ultra-short-wave reception. The internal construction of the converter set whose short-wave circuit is shown in the photograph in Fig. 5, has a damping decrement of 5 to 8 per cent in operation. The fact that the use of multiple modulated ultra-short waves for broadcast purposes does not involve difficulties in reception, may be explained

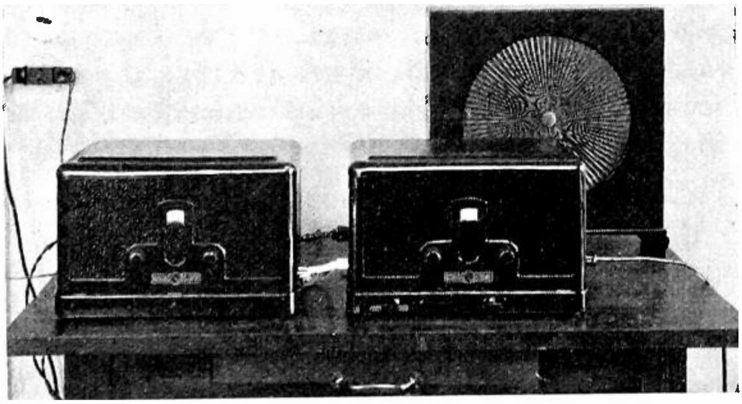

Fig. 6--View of set that is very simple to operate.

by the illustration in Fig. 6, in which there is shown a sensitive set operated entirely from the lighting circuit, whose operation is not more difficult than the operation of a normal radio broadcast receiver. At the right, in Fig. 6, there is the broadcast apparatus and at the left is

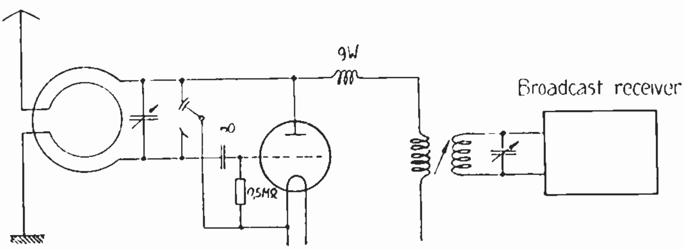

Fig. 7—Diagram of converter set for broadcast receiver.

the converter set. If the absorption in the city should make it necessary to use greater sensitivity than that given by the converter connections which have been described, this can be increased extraordinarily by the fact that in the converter set there is already available a double tube[3] with essentially higher degrees of amplification, or damping can be done in the ultra-short-wave circuit in so far as the width of the side band makes this seem desirable. A converter connection with regenera-

[3] Special multiple tubes with very high aperiodic radio-frequency amplification.

tion on waves between 4 and 10 meters, whose operation can be carried on by unskilled operators, has been made successfully as shown in Fig. 7. The use of reaction is only of advantage if the intermediate frequency is lower than $3 \cdot 10^5$ cycles. The best and very sensitive sort of converter may be a type which is using a new aperiodic ultra-short-wave amplifier with multiple tubes developed by the author and the Radio AGDS, Loewe, (Berlin).

In conclusion it should be stated that successful tests have also been made on the connection of several sets to the same converter. Such a method of operation might be useful if several participants are to be supplied with high frequencies in this manner, or if the simultaneous audio frequencies and frequencies for controlling clarity and synchronization are to be transmitted for television reception.

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THE PRECISION FREQUENCY MEASURING SYSTEM OF R.C.A. COMMUNICATIONS, INC.*

By

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Summary—*A frequency measuring system is described wherein transmitter frequencies are accurately compared with the harmonics from a precision, piezo-electric frequency standard. Through the medium of a system of multivibrators and a synchronous clock the frequency of the standard oscillator is referred to the time interval defined by the rotational frequency of the earth.*

Harmonics from a 100-kc crystal oscillator are fed into a frequency measuring receiver along with the transmitter signals. The receiver is equipped with a small vernier condenser having a micrometer scale which is used to make the measurements. The position of a signal in the frequency spectrum relative to known harmonics from the standard oscillator is obtained by direct interpolation from the micrometer readings of the tuning points of the signal and the adjacent harmonics between which it lies. To allow greater precision in making measurements, harmonics 10 kc apart are used. Methods used in measuring broadcast, high, and ultra-high frequencies are described.

A discussion of errors is given. The total probable maximum error of a routine measurement at 20,000 kc (15 m) with this system is ±59 cycles or 0.0003 per cent. At broadcast frequencies a measurement can be made to 0.2 cycle.

The operating aspects of the system are discussed. The number of measurements made each month is indicated and the various uses to which these measurements have been put are described.

With the increasing use of radio as a medium of communications has come the necessity for smaller separation and between frequency assignments more accurate operation on these frequencies. In order to make possible such operation it has become necessary to provide means whereby the frequency of a radio transmitter can be accurately measured. It is the purpose of this paper to describe the methods used by R.C.A. Communications, Inc., in making precision measurements of frequency.

The system now in use at Riverhead, N. Y., consists essentially of (1) a primary standard of frequency, and (2) a means of comparing transmitter frequencies with this standard. The standard of frequency, which is a special piezo-electric oscillator, is in itself relatively simple. However, considerable additional apparatus is necessary for accurately checking its frequency.

* Decimal classification: R210. Original manuscript received by the Institute, March 1, 1932. Presented before Twentieth Anniversary Convention of the Institute, Pittsburgh, Pa., April 7, 1932.

The time interval upon which our measurements are based is the standard second, which is the 1/86,400th part of the mean solar day. In order to check the frequency of the standard oscillator accurately a means is provided to count the number of cycles generated by the oscillator in a given time. This is accomplished by driving a clock with a synchronous motor operated by the oscillator through multivibrator circuits. By comparing this clock with the standard time signals from the Naval Observatory at Washington, we can determine the frequency of the oscillator in terms of the standard second.

The clock, which has been described by W. A. Marrison,[1] is designed to keep true time when operated from a source which is exactly 1000 cycles. The multivibrator circuits step the oscillator frequency down by a factor of 100 to 1 to drive this clock. It is therefore evident that it will keep true time if the standard oscillator is exactly 100,000 cycles, and one second on the clock will count 100,000 oscillations of the crystal. If the clock gains on true time, the crystal is oscillating at a frequency greater than 100 kc, and the percentage gain is the same as the percentage that the crystal frequency exceeds 100 kc. The gain or loss in seconds for a period of 24 hours multiplied by 1.1574, the ratio of 100,000 to 86,400, added to or subtracted from, respectively, 100,000, gives the average frequency of the standard for the 24-hour time interval.

A special measuring receiver is used to make the actual measurements of transmitter frequencies. This is an autodyne receiver which is provided with a small vernier condenser having a micrometer scale. By means of this condenser it is possible to interpolate between the tuning points determined by two adjacent harmonics from the standard oscillator. The receiver operates over a range of approximately 400 to 28,000 kc.

Two frequencies are utilized in the process of making measurements, namely, 100 kc and 10 kc. Harmonics 100 kc apart are obtained from the standard oscillator through the medium of a harmonic generator, all harmonics up to approximately the 300th or 30,000 kc, being available. Making a measurement of an unknown frequency consists in comparing that frequency with the known harmonics of the standard. If, for example, a signal is found to fall between the 100th and the 101st harmonics, its frequency is known to be between 10,000 and 10,100 kc. To determine its frequency exactly it is only necessary to establish its position in the frequency spectrum relative to the known harmonics. If it is found to be 65 kc above the 100th harmonic, we know its frequency to be 10,065 kc.

[1] W. A. Marrison, "A high precision standard of frequency," Proc. I.R.E., vol. 17, p. 1112; July, (1929).

In order to make measurements more accurately, 10-kc side bands from one of the multivibrators are produced on the 100-kc harmonics. This arrangement gives us tuning points of known frequency only 10 kc apart. The 10-kc side bands are modulated with 60 cycles which gives them a characteristic note that is easily identified. Means are provided to produce the 10-kc side bands at will.

A set of interchangeable coils, whose frequency ranges just overlap, is provided for the receiver. These are calibrated every 100 kc, from 410 to 21,400 kc, on the main tuning condenser dial. All the dials used in making measurements are arranged so that their scales increase with frequency.

The procedure for making a measurement is as follows: The micrometer condenser is set at the reference point, that is, the point at which the receiver is calibrated. The auxiliary vernier condenser, which is used only as an aid in adjusting the receiver to zero beat at the beginning of a measurement, is set at 0. The 10-kc shorting switch is thrown so as to cut out the 10-kc side bands. The signal to be measured is now tuned in. When this signal has been located, the receiver is tuned to the nearest 100-kc harmonic below it. The regeneration control condenser is then set so that it is about one dial division beyond the point of oscillation. This is the point at which the receiver is most sensitive, and at which the calibration of the harmonics was made. By means of the main tuning condenser and the auxiliary vernier the detector is set to zero beat with the harmonic, and the number of the harmonic is determined from the calibration. Everything is now in readiness for making the measurement. The 10-kc shorting switch is opened, introducing the side bands. Next the micrometer is slowly turned out until the signal again appears, the number of 10-kc harmonics passed on the way being noted. The micrometer is then turned back to the 10-kc harmonic just below the signal and set at zero beat. After the reading has been noted, the zero beat readings of the signal and of the harmonic just above it are determined. These three readings give us the position of the signal relative to the two 10-kc harmonics by direct interpolation. The figure obtained added to ten times the number of 10-kc harmonics passed, plus the number of the major harmonic multiplied by 100, gives the desired frequency. In the example cited previously, suppose that the tuning condenser is set with the 100th harmonic at zero beat. Now when the micrometer is turned out we will pass six 10-kc harmonics before we reach the signal. Suppose the readings of the zero beat points are as follows: 6th harmonic—11.70, signal—12.674, 7th harmonic—13.65. Since from 11.70 to 13.65 is 10 kc, from 11.70 to 12.675 will be in proportion, namely, 5 kc. Then, 10,000+60+5 gives 10,065 kc as the signal frequency.

When greater accuracy is desired, and when zero beat covers a large number of divisions of the micrometer, as at the low frequencies, a 1000-cycle comparator is used. This is merely a 1000-cycle tone fed into the audio output of the receiver. Now instead of setting the tuning condenser and micrometer at zero beat with the harmonics and the signal, we increase the tuning in each case until the beat note in the receiver approaches 1000 cycles. A zero beat can then be obtained between this note and the 1000-cycle tone. The readings are taken at these new zero beat points. It is evident that this procedure, while allowing of extreme accuracy in determining the readings, has no

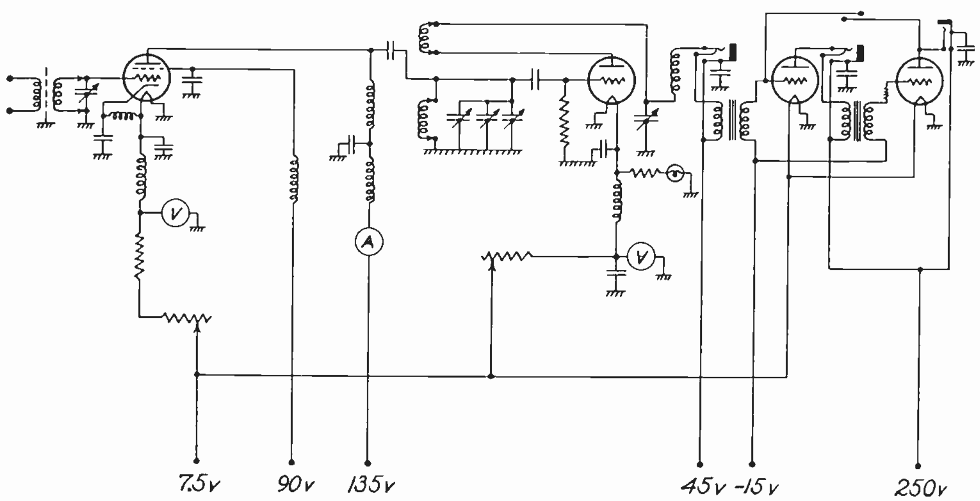

Fig. 1—Frequency measuring receiver circuit.

effect whatever on the method of calculation, since all the beat notes are displaced by the same amount and in the same direction.

In order to obtain the best possible results from the system, certain precautions must be observed. The regeneration control is always set at one dial division beyond the oscillation point, as the coil calibrations depend upon that setting. Great care is exercised in determining the exact position of zero beat.

The modulation on the 10-kc side bands is a distinct aid in this connection, as it narrows down the region of inaudibility. When necessary, strong signals are attenuated to as low a level as is consistent with good results before being fed into the receiver.

The procedure explained above is the one commonly used in making high-frequency measurements. At broadcast frequencies, a slightly different method is used. Broadcast carriers are generally found so near the 10-kc harmonics that a low frequency beat is produced between them. This beat is usually measured by means of a tape recorder. Where a signal is not quite so near a harmonic, but still produces an audible beat, this beat is measured with a frequency meter.

At ultra-high frequencies, a local oscillator, whose frequency is within the range of the receiver, is tuned so that one of its harmonics is at zero beat with the unknown signal. From the measurements of the local oscillator, the desired frequency is determined. In this manner precision measurements of frequencies up to 100,000 kc have been made.

The Measuring Receiver

The circuit of the frequency measuring receiver is shown in Fig. 1. This is a standard, autodyne, short-wave receiver which has been adapted for measuring purposes. To reduce interaction the tuned

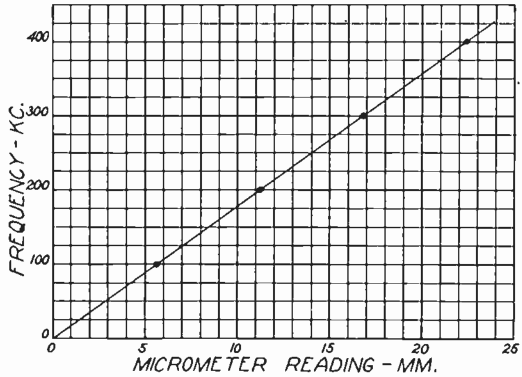

Fig. 2—Frequency characteristic of micrometer measuring condenser. This graph shows the range covered at 20,000 kc.

coupling stage is loosely coupled to the detector circuit by a small condenser. To reduce interaction still further between the coupling tube grid tuning and the oscillating detector a special type of coupling tube is used. This tube, which has the same characteristics as the UY-224, is so constructed that minimum coupling from plate to grid takes place. It may be added that two measuring receivers so equipped can be operated on the same antenna, and on the same frequency, without interference to each other.

Across the main tuning condenser are connected a small vernier and a micrometer-scale condenser. The vernier is used in setting the detector to zero beat with a harmonic before a measurement is made. The micrometer is, of course, used in actually making measurements. A curve showing the relation between micrometer reading and frequency is shown in Fig. 2. The coils for the receiver have already been mentioned.

The Harmonic Generator

In Fig. 3 is shown the harmonic generator circuit. This unit is fed with 100-kc energy from the standard oscillator unit, and with 10-kc energy from the first multivibrator. The 100-kc voltage is stepped up by two stages of tuned radio-frequency, screen-grid amplifiers to about 100 volts. This excitation is impressed on the grid of the harmonic generator tube which is a screen-grid tube, self-biased by means of a resistor and condenser. In the output, all harmonics of 100 kc up to approximately the 300th are available. The plate circuit is tuned so that maximum response at any harmonic can be obtained. However, it is only at the high frequencies that this tuning is necessary. A set

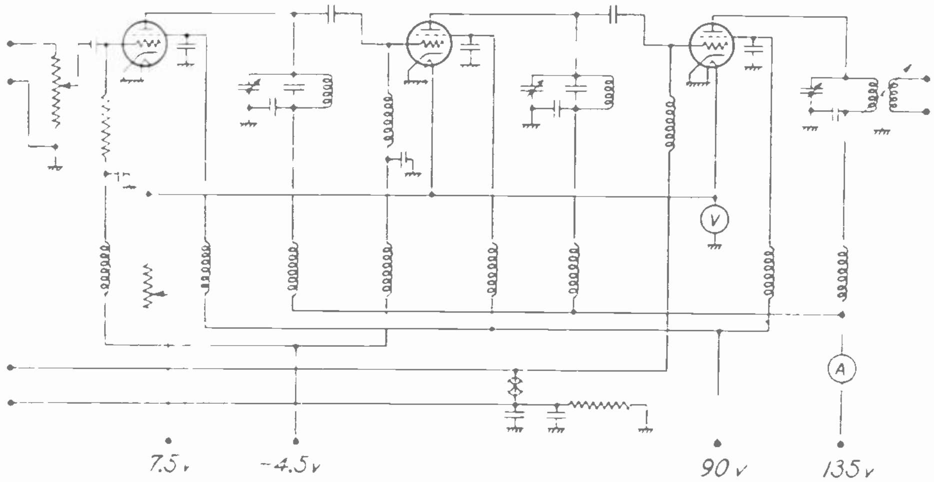

Fig. 3 - Harmonic generator circuit.

of three interchangeable coils covers the range of frequencies used satisfactorily. Introduction of the 10-kc frequency into the grid circuit of the harmonic generator tube is controlled by a key switch. This allows switching of the side bands in or out at will.

The Modulated 10-kc Amplifier

Fig. 4 gives the circuit of the modulated 10-kc amplifier. 10-kc energy from the multivibrator unit is passed through a band-pass filter, so that undesirable harmonics will not be fed into the harmonic generator. From the filter the energy is passed into the grid circuit of a screen-grid tube. Means are provided to impress an a-c voltage of 60 cycles on the grid of this tube from a low voltage transformer supplied with 110-volt alternating current. This modulation serves a twofold purpose. It gives the side bands a characteristic tone, and it makes all the side bands between 100-kc harmonics of nearly equal intensity. Without the modulation some of the side bands are very weak, due to interference of the two side bands from adjacent 100-kc harmonics. The output of the screen-grid tube is coupled to the grids of three output tubes. These tubes have transformers in their plate circuits, making available three separate sources of 10-kc energy, one of which supplies each harmonic generator unit.

The Crystal Standard Oscillator[2]

The standard frequency is obtained from a very carefully operated, quartz crystal controlled oscillator. The crystal, which has practically no temperature coefficient of frequency, is of a special, ring-shaped type. These crystals, and the temperature control equipment used with them are described in the paper mentioned previously.[1] Observa-

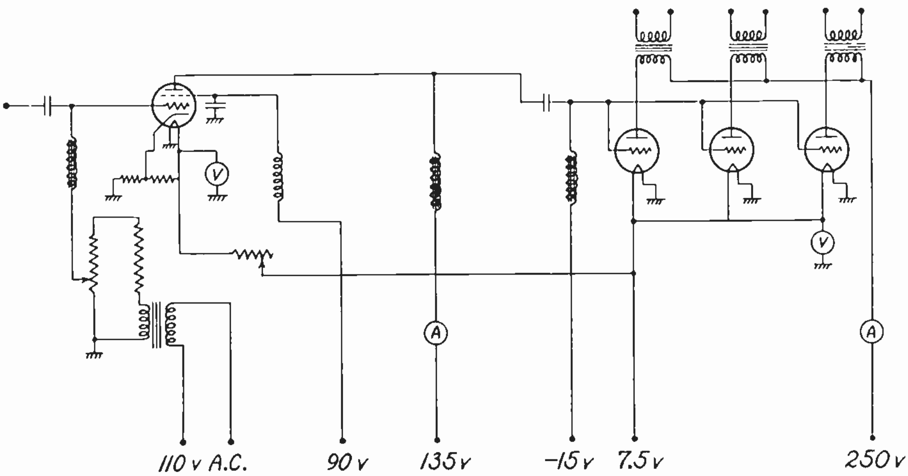

Fig. 4—Modulated 10-kc amplifier circuit.

tions show that the temperature of the heat distributing layer of the crystal oven fluctuates by about 0.008 degree C. This small variation never reaches the crystal, because of an attenuating layer of felt surrounding it. The crystal is maintained at a pressure slightly below atmospheric to protect it from humidity and pressure variations. It may be of interest to note, that ever since the installation of the unit, what might be called a "negative leak" has been very slowly taking place. That is, the pressure in the bell jar has actually been decreasing. It is believed that this is due to oxidation of some of the materials in the thermal tank, such as hard rubber, felt, and wire insulation.

A diagram of the oscillator circuit being used with this crystal is shown in Fig. 5. A UX-210 tube is employed as the driver, and is operated at reduced voltages to prolong its life. The circuit constants

[1] *Loc. cit.*, p. 1106.
[2] W. G. Cady, Proc. I.R.E., vol. 10, April, (1922).

were so chosen that variations in the coils, condensers, resistors, and tubes have as little effect as possible on the frequency of the oscillator.

In a circuit oscillating at 100 kc it is necessary that some fixed capacity, in addition to the variable capacity, be used in tuning, with the small values of inductance usually used. It is extremely important that any such capacity be of the best quality. The ordinary run of paper or mica condensers are not suitable in this connection. Most of them change with age, and the majority have very poor temperature coefficients. Change of frequency with tuning capacity still remains an important factor in a crystal oscillator. To insure the least possible trouble from this source, special mica condensers are used

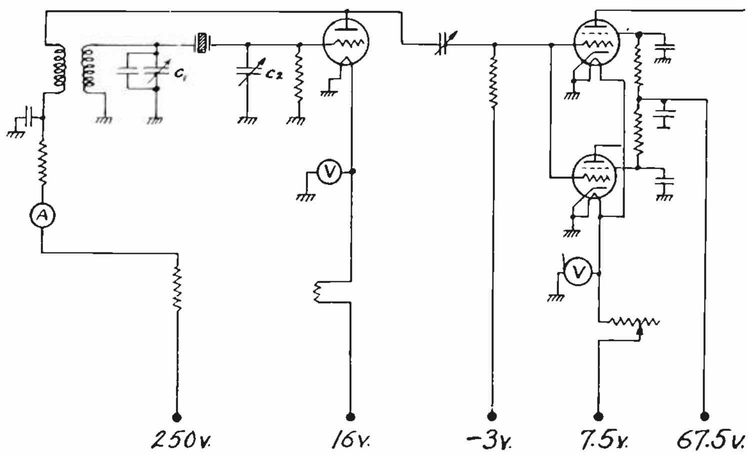

Fig. 5—Frequency standard oscillator circuit.

for the fixed capacity in this oscillator. These are relatively permanent, and are known to have a low temperature coefficient of capacity. The circuit temperature is closely maintained at a fixed value.

Some figures showing the stability of the circuit will now be shown.

1 per cent change in C_1—± 0.67 part per million.
1 per cent change in C_2—± 0.3 part per million.
10 per cent change in E_f—± 0.06 part per million.
10 per cent change in E_p—± 0.12 part per million.

It was found possible to reduce the variations in frequency due to the supply voltage changes to practically zero, but under these conditions the variations with changes in tuning capacity became quite large. Since it is possible to maintain more effective control of the supply voltages than the temperature of the circuit, the constants were chosen which gave the best stability with tuning.

Mechanical shocks were found to have an appreciable effect on the frequency, due to shifting of the crystal in the holder. Mounting of the oscillator unit on resilient material and locating it at a point remote from centers of activity minimize errors due to this cause.

Riverhead Installation

At Riverhead the standard oscillator is kept in a shielded and heat-insulated vault. The multivibrators, a 1-kc amplifier, and a frequency

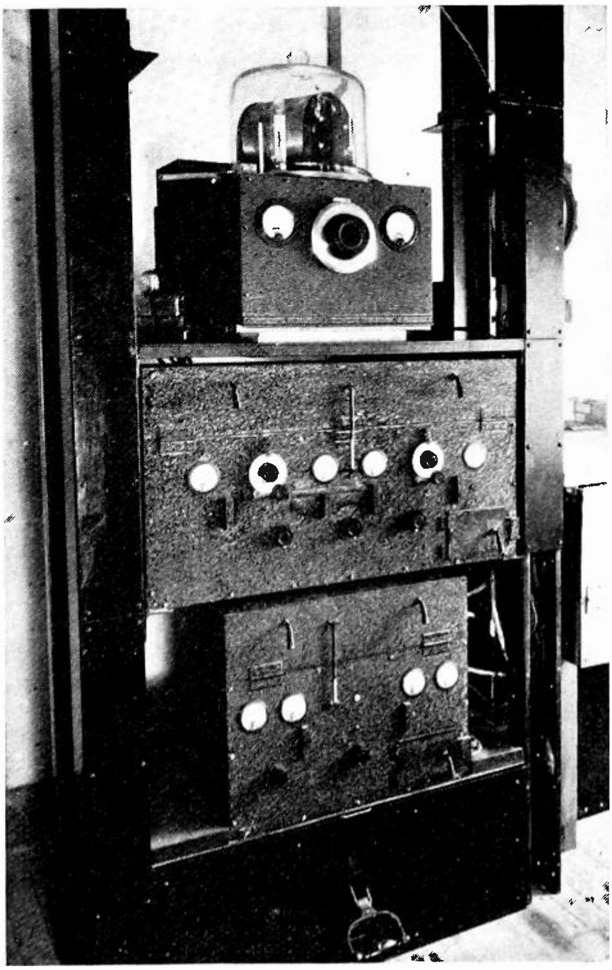

Fig. 6—Frequency standard—Riverhead station. The crystal, in its thermal tank, is under the bell jar on the top of the oscillator unit. The multivibrator unit, containing the 10-kc and 1-kc subharmonic generators, is beneath the oscillator unit. Below this is the 1-kc amplifier unit. This equipment, including a frequency meter which is not shown, is located in a special vault, remote from the measuring apparatus.

meter are also located here. The frequency meter is used as a check on the multivibrators. When the meter reads 1000 cycles the multivibrators are known to be functioning at their proper frequencies. All supply leads to the vault are well filtered where they enter. In addition, each unit has individual radio-frequency and audio-frequency filtering for all supply voltages.

All measuring is done in another part of the building known as the Frequency Measuring Laboratory. Here are located the measuring positions, clock, and time signal recorder. Each measuring position contains the following components: antenna panel, radio-frequency amplifier unit, frequency measuring receiver, 10-kc filter and modulated amplifier unit, and harmonic generator unit. Here again, each unit is equipped with individual radio-frequency and audio-frequency filtering, as all apparatus is supplied from a common bus system. There are in operation at present two such complete positions at this station.

Transmission lines from the various receiving antennas are terminated at jacks on the antenna panels. Seven directive antennas and

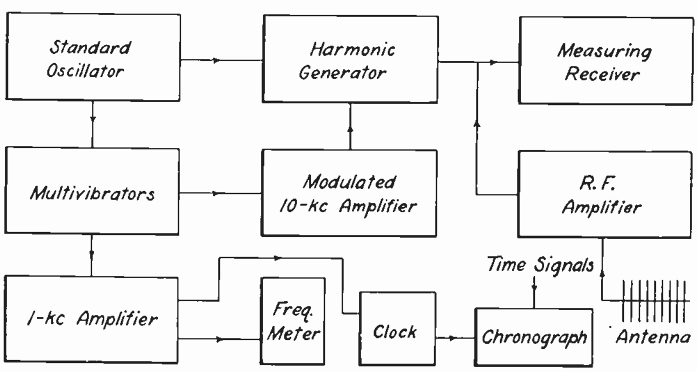

Fig. 7—Block diagram of complete frequency measuring system.

a doublet are in use at present, both positions using the same set of antennas. The radio-frequency amplifier unit is used only for the reception of weak signals or in cases of interference from other signals. A mobile rack carrying the tape recorder, and its amplifiers, is available for measurements at either position. 100 kc, 10 kc, and 1 kc are brought from the standards vault by means of shielded conductors. All a-c leads between units are run in shielding braid.

Theoretical Limits of Accuracy

The accuracy of a completed measurement is limited by (1) inherent errors of the system, and (2) observational errors. The inherent errors of the system may be divided into two classes, namely, errors of the standard frequency, and errors due to the linear variation of capacity characteristic of the micrometer condenser. The accuracy of the standard oscillator has been found to be better than one part in a million. By means of the recorder, the clock can be compared with the standard time signals to 0.01 second. This limits the accuracy of the standard to 0.00002 per cent.

In interpolating between 10-kc harmonics it is assumed that a linear relationship exists between the micrometer reading and frequency. This, however, is not strictly true, since the capacity of the condenser varies inversely with the scale reading, and the frequency is therefore actually inversely proportional to the square root of the capacity. It can, however, be shown that the maximum error possible

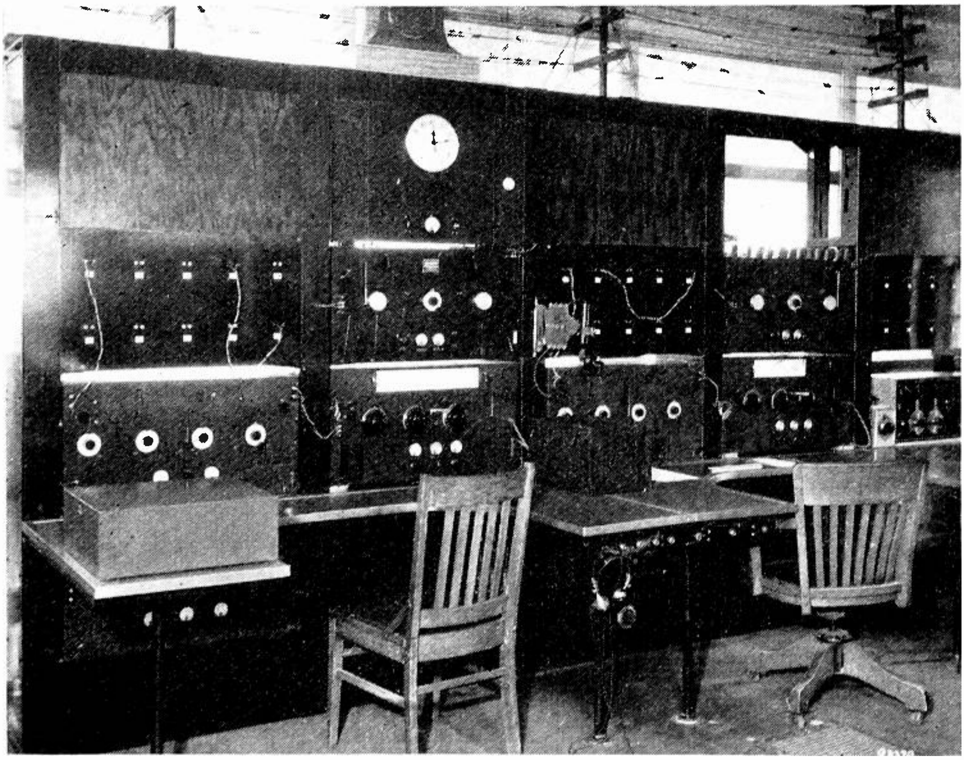

Fig. 8—Frequency measuring laboratory. The two measuring positions of the Riverhead station. Each position occupies two bays of the rack. The units, from top to bottom, in the first bay, at the left, are: antenna panel, harmonic generator unit, modulated 10-kc amplifier unit; second bay: r-f amplifier unit, measuring receiver. Above the amplifier unit is the 1000-cycle, synchronous clock. On the table, at the right of the receiver, is a heated box for the receiver coils. The chronograph and the tape recorder for measuring broadcast stations are not shown.

in assuming the relationship to be linear is only on the order of 0.5 cycle.

The observational errors may be divided into two classes, those made in reading the micrometer condenser, and those made in setting the condenser to zero beat. It may be assumed that the zero beat adjustment can be made to ± 15 cycles. The accuracy of reading the scale at the high frequency, or least accurate, part of the range, on the assumption that the observer can estimate to 0.2 of a division, is 0.0002 per cent. At the lower frequencies, where there are more divisions per kilocycle, the error of reading the micrometer is slightly less.

Taking account of all the errors, the total probable maximum error of the system, when used in ordinary routine measurements, may be expressed as follows:

$$\text{Error} = \pm(15 \text{ cycles} + 0.00022 \text{ per cent of the signal frequency}).$$

At 6000 kc (50m) this would amount to ± 28 cycles or 0.00047 per cent and at 20,000 kc (15m) to ± 59 cycles or 0.0003 per cent. When

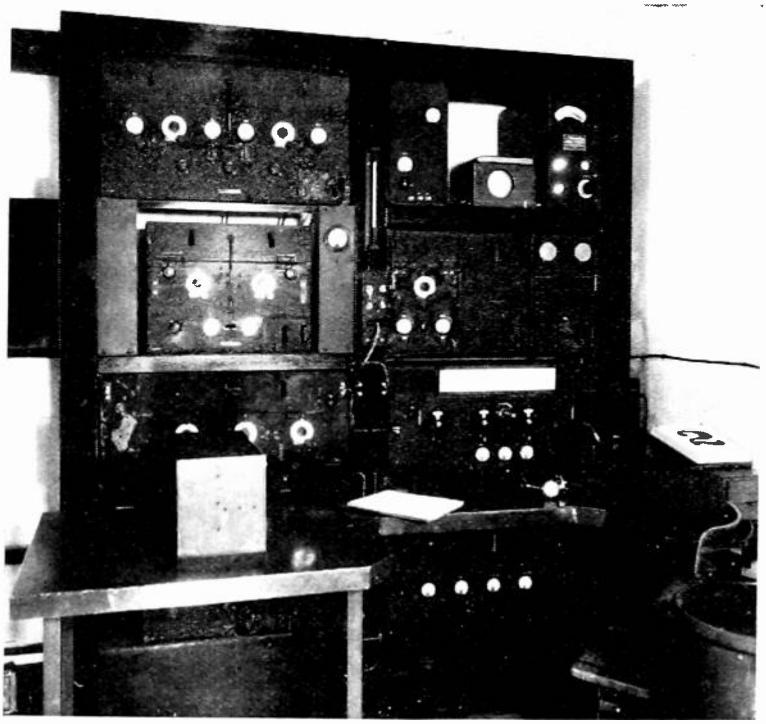

Fig. 9—Frequency measuring system—Rocky Point station. The complete equipment is mounted in one rack. The units, from top to bottom, in the first bay, at the left, are: multivibrator unit, transmitter crystal frequency multiplier unit, harmonic generator unit, 1-kc amplifier unit; second bay: 100-kc coupling tube unit and clock and frequency meter, 100-kc oscillator unit, measuring receiver, modulated 10-kc amplifier unit. The heated box for the receiver coils is on the table, to the left of the receiver. The small box on the panel to the left of the oscillator unit is the signal attenuator. The pick-up terminal boxes, which are not shown, are located on the wall to the right of the rack.

one considers that only a few of the commercial high-frequency stations regularly attain a stability of ± 0.1 per cent and that the most stringent tolerance for fixed stations is internationally recognized as ± 0.02 per cent it will be seen that routine measurements are of the order of 20 to

60 times the accuracy of the station measured and the system would appear to be adequate for commercial high-frequency conditions for some time to come.

By using the 1000-cycle comparator, which has already been explained, the constant part of the error is reduced to ± 1 cycle, giving a total of ± 45 cycles.

In broadcast measurements, where beats may be counted over a period of time, a measurement may be made to 0.01 cycle, but the error of the standard limits the accuracy to 0.2 cycle.

Equipment at Other Stations

The installation at Point Reyes, Calif., will be a duplicate of that at Riverhead, except that there will be only one measuring position, at least for the time being.

At the Rocky Point, N. Y., transmitting station there is an installation which differs in some respects from the one already described. There the system is located in the midst of a score or more of high power transmitters, and good shielding is essential. Since the purpose of the system there is only to check high-frequency transmitters at the plant, a standard oscillator of a slightly lower degree of precision is employed. A rectangular quartz plate is used, with no regulation of the air pressure on the crystal or the temperature of the oscillator circuit. However, the thermal system is so designed as to maintain the temperature of the crystal to approximately the same limits as the one at Riverhead.

The standard frequency and measuring equipment are assembled in one rack. Fig. 9 shows the complete installation. Signals from the various transmitters are brought into the measuring room by means of four shielded pairs. These are terminated at jacks in individual shielded boxes. Each box serves a separate group of transmitters. The radio-frequency transmission lines from the various transmitters to antennas leave the building at three different points. At each of these points, in close proximity to the radio-frequency feeders, is a small pick-up coil of a few turns which collects enough energy to supply the receiver. Another pick-up coil, located in a separate building about one mile away, serves the transmitters installed there. Energy from this building is fed to the measuring room by way of an underground transmission line. Connected to the input of the receiver is a shielded high-frequency attenuator box, where signals are adjusted to the proper level for measuring. No radio-frequency amplifier is necessary. Connection to the pick-up terminal boxes is made through a shielded cable and plug.

In order that the frequency of a transmitter may be measured before it is put on the air, a unit has been provided which makes it possible to measure the frequency of the crystal stage, with the power amplifiers and frequency multipliers shut down. Low-frequency energy from the crystal stage of a transmitter is fed into this unit, which is simply a harmonic generator. The frequency is stepped up and measure-

Fig. 10—Frequency standard—Rocky Point station. The oscillator and receiver units with doors open. In the central compartment of the oscillator unit is the thermal tank containing the crystal, in the left is the oscillator circuit, and in the right, the temperature control equipment.

ment then made at high frequency. To simplify calculations, the amount that the frequency is multiplied is made the same as it is normally stepped up by the frequency multipliers in the transmitter. The transmitter is thus always measured at its normal operating frequency.

The Rocky Point standard is accurate to about one part in a million. The clock is checked visually with an accuracy of 0.2 of a second from audible time signals. This limits the accuracy of the standard to 0.0002 per cent. The total probable maximum error with this system would be $\pm$(15 cycles+0.0004 per cent of the signal frequency). At 20,000 kc this would amount to $\pm$95 cycles.

In routine operation of the high-frequency transmitters of the Communications systems it is endeavored to keep within 0.025 per cent

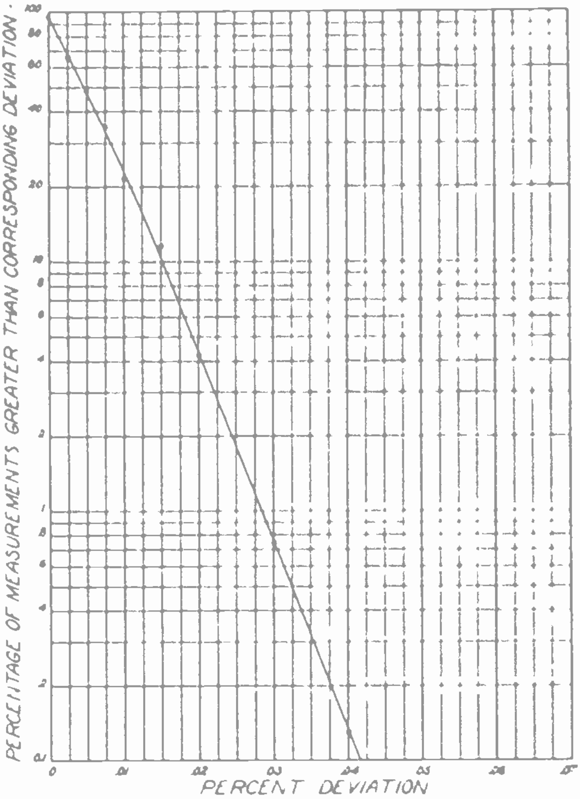

Fig. 11—Average frequency stability of a group of Rocky Point transmitters. The above graph shows the results of 1087 measurements made on eight transmitters, with frequencies ranging from 21,220 kc to 6,725 kc, over a period of three months.

of assigned frequency. (Federal Radio Commission regulations specify $\pm$0.05 per cent for stations authorized prior to September 3, 1931.) At 20,000 kc, 0.025 per cent is equal to 5000 cycles. Hence, an accuracy of $\pm$95 cycles is quite adequate. Fig. 11 is typical of the kind of data readily obtainable with these facilities.

Conclusion

In conclusion it might be interesting to observe that the system above described has been found entirely practical in service covering a continuous period of several years. At Riverhead an average of approximately six thousand measurements per month are made with two operators' positions. Not only have these measurements been found very useful in supervising the performance of our transmitters, even as distant as Manila, but they have been indispensable in resolving such cases of interference as occur on our various circuits by providing ready and reliable information as to the stations involved. This is available not only as of the time the interference is experienced but also from thousands of routine measurements which are regularly taken and supplied to the R.C.A. Central Frequency Bureau. At the Frequency Bureau continuous records are maintained of the history and performance of more than a thousand active high-frequency stations throughout the world. Records are also kept of the frequencies on which some 5000 additional stations are projected or are occasionally measured.

Precision frequency measurements are regularly supplied to a growing number of broadcast stations in the eastern and central sections of the United States. Upon the completion of the frequency measuring installation at Point Reyes, Calif., this service will be available regularly to broadcast stations in the western section of the United States.

Additional Bibliography

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

J. K. Clapp and John D. Crawford, "Frequency standardization," *QST*, vol. 14, p. 9; March, (1930).

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A NEW CIRCUIT FOR THE PRODUCTION OF ULTRA-SHORT-WAVE OSCILLATIONS*

By

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Summary—*A new circuit for the generation of ultra-short-wave electronic oscillations is described. This circuit consists of two tubes connected by symmetrical plate and filament Lecher systems instead of the usual plate-grid arrangement. The wavelength of the oscillations is determined by the length of the plate Lecher circuit. The tuning of the filament Lecher system governs the amplitude of the oscillations. It has been found that the same wavelength can be obtained even though the grid voltage is varied over a wide range of values.*

The radio-frequency output from this oscillator circuit is at least 5 watts, as actually determined by photometric measurements using a lamp in an absorption antenna. This is the largest output with electronic oscillators which has so far been reported.

Certain experimental details which are important in the operation of this circuit are outlined.

THE generation of ultra-short waves by electronic oscillations, discovered by Barkhausen in 1919, has, until the last few years, been a laboratory feat, studied by many experimenters for its purely scientific interest. However, within a comparatively short period, the possible technical applications of ultra-short waves, of wavelengths of a fraction of a meter, have become so numerous that they have given impetus to the development of circuits having sufficient power and stability to be technically and commercially feasible.

The properties of radio waves less than one meter in wavelength make them particularly suitable for directional or beam transmission of intelligence. The short wavelength makes possible the use of parabolic reflectors and antenna arrays which are physically very small compared to those which are necessary in the range of 3 to 7 meters. This feature furnishes a much desired directional flexibility which it is difficult to realize at wavelengths of 3 meters and above. The economical considerations are also worthy of notice. The cost of transmitting antenna or reflector at 60 cm is trifling compared to that at 5 meters.

However, up to the present time, the energy available at 65 cm has been very small. So far in the published literature the power output has been reported as being of the order of a fraction of a watt. It is the purpose of this paper to describe a new circuit for the generation of

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waves in the 60-cm region with which measured outputs of at least five watts have been obtained.

The general principles of electronic oscillations of the Barkhausen-Kurtz type have been quite completely discussed in many papers, so there is little need for reviewing them here. It might be mentioned that instead of the usual arrangement of voltages in the triode used as a long-wave oscillator, the grid is kept at a high positive potential with respect to the filament, and the plate potential is either zero or negative. Electrons emitted from the filament are accelerated by the grid; some pass through the grid mesh, a great number being lost by grid interception. The electrons which have passed through the grid find themselves in the retarding or brake field of the plate, move back in the direction of the grid, pass through the mesh toward the filament, when

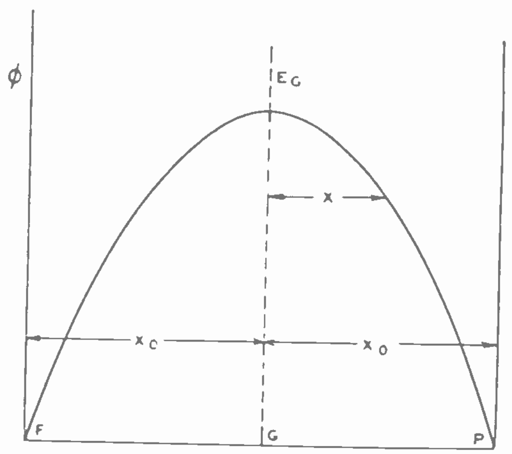

Fig. 1

the whole process is repeated. Thus we should expect that the frequency of oscillations in an external circuit, such as a Lecher system coupled to such a tube is intimately connected with the period during which the emitted electrons execute their orbits.

A derivation due to Möller,[1] of the frequency of such oscillations as a function of grid accelerating voltage and idealized tube dimensions, although based on a very simplified and perhaps questionable assumption of the potential distribution in such a tube, is nevertheless very useful in presenting a picture of the mechanism of these oscillations.

Fig. 1 gives the approximate potential distribution in a tube with plane electrodes, the grid G being located at a distance x_0 from the plate P and the filament F. Assume that this potential distribution can

[1] H. G. Moller, "Der Mechanismus der Barkhausenschwingungen," *Elek. Nach.-Technik*, p. 298, August, (1930).

be approximated by a parabola. Then we can write for the potential at a distance x from the grid,

$$\phi = E_g[1 - (x/x_0)^2] \tag{1}$$

where E_g is the grid voltage.

Then the electric field E is given by $d\phi/dx$, or

$$E = d\phi/dx = -2\frac{E_g x}{x_0^2}. \tag{2}$$

But the force on an electron is Ee, where e is the electronic charge.

$$F = -Ee = \frac{2eE_g x}{x_0^2}. \tag{3}$$

Thus the force is proportional to the displacement x, a distinguishing characteristic of simple harmonic motion. The period of oscillation of an electron is given in such a case by the familiar expression:

$$T = 2\pi\sqrt{\frac{M}{F/x}}$$

where M is the mass of the electron, and F/x is the force constant. But for T, the period of oscillation, we can write $1/f$, where f is the oscillation frequency in cycles per second. Making this substitution and using the value of F/x given in (3), we have:

$$f = \frac{1}{2\pi}\sqrt{\frac{2e}{M}}\,\frac{E_g^{1/2}}{x_0}. \tag{4}$$

This shows that the electronic orbital frequency is directly proportional to the square root of the accelerating grid voltage and inversely proportional to the distance between the plate and grid in a symmetrical plane tube. This relation was established by Gill and Morrell,[2] and holds quite accurately only in the case of zero or slightly negative plate voltage.

The first generator studied consisted of a push-pull arrangment of two standard UX-852 transmitter tubes, having independently variable plate and grid Lecher systems. The schematic arrangment is given in Fig. 2. It was found that this circuit oscillated quite well in the region of 90 cm. However, all attempts to decrease the wavelength were accompanied by a sharp decrease of the output power. At 80 cm the power obtained was very small, even with the most favorable com-

[2] E. W. B. Gill and J. H. Morrell, *Phil. Mag.*, p. 161, July, (1922).

binations of positive grid and negative plate voltages. It was found that when a sheet of metal was moved in the vicinity of the tubes, there were certain rather critical positions which caused the system to oscillate as strongly as at the longer wavelengths. It appears that this sheet furnishes a certain capacitative coupling which is essential for strong oscillations. More detailed investigation showed that the maximum output was obtained when this coupling existed between the plates and filaments; coupling the plates and grids had little effect on the output. It was observed that under optimum adjustment, the two grids were practically at zero radio-frequency potential, while the plates and filaments gave evidence of a relatively high radio-frequency swing. A quarter-wave antenna with a small flash-light bulb near the

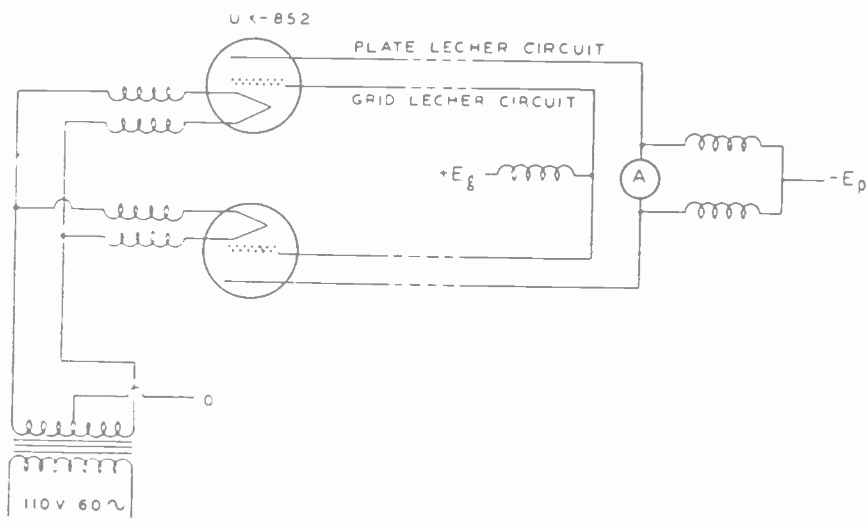

Fig. 2

current maximum was used to explore the radio-frequency potentials at various points of the oscillating system.

The fact that the grids are at zero radio-frequency potential while the plates and filaments show a large swing is a logical starting point for further development. It appears that in this case the oscillations are analogous to the mechanical oscillation of a bar clamped at the middle and vibrating in its fundamental mode. The two ends oscillate with maximum amplitude, 180 degrees out of phase, while the middle is fixed. In the circuit, we see that the plates and filaments fluctuate in potential while the grid is relatively constant. According to the theory that the electrons execute their orbits in groups, the so-called 'Zusammentanz', we can imagine the grid immersed in a space-charge cloud which oscillates between plates and filaments. The grids, therefore, show little or no change in potential, while the plates and filaments oscillate in unison with the electrons. In fact, there is good evidence to believe that the current reaching the plate during oscillation, and indicated by the plate milliammeter, is in the nature of a loss, being composed of electrons which have started their flight out of phase with the main cloud, and are sorted out. Thus it may well be that the whole

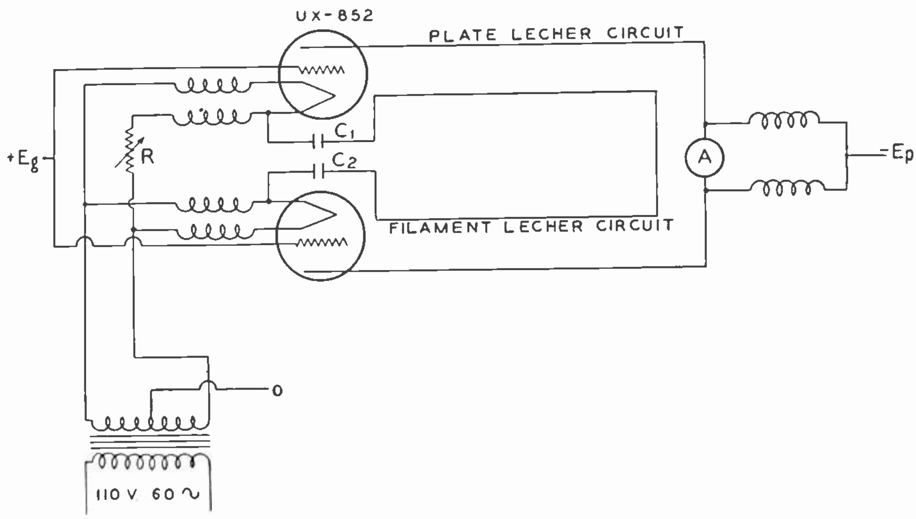

Fig. 3

process can be reduced to a capacity effect of the space-charge oscillation between the plate and filament.

As the grids do not oscillate in potential, and the plates and filaments do, it seems quite evident that, in this case, the plates and the

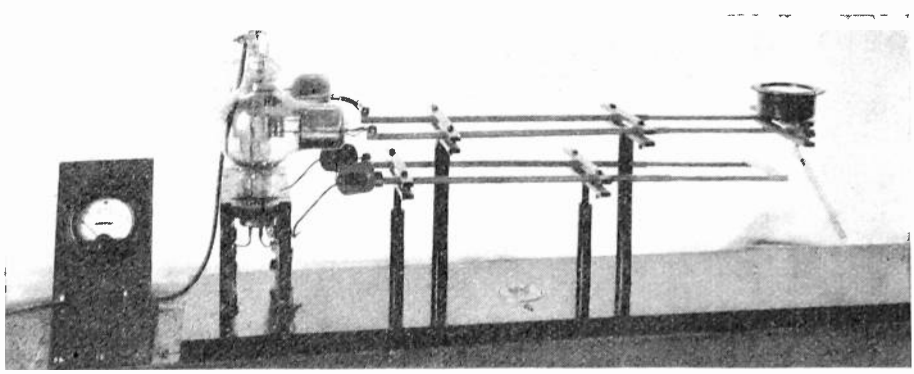

Fig. 4

filaments are the elements to be coupled to the Lecher system. This was tried, with very satisfactory results. It was found that the grids in this arrangement can be tied together and connected directly to the supply voltage source. When the circuit was adjusted for maximum output, it was possible to remove the grid choke without affecting the operation of the circuit.

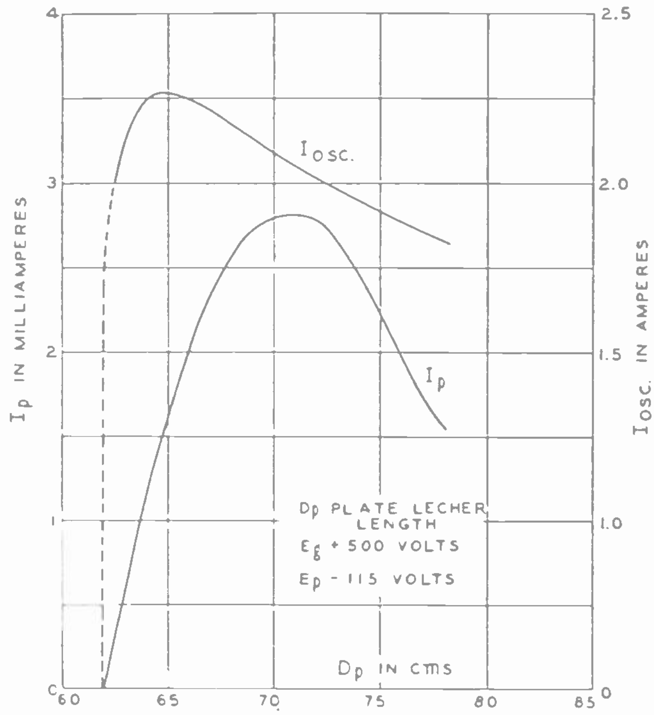

Fig. 5

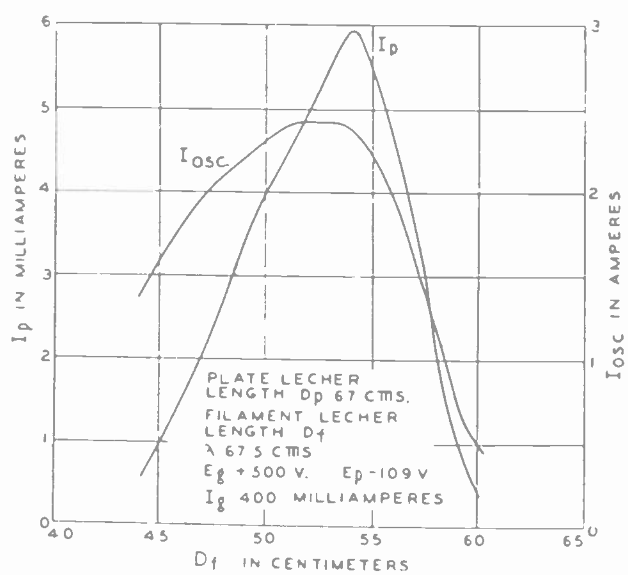

Fig. 6

Fig. 3 gives the circuit at present being used in our laboratories. The condensers C_1 and C_2 of Fig. 3 are used to keep the filament Lecher system isolated from the filament supply voltage, as a convenience in experimentation. They may be replaced by a direct metallic connection without affecting the operation of the circuit. A photograph of the arrangement of the tubes and circuits of Fig. 3 is given in Fig. 4.

The number of parameters which can be varied in a study of the circuit is very large. Among the more important of these parameters are:

1. Length of plate Lecher system.
2. Length of filament Lecher system.
3. Grid voltage.
4. Filament temperature.
5. Negative plate voltage.

The effect of varying these parameters will now be discussed in greater detail.

Function of the Plate Lecher System

The circuit of Fig. 3 was adjusted so as to obtain maximum circulating current as indicated by the terminating radio-frequency ammeter of the plate Lecher system. Then, the length of the plate Lecher system was varied on both sides of this maximum. The oscillating current and the electron current to the plate were observed. The response is given in the curves of Fig. 5. The important conclusions to be drawn from these data are:

1. The maxima of oscillation and plate current do not coincide, the maximum of the former being realized before the maximum plate current is obtained.

2. The electron plate current is not a direct measure of the oscillatory powers, being of the nature of a loss.

It was found that the length of the plate Lecher system governs the external oscillating wavelength directly. In the circuit arrangements used, the distance from the plate of the tube to the terminating ammeter is practically equal to the wavelength of the oscillations measured by an independent Lecher wavemeter. Within the limits of accuracy of observation, a change in the length of the plate system produces a corresponding change in the oscillation wavelength over a relatively large operating range.

Effect of Varying the Length of Filament Lecher System

The plate Lecher system was adjusted for a wavelength of 67.5 cm, and operating conditions were adjusted for maximum oscillating output. The length of the filament Lecher circuit was then varied on both sides of the maximum output adjustment and the oscillating and plate current data were obtained. In Fig. 6 the oscillating and plate current have been plotted as function of the length of the filament Lecher system. This length is measured from the terminating ammeter to the middle of the tube. Obviously this does not include the length of the filament and of the press leads which act as part of the oscillating circuit.

1. Again, plate and oscillating current maxima do not coincide, the sequence being the same as that in Fig. 5.

2. Over the entire range of filament Lecher system variation, sixteen cm. the wavelength change was less than two cm, the greatest part of this change taking place at the extremes of the Lecher system variation.

We see that the oscillating current, filament Lecher length curve has a sharply defined maximum, showing that the filament Lecher system plays a clear-cut rôle in determining the power output from the circuit.

Effect of the Grid Voltage

If we are to admit implicitly the theory that the frequency of electronic oscillations of the Barkhausen type is given by $\lambda E_g^{1/2} = K$, we should expect only a single frequency, or at most, a very narrow range of frequencies, for any particular accelerating grid voltage. The evidence obtained in the study of this circuit points to the fact that the accelerating grid voltage plays a second-order part in the determination of the oscillating wavelength. To determine the range of accelerating grid voltages which will give constant wavelength, accelerating voltages from 300 to 600 volts were applied to the grids of the two-tube circuit, and the oscillating and plate currents were noted. The filament temperature was adjusted so as to obtain approximately the same grid dissipation at each of the accelerating voltages used.

A tabulation of the results is given in the following table:

E_g	E_p	I_g	I_p	λ	D_p	D_f	I_{osc}
300	−100	[illegible]50 ma	1.4 ma	67.7	67 cm	54 cm	1.1 amp
400	−100	[illegible]25	4.7	67.5	67	54	2.0
500	−100	[illegible]00	6.0	67.5	67	54	2.4
600	−100	120	3.2	67.7	67	54	2.0

E_g is the positive accelerating grid voltage, E_p, negative plate voltage, I_g, grid current, I_p, plate current, D_p, length of plate Lecher system, D_f, length of filament Lecher system, and $I_{osc.}$ is the oscillating current measured by a radio-frequency ammeter at the termination or current maximum of the Lecher system.

It is evident from the above data that oscillations of a given wavelength, 67.5 cm, can be realized over a large range of grid voltages There is, however, an optimum value of accelerating grid voltage, about 500 volts, where the power output is a maximum.

There are two immediate possibilities, which are probably closely connected, which can be mentioned to explain the independence of wavelength and grid voltage over the range studied. The first is that the space charge oscillates, not at a single sharply defined frequency, but over a range of frequencies, whose maximum is determined by the grid voltage, the relation being probably of the type $\lambda E_g^{1/2}=K$. The circuit in this case selects the frequency range to which it is resonant.

The second view, which seems more probable, is that potentialities for oscillation over a range of frequencies exist. The amplitude of the external circuit power then depends on the relative number of electrons which can be made to oscillate at a given characteristic frequency, determined by the external circuit adjustment. In other words, at a given accelerating potential on the grid, and with a definite plate Lecher system length D_p, a resonance or "pulling-in" condition may exist between the electronic oscillations in the tube and the electric oscillations in the circuit. Electrons having characteristic frequencies much different from the fundamental may be removed by a simple 'phase sorting-out.' This sorting-out explains the noncoincidence of maximum power output and maximum plate current. On this basis, we should expect to find it impossible to get oscillations at long waves when the grid voltage is very high, and vice versa. Indications at present are that such is the case, but further tests must be devised before the mechanism of these oscillations can be more completely described.

Filament Temperature and Power Output

It was found that, within the limits of experimental error in measurement of wavelength, there is no first order variation of oscillation frequency with electron grid current as governed by filament temperature and hence filament emission. We may expect this as long as we keep away from conditions of appreciable space charge. Fig. 7 shows the relation between power output, current to the negative plates, and current to the grid, as adjusted by the temperature of the filaments. We see that the current to the plate is practically a linear function of the current to the grid until high values of grid current are reached. It is evident that the rise of the oscillating current in the Lecher circuit is much more rapid, reaching a well-defined maximum; further increase of the grid current causes a decrease in the oscillating output. Physical restrictions governing the amount of power which can safely be dissipated at the grid prevent carrying these observations to higher grid currents.

It is evident from Fig. 7 that there is little to be gained from the standpoint of power output by operating with more than 500 milliamperes to the grid circuit. This corresponds to a dissipation of 125 watts per grid. The circuit operates stably over long periods of time with the grids white-hot, with no apparent effect on the structure and characteristics. It is probable that the upper limit of the power output of this circuit with the tubes used is governed mainly by the damping influence of space charge.

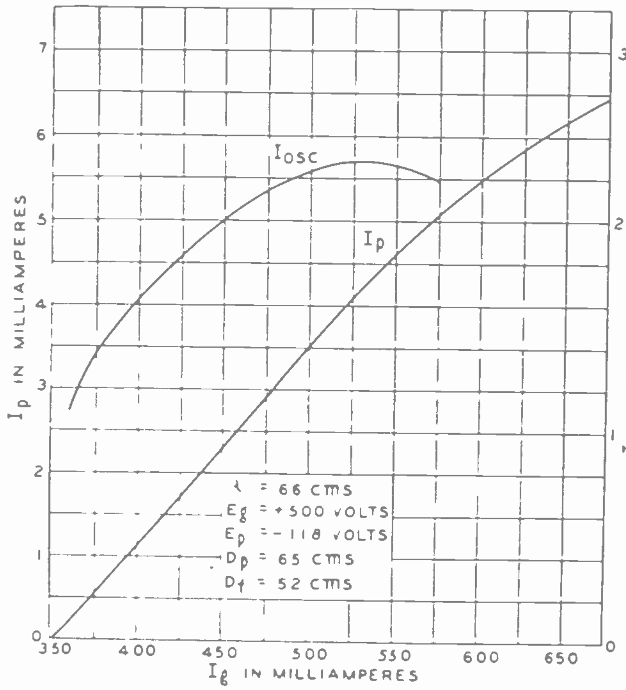

Fig. 7

Negative Plate Voltage and Oscillations

Most of the theoretical work on the mechanism of Barkhausen oscillations has been founded on the assumption that the nonoscillating potential of the plate is zero or very slightly negative. In the circuit we have used, the negative potential of the plate must be as much as 150 volts negative in order to obtain oscillations of the order of 55 cm. A theoretical difficulty is encountered in explaining how oscillations can start with the plate at such a potential. This difficulty is treated by Möller in the previously mentioned article.[1] He shows that a phase sorting-out of the electrons of the oscillating space-charge cloud which are out of step with the rest can take place. These electrons are lost by traveling to either the plate or the filament. We can see qualitatively that a negative or "brake" field due to the negative plate voltage has the effect of making the electron path shorter, increasing the frequency of electronic oscillation, and thus allowing oscillations of shorter wavelength or higher frequency in the external circuit.

In Fig. 8 are shown the variations of the oscillating and plate currents with the negative plate potential. Wavelength change in the region from −150 volts to −80 volts was inappreciable. However, with a further decrease of plate voltage, oscillations in a different mode, at 85 cm were detected. It is interesting to note the character of the oscillating current and plate current peaks, their sequence being the same as in Figs. 5, 6, and 7. The oscillating current plotted is that in an independent Lecher wavemeter coupled to the oscillating circuit.

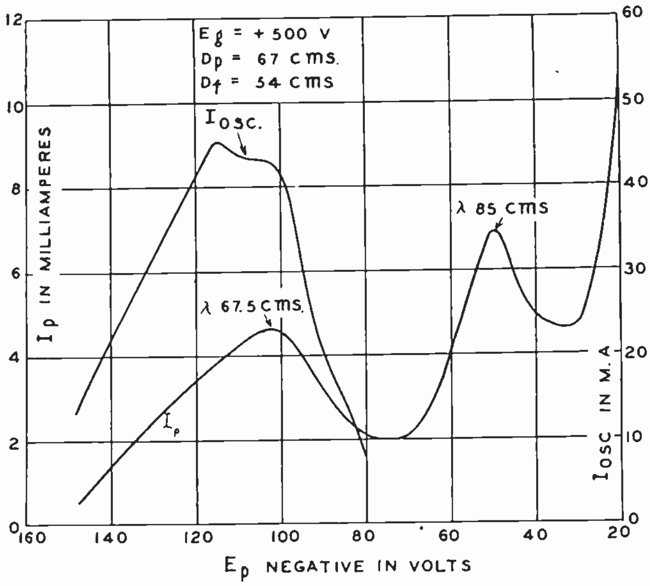

Fig. 8

It is important to note that the maximum of the oscillating current plotted against negative plate voltage is quite broad. This is of great practical importance in the problem of modulation of the carrier. If modulation is attempted by the use of a plate choke or transformer, with the negative plate voltage adjusted for maximum carrier output, poor results are obtained, as the amplitude of the carrier does not vary appreciably with the plate modulation voltage swing. Modulation carried out on the steep and linear portion of the oscillating current-negative plate voltage characteristic is very satisfactory.

Lecher Wire Spacing

The separation of the telescoping copper tubes of the Lecher system governs the radiation from the system. For a closed, low radiation system, the spacing is as small as possible. The coupling between the plate and filament Lecher wires is not very critical. However, there is a minimum value of coupling, or a maximum separation of the plate and filament Lecher system, beyond which instability occurs and the behavior of the circuit is erratic and influenced greatly by external capacity changes.

Oscillations with Single-Tube Circuits

In order to be in a position to study the effect of changes in tube design on the amplitude and frequency of ultra-short-wave oscillations, it was thought advisable to study in some detail the operation of single-tube electronic oscillators. This simplifies experimental procedure, as only one tube of a given structure need be made in order to determine oscillation characteristics. It is practically impossible with a UX-852 tube to obtain wavelengths shorter than 90 cm with any appreciable power output when using a single-tube plate-to-grid oscillating circuit. In contrast, wavelengths of 70 cm or less can readily be obtained under the same operating conditions with a plate-filament Lecher circuit. Indications are that the power output of two tubes in the circuit described in this article and shown in Fig. 4 is much greater than the sum of power outputs of two tubes working separately, in single-tube circuits.

There are several experimental details worth mentioning in connection with the push-pull circuit. The filament of the standard UX-852 tube is of thoriated tungsten. Two tubes selected at random for use as electronic oscillators seldom have the same electron emission at the same temperature. If these are operated in the circuit, the one with the greater electron emission has the larger grid current. This larger current causes the grid temperature to rise to a high value, heat radiation back to the filament causes its temperature and emission to increase, and the tube shows a decided tendency toward "running away." However, if, as shown in Fig. 3, a variable resistance is included in the filament circuit of the tube having the greater electron emission, conditions can very easily be adjusted so that the current to each grid is the same. Under these conditions, it is possible to operate the circuit with little or no attention and excellent stability. Special UX-852 tubes, using pure tungsten filaments have been constructed and operated with satisfactory results, giving the same power output at the same wavelength as the standard tubes.

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THE CAMPBELL-SHACKELTON SHIELDED RATIO BOX*

By

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Summary—*The Campbell-Shackelton shielded ratio box is intended to serve as the nucleus of a one-to-one bridge for the comparison of impedances. The transformer used in it operates effectively over the range from 50 to 50,000 cycles per second and in that range the limit of error is considered to be the greatest one of the three following terms:*

(1) ± 0.01 ohm (resistance, inductive, or capacitive reactance)

(2) ± 0.01 per cent

(3) $\pm 2\pi \times$frequency$\times 10^{-7}$ micromhos (conductance, inductive, or capacitive admittance)

Item (1) is the limiting factor in the measurement of low impedances, (2) in the measurement of intermediate impedances, and (3) applies for high values. Thus at 1 kc, for example, impedances between 100 ohms and 150,000 ohms can be compared to 0.01 per cent. Below this range, measurements can be made to 0.01 ohm and above this range to 6×10^{-4} micromhos. In practice there is no difficulty about sufficient power and amplification for attaining the precision needed to realize this accuracy. The above figures refer to the ratio box only and do not include errors in the standards used with the ratio box.

The above limits of error apply to measurements made under the most adverse conditions, as when measuring the smaller of the two components of an impedance. In many measurements it is possible to do much better than is indicated above, particularly in respect to item (3).

The ratio box may be used to form either a bridge with a Wagner earth connection or a bridge in which the junction point of the "standard" and "X" arms is grounded. Provision is made in the instrument for the limited conductance and capacitance adjustment required in the Wagner earth connection and in the initial balance of the grounded point bridge.

When using the Campbell-Shackelton ratio box to measure an impedance, adjustable standards of resistance and of inductance or capacitance are required, in addition to a power source and a detector. The standards must match the resistance and reactance components of the impedance to be measured. By resonance methods, and by various artifices, it is possible to measure a wide range of impedances in a one-to-one bridge and with comparatively few standards.

INTRODUCTION

AN IMPORTANT difference between a-c and d-c bridge measurements, is the effect of stray capacitances on the a-c measurements. Their influence is well brought out in the following quotation from G. A. Campbell:[1]

* Decimal classification: R241.5. Original manuscript received by the Institute, March 1, 1932. Presented before Twentieth Anniversary Convention, Pittsburgh, Pa., April 9, 1932.

[1] *Electrical World and Engineer*, vol. 43, p. 647, (1904).

"Experience shows that an ordinary balance when employed with an alternating current of the order of 2000 cycles per second is variable and indefinite. It is the purpose of this article to show how this source of error may be entirely eliminated by shielding.

"The difficulty encountered lies mainly in the direct capacity[2] between the different parts of the system.

"Since the ether permits the flow of alternating currents in all directions, the attempt to employ an ordinary balance for alternating measurements is much the same as the attempt to measure resistance with a Wheatstone bridge immersed in a conducting fluid, such as acidulated water. In general, a movement of the observer will change the distribution of the capacity effect and will change the adjustment required for a balance. Since it is necessary that the observer make certain movements in order to adjust the apparatus for a balance, this is a serious difficulty. Again, the entire generator circuit and connections form a part of the system, and any change in their capacity or leakage may affect the adjustment required for a balance. In case the generator is run from a lighting circuit, there is, of course, a direct capacity from the alternating-current side of the generator circuit to the lighting circuit, and this introduces the entire lighting system into the balance.

"Even although the capacity of the entire system were kept invariable, there would be the difficulty that its distribution could not be determined. Thus, there may be direct capacity bridged between any number of points of the balance. Experience has shown and theory confirmed the fact that, with telephonic frequencies and impedances, these capacities are sufficient to cause large errors in the balance measurements.

"As an example, take a balance having ratio arms of 1000 ohms each, coils of 0.25 henry and 10 ohms effective resistance in the other arms and a frequency of 1592 cycles per second, making[3] $p=10{,}000$. Then 100 micro-microfarads shunted around one ratio arm will introduce an error of 2.5 ohms, i.e., 25 per cent, in the effective resistance of the coil. The error varies as the square of the frequency and thus amounts to 100 per cent, at a frequency of 3184 cycles per second.

"It is impracticable to isolate the different parts of the unbalance sufficiently to reduce these capacities to a negligible amount. The only practical way is to shield the different parts of the balance from each other and from any outside sources of disturbance."

The shielding of the present instrument is based largely on the work of the Bell Telephone Laboratories and the communications[4] from that organization form an interesting and important contribution to precise a-c bridge measurements.

[2] See Appendix A.

[3] $p=2\pi\times$frequency.

[4] G. A. Campbell, *Electrical World and Engineer*, vol. 43, p. 647, (1904); U. S. Patent No. 792,248; *Bell Sys. Tech. Jour.*, vol. 1, p. 18, (1922).

Shackelton, *Bell Sys. Tech. Jour.*, vol. 6, p. 142, (1927); Shackelton and Ferguson, *Bell Sys. Tech. Jour.*, vol. 7, p. 70, (1928); *Ferguson, Bell Sys. Tech. Jour.*, vol. 8, p. 560, (1929).

A description of the ratio box and its use is largely a description of the shielding and, before discussing the shielding of the entire bridge, it is necessary to consider the shielding of individual impedances.

Shielding of Individual Impedances

The present discussion is confined to shielding for eliminating electric effects. Magnetic shielding does not present any particular diffi-

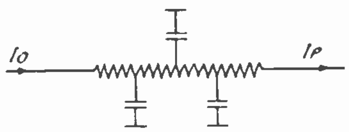

Fig. 1

culty because the instrument is substantially noninductive. The magnetic shielding is confined to the input transformer.

An unshielded impedance is shown in Fig. 1 where the distributed capacitance to the surroundings is indicated by the condensers. An impedance is defined by the ratio of the voltage across its terminals to the current through it, and, in the case of Fig. 1, the terminal voltage is a

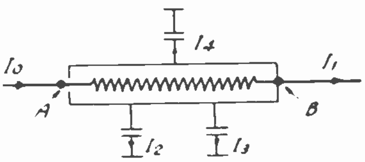

Fig. 2

definite, measurable quantity but the current through the impedance is not. Current I_o differs from I_p and the relation between them depends upon the surroundings.

A shielded impedance is shown in Fig. 2, with the shield connected to one terminal B and completely surrounding the impedance except for the other lead A. The shield is of sufficiently low resistance and in-

Fig. 3

ductance to form an equipotential surface; i.e. the voltage from A to B is the same as the voltage from A to any other part of the shield. In addition, the current leaving at B is considered as not only the current I_1 but as the vector sum of all the currents crossing the shield: $I_1+I_2+I_3+I_4$. With this definition of the current, and remembering that the total current crossing a closed surface is equal to zero, it is clear that the current entering at A is equal to the current leaving at B.

This construction and these definitions thus define a voltage and a current, the ratio of which uniquely defines an impedance.

Another method of shielding for obtaining a definite impedance is shown in Fig. 3. Two shields are used, one connected to each terminal. The two shields are insulated from each other and, in combination, they completely surround the impedance. From the discussion given above it is clear that this method of shielding also effectively defines an impedance.

Of the two types of shielding described, the single shield is generally easier to make and is the more widely used. In the present instrument, the split shield is used only in the transformer, where it is desirable, electrically, for reasons that will become clear when the bridge circuit is considered. In that particular case it is also mechanically convenient

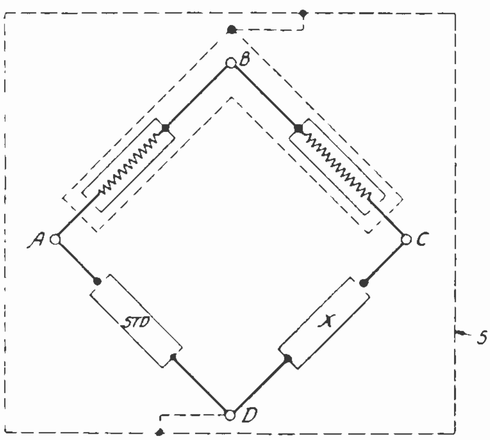

Fig. 4

to use a split shield, because of the division of the windings into two distinct sections on opposite legs of the transformer core.

Shielding of Assembled Bridge

Grounded Point Bridge

1. Stray Capacitances

The full lines of Fig. 4 show a bridge circuit exclusive of the current supply and detector. *AB* and *BC* are equal ratio arms shielded as described above. The *X* and standard arms represent the admittances to be compared and are shown with enclosing shields connected to one terminal. This is not a necessary limitation on the admittances to be compared but is imposed here for simplicity.[5]

[5] The careful shielding of the bridge circuit introduces no new difficulties in the measurement of unshielded admittances. Such admittances will, however, be indefinite to the extent that the admittance itself is indefinite and influenced by its surroundings. When the admittance to be measured is large, or when the ratio

In the usual elementary treatment of the conditions for a bridge balance, in which only the direct admittances between A, B, C, and D are considered, it is shown that if the admittances AB and BC are equal, balance is attained when AD and CD are also equal and the balance does not depend on the admittances connected directly between A and C or between B and D. In addition, however, to the circuit elements explicitly indicated in Fig. 4, there are admittances between the points A, B, C, and D taken two at a time and between each of these points and all the surroundings, for the junction "points" A, B, C, and D are not geometrical points but are in fact extended bodies. The point B, for example, is made up of the leads to the ratio coils and also of their shields, and similarly with the other junction points.

In view of this multiplicity of admittances, the question may arise as to just what has been gained by shielding the impedances as described. Briefly, the stray admittances are confined to the four corners of the bridge instead of being effective at every point of the network. It will now be shown that by appropriate shielding of the bridge network it is possible to realize in practice the ideal conditions assumed in the theory of the bridge circuit.

The capacitances between the junction points of the bridge and external objects are variable and beyond control. The first step is to make them definite and this may be accomplished by enclosing the entire bridge in a conducting shield, as indicated in Fig. 4, by the dashed-line, circumscribed reactangle marked S. The stray capacitances can now be visualized as due to condensers connected between all possible combinations of A, B, C, D, and S, taken two at a time. It should be noted that these condensers are in general not perfect and must be considered to have conductance as well as capacitance. There are ten such condensers and they are all listed below. The reason for the particular grouping will become apparent shortly.

I	*II*	*III*	*IV*
A-D	A-B	A-C	A-S
C-D	B-C	B-D	B-S
			C-S
			D-S

In the grounded point bridge, D is connected to S and, considering group IV, this makes S a part of D and A-S, B-S, and C-S become parts of A-D, B-D, and C-D, and will therefore be considered as members of groups I and III.

In group III, the condensers A-C and B-D are in the input and out-

of stray-to-measured admittance is made small by judicious location of the admittance at a distance from disturbing elements, an unshielded admittance may be sufficiently definite.

put branches. They do not influence the bridge balance and require no further consideration, provided they are not large enough to affect seriously the power consumption or sensitivity.

Groups I and II are considered in detail immediately below.

2. Ratio Arms

In group II the condensers *A-B* and *B-C* introduce no error if they are equal, for the only requirement of the ratio coils is that they be

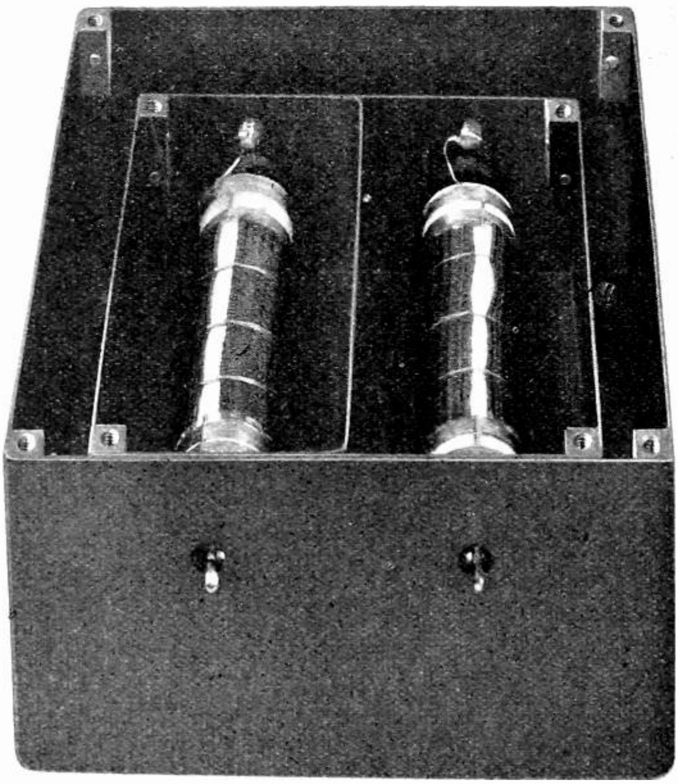

Fig. 5

alike. In order that the capacitances *A-B* and *B-C* may permanently remain alike to the high accuracy desired, it is well to have these capacitances as small as possible. Point *B* and the shields connected to it are surrounded by a shield connected to *D*. Such separation of *B* from *A* and *C* by a shield, limits the direct admittance between *B* and *A* or *C* to that introduced by the ratio coils.[6] This construction not only reduces the capacitance shunted about the ratio coils but also has the advantage that the ratio coils and their two shields can be treated as a

[6] See Appendix A.

unit and adjusted before being mounted in the instrument case. The capacitances *A-B* and *B-C* are taken into account in the adjustment of the ratio coils and, as regularly manufactured, the ratio coils have a nominal resistance of 1000 ohms and are adjusted to be alike to 0.01 per cent in resistance and to 0.2 $\mu\mu$f. The ratio coils and their two sets of shields, with the covers removed, are shown in the photograph of Fig. 5.

The arrangement of Fig. 4, although theoretically correct, is open to the serious inconvenience that the outer shield has to be large enough to include the standard and unknown impedances to be compared. This is avoided as in Fig. 6, where the *A* and *C* points are brought to the outside of the box through shielded binding posts which are con-

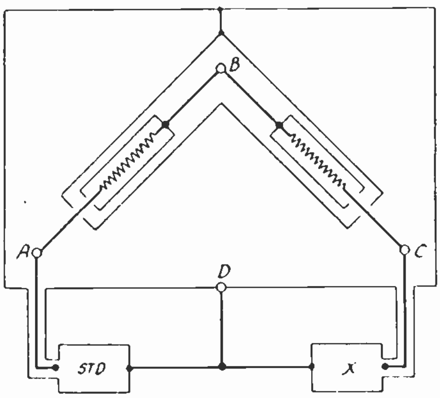

Fig. 6

nected to the standard and unknown impedances by shielded leads. It is clear that this is the exact electrical equivalent of Fig. 4.

3. Zero Balance

Considering group *I*, the condensers *A-D* and *C-D* are in the "standard" and "*X*" arms of the bridge. As it is a one-to-one bridge, if the condensers are alike, they have no effect on the bridge balance. They are made alike by a preliminary balance of the bridge before the standard and unknown impedances are connected in the circuit. This is an adjustment that could be made once for all in the construction of the bridge except for the fact that the condenser *A-D* includes not only the condenser between *A* and *D* proper, but also the condenser between the lead and the shield, of the shielded lead joining the *A* binding post to the standard impedance, (Fig. 6). The same condition exists in the *C-D* arm.

The limited adjustment needed to take care of the difference in the capacitance and conductance of the *A-D* and *C-D* arms introduced by the condensers as described above, is obtained by means of a small condenser and slide-wire, so connected in the circuit as to permit the transfer of capacitance and conductance between the two arms. The details will be given later.

4. Detector

To complete the bridge, connections must be made to the detector and to the power source. The detector is connected to D and B and the part of the detector circuit so connected must be surrounded by a grounded shield. The connection between D and B introduces an admittance between these points, which has no affect on the bridge balance. The grounded shield around the detector branch insures that

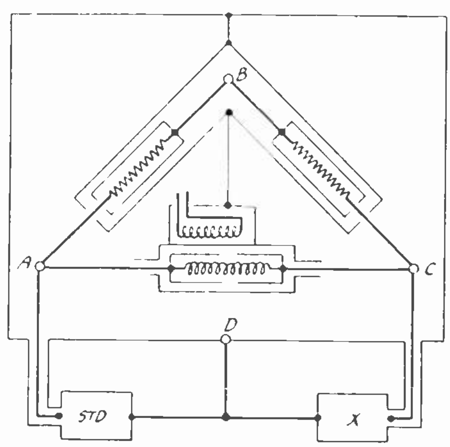

Fig. 7

there are no direct admittances introduced by the detector, between B and points external to the bridge.

5. Input Transformer

The connections to the power supply are made as in Fig. 7, which shows the transformer with its secondary winding connected to A and C. The secondary winding is enclosed in split shields connected to the terminals of the winding, as in the shielded impedance of Fig. 3, and the split shields are in turn surrounded by, but insulated from, a shield connected to D, the ground point.

The insertion of the secondary winding introduces direct admittances between A and C, A and D, and between C and D. The admittance A-C does not enter into the bridge balance and admittances A-D and C-D have been considered and it has been shown that they are only required to be equal and they can therefore be balanced out. It is for this reason that a split shield is used on the secondary of the transformer, as the symmetrical construction ensures approximate equality of the admittances introduced between A and D and between C and D and thereby facilitates their accurate adjustment to equality.

Although any inequality of the admittances A-D and C-D can be balanced out, the capacitance component should be stable enough not to make frequent balancing necessary and the conductance should be small, because the conductance of insulating material changes with the frequency and is in general not precisely constant. Careful design of the transformer is needed to meet these requirements.

In the transformer designed and made for this use, the sum of the capacitances between the two inner shields and the ground shield is less than 50 $\mu\mu$f, and the difference of the capacitances is less than 1

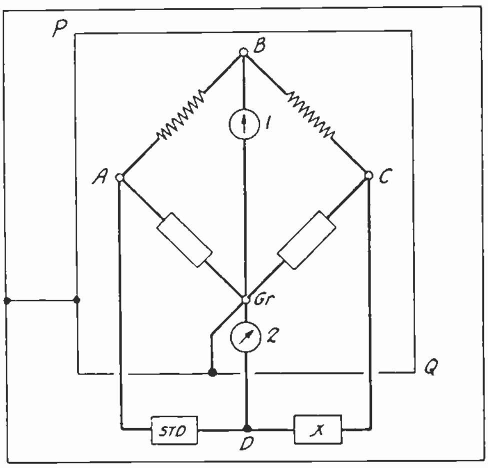

Fig. 8a

$\mu\mu$f. The conductance between the inner shields and the ground shield, at 50 kc, is less than 0.004 micromho, and the difference in conductance is smaller than the precision of measurement at this frequency, 0.001 micromho. In the measurement of conductance to this precision at this frequency, it is necessary to balance the capacitance to better than 0.001 $\mu\mu$f. At 1 kc, the conductances are less than 0.0001 micromho and their difference is not detectable.

As explained above, the bridge is enclosed in a shield connected to D, in order that the A, B, and C points may have no direct admittances to the external surroundings. For convenience, it is desirable to mount the transformer inside the shield and this places the primary with its external connections inside the shield. To make the shielding as described above still effective, the primary is surrounded by a shield connected to D, or the ground shield. In the transformer as thus constructed, the direct capacitance between the primary and secondary windings, that is, the total direct capacitance between the primary winding and both the A and C points, is less than 0.01 $\mu\mu$f.

Wagner Earth Connection

In Fig. 8a the bridge circuit, as previously described, but with ratio coil shields and the input transformer omitted, is shown in its case PQ. The rectangles in the AGr and CGr arms are admittances with whose characteristics we are not concerned beyond requiring that one or both of them be adjustable to permit obtaining a balance as indicated by the detector between B and Gr. The remainder of the network consists of the two admittances to be compared, standard and X, and a detector between D and Gr. As before, in order to eliminate indefinite

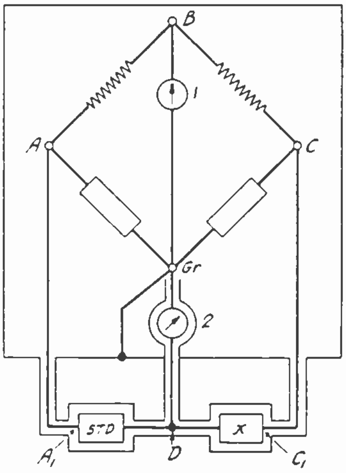

Fig. 8b

admittances to external objects, the entire network is surrounded by a shield connected to the point Gr.

When balance is attained, as indicated by absence of current in detectors 1 and 2, it is clear from the elementary theory of the bridge that the direct admittances AD and CD, as well as the admittances AGr and CGr, are equal. The equality of the admittances AD and CD is by itself not a sufficient condition to ensure the equality of standard and X. There may be other admittances between A and D and between C and D, as for example, stray capacitance and conductance between the D terminal and the leads connecting standard to A, or X to C.

Such stray capacitances can be entirely eliminated by completely separating the A and C points from the D point by a shield connected to Gr as in Fig. 8b. Such shielding reduces to zero the stray direct admittance between A and D and between C and D.[7]

[7] Appendix A.

As far as the instrument itself is concerned this shielding is accomplished by enclosing the instrument in a metal case and by providing the A and C terminals with grounded caps. The part of D internal to the case is separated from the rest of the circuit by a grounded shield.

In the external circuit the shielding is extended by the use of shielded leads from A to A^1 and C to C^1 and by surrounding branch DG by a shield connected to Gr. These shields not only eliminate the stray admittances mentioned above, but also ensure the absence of any admittances to external points so that the large enclosing shield of Fig. 8a is no longer necessary.

Fig. 9

The introduction of shielded leads AA^1 and CC^1 introduces admittances between AGr and CGr. These arms must, therefore, be rebalanced after the bridge circuit has been completed. As in the grounded point bridge therefore, the bridge with the Wagner earth connection requires a double balance.

In general, measurements can be made equally well on the grounded point bridge and the bridge with a Wagner earth connection. The choice between the two methods may be determined by convenience in shielding. Where one terminal of the impedance to be measured, or of the standard available, is connected to the case and must remain so connected for correct results, the grounded point bridge usually permits the simpler shielding. In the measurement of a small direct admittance, the precision required in the adjustment of the Wagner earth connection is usually less than that needed in the zero balance of the grounded point bridge. The theory of the grounded point bridge is simpler and the significance of the bridge balance is more obvious than for the bridge with the Wagner earth connection, and measurements can usually be made more rapidly on the grounded point bridge.

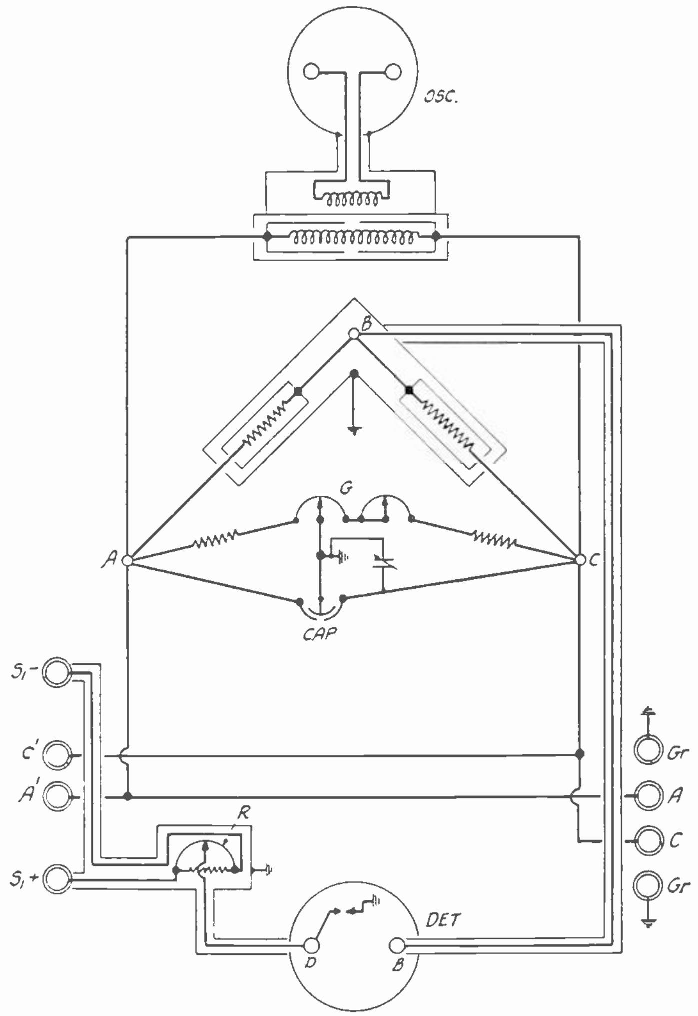

Fig. 10

Details of Construction

The completed instrument is shown in Fig. 9 and in the detailed wiring diagram of Fig. 10. A, B, C, and D identify the four corners of the bridge. The points of the circuit, indicated as connected to ground, are in fact connected to a common bus which is connected to the metal case of the instrument. The junction point of the doubly shielded ratio coils is at B and is connected to the B detector post by a shielded lead. The other detector post, marked D, can be grounded, at will, by screwing down tightly the small knurled head screw visible near the detector posts.

Slide-wire R is shunted to have a total resistance of 0.6 ohm. The slide-wire and the three leads joining it to the rest of circuit, are surrounded by a grounded shield. The slide-wire brush is joined to the D detector post and the ends of the slide-wire terminate at posts S_1+ and S_1-. The A and C points of the bridge are each made accessible at two binding posts A, A', and C, C', respectively.

The capacitance balance required for both the Wagner earth and grounded point bridge is made with the condenser "Cap". The condenser has two sets of stator plates, connected to the A and C points, respectively, and a set of rotor plates connected to ground. Rotation of the condenser from one extreme of its motion to the other corresponds to a transfer of 50 $\mu\mu$f from between A and ground to between C and ground. The knurled-head screw near the "Cap" dial operates a low range condenser and permits fine adjustment of the capacitance. One complete clockwise turn of the screw adds approximately 0.05 $\mu\mu$f to the branch C-Gr.

The corresponding conductance balance is obtained with the slide-wires G and the two end coils which are all connected in series between A and C. One of the two slide-wires has a range of about 0.5 ohm, the other about 8 ohms. The two are so arranged that manipulation of knob G of Fig. 10, over the intermediate portion of its range of motion, results in movement of the brush on the fine slide-wire only. When either end of the fine slide-wire is approached, further motion of the knob actuates the brush on the coarse slide-wire also.

Method of Use

The following measurements that can be made with the ratio box, are described here with the object of making clear what the ratio box circuit is and how the instrument may be used as the nucleus of various bridge circuits.

A. Two-Terminal Admittance

1. Grounded Point Bridge

Figs. 11a and 11b show the ratio box as an element of a grounded point bridge used in this particular case for the comparison of two variable air condensers.

The bridge is initially balanced by means of G and Cap, with standard and X out of the circuit, but with the shielded leads to be used connected to A and C. Subsequent balance with standard and X in the circuit is indicative of the equality of the two condensers.

Any slight difference in the conductance components of the condensers can be balanced by adjustment of G.

If it is desired to measure the conductance component, as well as the capacitance, the circuit of Figs. 12a and 12b can be used. A fixed resistance and a resistance box are connected as shown.

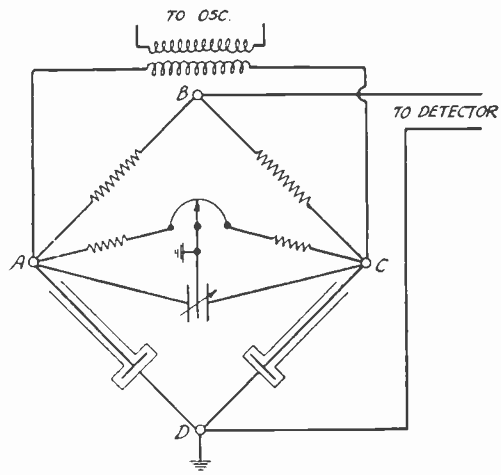

Fig. 11a

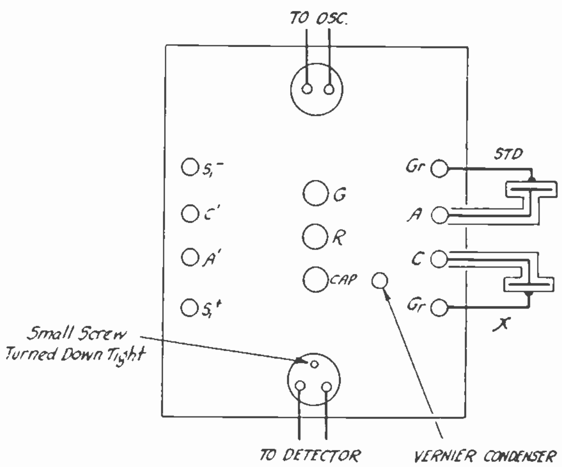

Fig. 11b

The initial balance is obtained by means of G and Cap, with standard and X out of the circuit but with the shielded leads to be used connected to A and C and the fixed resistance and the resistance box connected as shown in the figure. During the initial balance, the resistance box is conveniently set at the same nominal value as the fixed resistance.

A series resistance may be used for balancing the conductance, but the method of measuring the conductance component described above, is preferred because it is applicable over the entire range of conductance (0 to ∞) and because the shielding is simple. Fig. 12c shows two methods of shielding when the *CD* arm is made up of a resistance in series with a condenser. The shielding introduces capacitance in the

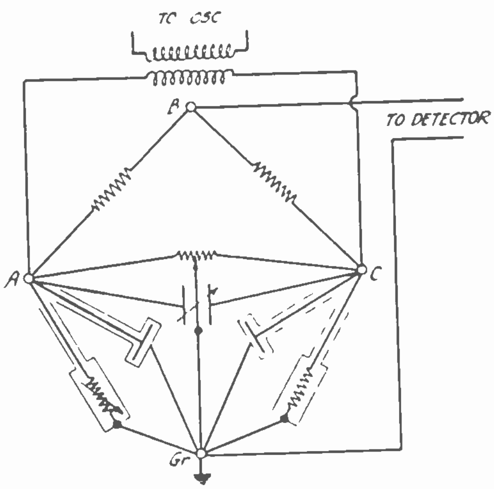

Fig. 12a

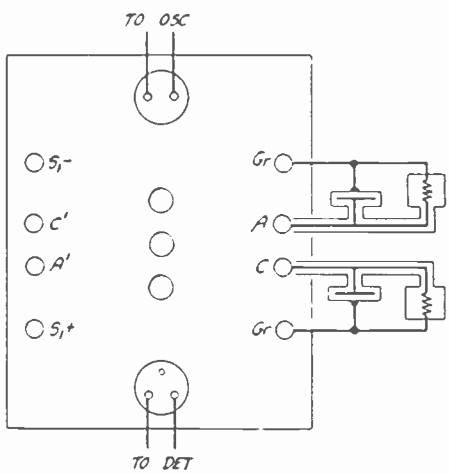

Fig. 12b

CD arm which can be taken into account by an initial balance of the bridge. The shielding of Fig. 12c is also effective in series resonance methods of comparing inductance and capacitance.

In many cases the conductance balance is made merely to get complete silence; the capacitance is the quantity to be measured but the conductance balance must be made in order to be certain that the capacitance balance is correct. In such a case it may be more convenient to connect the resistance box between A' and S_1+ and the fixed resistance between C' and S_1-. Fine adjustment of the conductance balance can then be made on slide-wire R which is a shunted slide-wire. The condensers remain connected between A and Gr and between C and Gr.

2. Bridge with Wagner Earth Connection

The wiring for capacitance measurements when using the Wagner earth connection is shown in Figs. 13a and 13b.

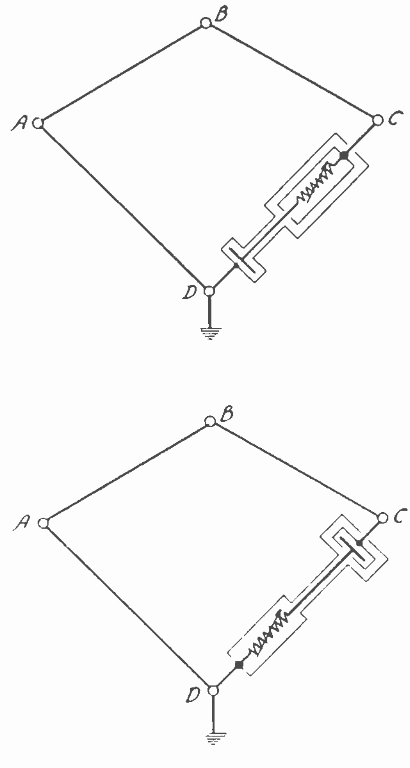

Fig. 12c

With the two condensers connected as shown, the bridge is balanced by means of G and Cap, with the detector connected between B and ground. The detector is then connected to D and ground and the bridge rebalanced by adjusting standard or X. The balances are then repeated until no change in setting is necessary.

If the conductance component is to be measured, or balanced out, a fixed resistance and a resistance box may be connected in parallel with X and standard, respectively, or used in series as in the grounded point bridge.

B. Direct Admittance

1. Grounded Point Bridge

Figs. 14a and 14b shows the circuit for a grounded point bridge when used to measure the direct capacitance between two terminals of a three-terminal network. The bridge is balanced with switch T closed on A and closed on C. The change in standard necessary for a

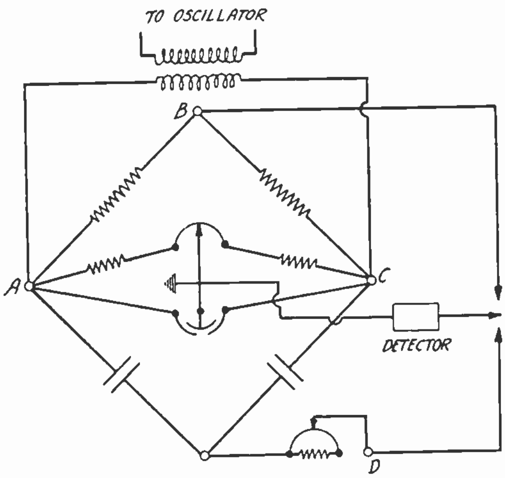

Fig. 13a

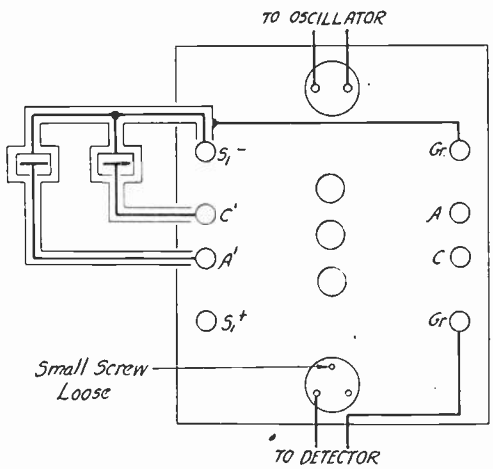

Fig. 13b

balance in the two positions is twice the direct capacity between 1 and 3. If the conductance component is also desired, a resistance is connected between A and D, as before, and a fixed resistance between C and D.

2. Wagner Earth Bridge

The Wagner earth bridge described above measures the direct admittance connected to its terminals A and D. To measure the direct admittance between two terminals of a three-terminal network, the terminals are connected to A and D and the third terminal to ground. The procedure as already described then gives the desired direct admittance.

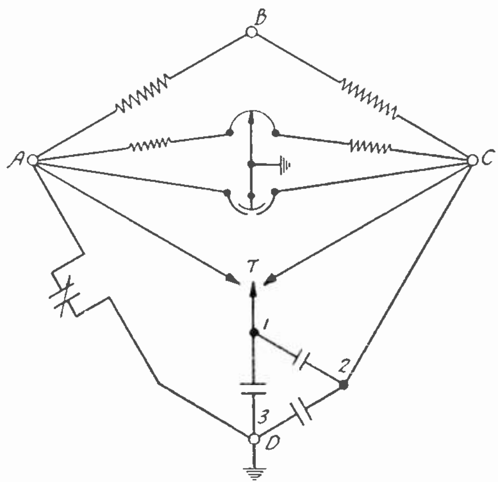

Fig. 14a

C. Inductance

In the comparison of inductances, particularly low inductances and at low frequencies, it is necessary to balance out the resistance component with precision even though its numerical value is not of interest.

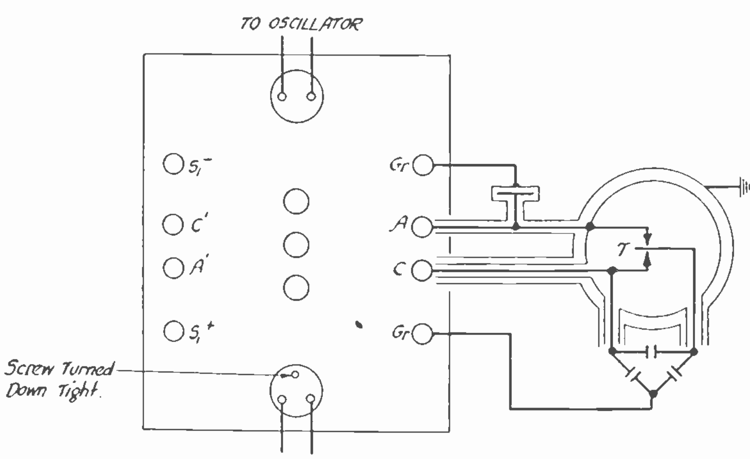

Fig. 14b

A low resistance slide-wire R is incorporated in the ratio box and, in conjunction with a resistance box with minimum steps of 1 ohm, makes possible a resistance balance with a precision of better than 0.01 ohm.

The diagram of connections for the grounded point bridge is shown in Figs. 15a and 15b. It differs from the previous grounded point bridge only in the use of the slide-wire R.

The slide-wire R is shunted to a resistance of 0.6 ohm and its resultant inductance is less than 0.1 microhenry. In Fig. 15a, when

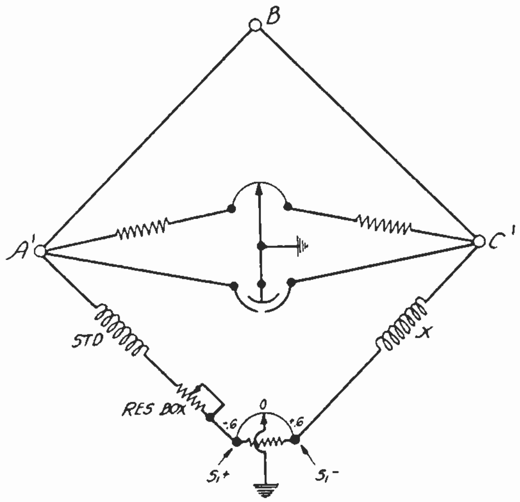

Fig. 15a

slide-wire R is rotated from -0.6 to $+0.6$, this inductance is transferred from the CD arm of the bridge to the AD arm. If this inductance change is objectionable, the resistance balance may be obtained by an appropriate external resistance.

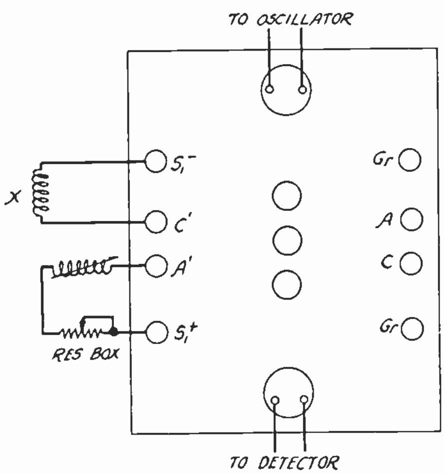

Fig. 15b

Appendix A

For the concept of direct admittance and for methods of measurement, a paper by G. A. Campbell[8] should be consulted. It is shown

[8] *Bell Sys. Tech. Jour.*, vol. 1, page 18, (1922).

there that any network, accessible through a group of terminals only, may be replaced by a network consisting of branches connecting together the accessible terminals.

The definition is illustrated in Fig. 16. I represents a box containing resistance, capacitance, mutual inductance, etc., connected together

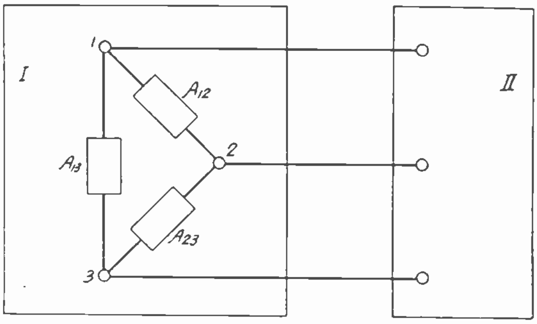

Fig. 16

inside the box. Terminals 1, 2, and 3 are connected to points in the network of box I.

If box I is joined to some external circuit (II) by connections at 1, 2, and 3 only; i.e., there is no electric or magnetic coupling between

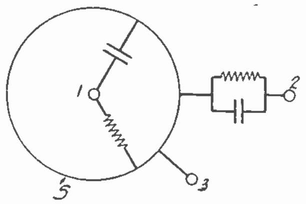

Fig. 17a

I and the external circuit, box I may be completely represented by three admittances A_{12}, A_{13}, A_{23} shown joining the terminals 1, 2, and 3.

A special case is of particular interest. In Fig. 17a, S is a shield connected to terminal 3 and completely separating terminal 1 from 2. It is

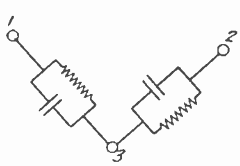

Fig. 17b

clear that this may be redrawn as in Fig. 17b, the important point being that the only path from 1 to 2 is by way of 3; there is no direct admittance between 1 and 2. In general, a shield, connected to an accessible terminal and completely separating a network into two parts, reduces to zero the direct admittance between accessible terminals on opposite sides of the shield.

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SOME NOTES ON GRID CIRCUIT AND DIODE RECTIFICATION*

By

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Summary—*The equivalent input resistance of a grid leak and condenser in parallel and the combination in series with a diode or the grid-cathode circuit of a triode are calculated for various combinations by means of the static I_0-E_0 characteristics and an extension of the work of Colebrook and Peterson and Llewellyn. The equivalent internal resistance of the diode is also calculated and an expression for the equivalent generator is also derived. The relations between X, the grid condenser modulation frequency reactance, R, the grid leak, and m, the percentage modulation, to give good quality are considered theoretically and experimentally. The part played by the values of X, R, and m in the quality of the audio-frequency output was first considered by Terman and Morgan. Limiting values of X and R for the cases of the triode and diode are also estimated.*

The theory of grid circuit rectification has received considerable attention recently. Peterson and Llewellyn[1] in their paper considered among other things, the properties of an ideal two-element rectifier whose static characteristic is linear so that $I=KE$ for positive values of E and $I=0$ for negative values of E. They showed that if a carrier voltage, $P \cos pt$, is applied the current of fundamental frequency is

$$I_p = \frac{PK}{\pi}(\alpha - \tfrac{1}{2} \sin 2\alpha) \cos pt \tag{1}$$

and that d-c space current is

$$I_0 = \frac{PK}{\pi}(\sin \alpha - \alpha \cos \alpha) \tag{2}$$

where α is one half the angle during which current flows per cycle.

Colebrook[2] considered the problem of finding the fundamental frequency and space currents of an ideal rectifier in terms of the displacement, b, of the characteristic from the origin, the bias voltage, E_0, and the direct voltage, V_c, across the grid leak and condenser. The grid condenser was assumed to act as a short circuit for the carrier voltage.

* Decimal classification: R149. Original manuscript received by the Institute, February 15, 1932.

[1] Peterson and Llewellyn, "Operation of modulators," Proc. I.R.E., January, (1930).

[2] Colebrook, "The theory of the straight line amplifier" *Experimental Wireless and Wireless Engineer*, November, (1930).

He derives the following forms of (1) and (2).

$$I_p = \frac{KP}{\pi}(\theta - \sin\theta\cos\theta)\cos pt \tag{3}$$

and,

$$I_0 = \frac{KP}{\pi}(\sin\theta - \theta\cos\theta) \tag{4}$$

where,

$$\cos\theta = (V_c + b - E_0)/P.$$

Terman and Morgan[3] found that grid circuit power detection may be obtained with reasonable values of distortion provided that the grid condenser reactance at the modulation frequency and the grid leak resistance R are related to the degree of modulation m in such a way that $X/R > m/\sqrt{1-m^2}$. This equation is rather startling as it implies that it will be physically impossible to obtain power detection with satisfactorily small values of distortion if the percentage modulation approaches 100 per cent. A study of the physical mechanism of grid circuit rectification does not lead one to believe that it is impossible to obtain satisfactory detection with large percentages of modulation. The formula derived above considers that the condenser may only discharge through the grid leak.

It is proposed in this paper to derive formulas giving the equivalent input resistance of the grid leak and condenser in parallel, with this combination in series with an ideal rectifier and also giving the equivalent internal resistance and audio-frequency generator of the ideal rectifier. It is to be expected that the equivalent internal resistance in parallel with the grid leak R would modify the resistance R through which the grid condenser discharges so that an experimental study was also made of the distortion versus input voltage for different values of X/R. An alternative expression for the relation between X, R, and m is also derived which gives results more in line with those to be expected. Unfortunately equipment was not available to determine experimentally which expression is correct as an input signal modulated at least 75 or 80 per cent is necessary to differentiate between the expressions derived by Terman and Morgan[3] and the writer, and 50 per cent modulation only was available with fair values of distortion in the modulator itself. The data given in Fig. 5 of the above paper by Terman and Morgan[3] also give results only up to 50 per cent modulation. The value of internal resistance found here may be used to calculate frequency discrimination curves of the grid circuit detector such as

[3] Terman and Morgan, "Some properties of grid leak power detection," Proc. I.R.E., December, (1930.)

those found experimentally in another paper.[4] The method of calculating the discrimination curves is obvious so this phase is not considered further here.

If $b-E_0$ is made zero in (3) and (4) they may be written as follows:

$$I_p = \frac{K}{\pi}(P\theta - V_c \sin \theta) \tag{5}$$

$$I_0 = \frac{K}{\pi}(P \sin \theta - V_c\theta). \tag{6}$$

If P varies in (5)

$$\frac{\partial I_p}{\partial P} = \frac{K\theta}{\pi}. \tag{7}$$

If V_c varies in (5)

$$\frac{\partial I_p}{\partial V_c} = -\frac{K}{\pi}\sin\theta. \tag{8}$$

If P varies in (6)

$$\frac{\partial I_0}{\partial P} = \frac{K\sin\theta}{\pi}. \tag{9}$$

If V_c varies in (6)

$$\frac{\partial I_0}{\partial V_c} = -\frac{K\theta}{\pi}. \tag{10}$$

The reciprocals of the right-hand members of (7), (8), (9), and (10) are resistances. The negative signs of (8) and (9) show that the currents decrease as the voltage V_c increases. The above equations are derived under the assumption that the external impedance is zero for the change of voltage and the currents found using these impedances may be interpreted as short-circuit currents. We may find the internal resistance and equivalent internal generator e.m.f. from these equations using the standard signal.

$$e = P \sin pt(1 + m \cos at) \tag{11}$$

where p is 2π times the radio frequency
a is 2π times the audio frequency.

It will be assumed that p is many times a so that the variation of P is $Pm \cos at$. If P varies (9) becomes

[4] J. R. Nelson, "Grid circuit power rectification," Proc. I.R.E., March, (1931).

$$\frac{\partial I_0}{\partial P} = \frac{Km}{\pi} \sin \theta \cos at. \tag{12}$$

If we assume that the change of I_0 causes V_c to vary, the resistance to this change of V_c will be given by the reciprocal of (10). The internal e.m.f. is equal to the short-circuit current, given by equation (12) times the applied voltage P, and the internal resistance, given by the reciprocal of equation (10), and becomes

$$e_i = \frac{\pi}{K\theta} \times \frac{PK}{\pi} m \sin \theta \cos at = Pm \frac{\sin \theta}{\theta} \cos at. \tag{13}$$

The external voltage is

$$e_a = \frac{Pm \dfrac{\sin \theta}{\theta} \cos at \, (Z_a)}{\dfrac{\pi}{K\theta} + Z(a)}. \tag{14}$$

The equivalent internal resistance and e.m.f. may be derived more directly as follows under the usual conditions making no assumptions except that the by-pass condenser in the grid leak-condenser combination is a short circuit for the carrier voltage and $b-e_0$ is zero. (Refer to (5).) V_c in this equation is equal to I_0R, where R is the external grid resistance, so (5) may be written

$$I_0 = \frac{K}{\pi}(P \sin \theta - I_0 R\theta) \tag{15}$$

or,

$$I_0 = \frac{KP \sin \theta}{\pi + KR\theta} \tag{16}$$

which may be written as follows:

$$I_0 = \frac{P \sin \dfrac{\theta}{\theta}}{\dfrac{\pi}{K\theta} + R}. \tag{17}$$

If P is now modulated so that the voltage is given by (11) and the change of I_0 is denoted by I_a, the current of the modulation frequency $a/2\pi$, (17), becomes

$$I_0 + I_a = \frac{P\dfrac{\sin\theta}{\theta}}{\dfrac{\pi}{K\theta} + R} + \frac{Pm\dfrac{\sin\theta}{\theta}\cos at}{\dfrac{\pi}{K\theta} + R}. \tag{18}$$

Hence, I_a becomes

$$I_a = \frac{Pm\dfrac{\sin\theta}{\theta}\cos at}{\dfrac{\pi}{K\theta} + R}. \tag{19}$$

The value of e_a may be found by multiplying (19) by R. It is thus seen that if Z_a in (14) is made equal to R the two equations are the same. The resistance r_a as regards the modulation frequency is $\pi/K\theta$ as may be seen from (19).

This concept differs in no wise from that given by the small signal theory as in both cases the modulation frequency voltage may be thought of as the voltage built up across an external impedance in series with a generator having an internal impedance. This will be discussed in more detail later.

If $b - e_0$ is not zero the values of I_0 and I_a may be still found readily. Under the usual conditions of operating either a grid circuit detector or the cathode type of triode as a diode e_0 is zero and b is negative, that is, current starts to flow at some small negative voltage. Cos θ in (4) becomes $(V_c - b)/P$ instead of $(V_c + b - e_0)/P$. (17) then becomes

$$I_0 = P \sin \frac{\dfrac{\sin\theta}{\theta} + b}{\dfrac{\pi}{K\theta} + R}. \tag{20}$$

It is also easily seen that (19) is not changed. The internal resistance may be found experimentally by means of the equations given so far and the static $I_g - E_g$ curves for various a-c input voltages. For example, if P is zero the external voltage for a resistor R is

$$E = \frac{bR}{r + R} = \frac{b}{1 + \dfrac{r}{R}} \tag{21}$$

where r is the internal resistance of the device.

If a carrier voltage of peak value P is impressed in the circuit and the impedance to the audio frequency is R ohms the peak audio-frequency voltage for 100 per cent modulation may be found in the well-known manner by projecting the intersections of the load line with the curves for $2P$, P, and zero volts on the voltage axis of the I_g-E_g curves. The voltage between the points for P and zero volts give the peak voltage on one side while the other peak value is given by the points for $2P$ and P. We shall make use only of the values given

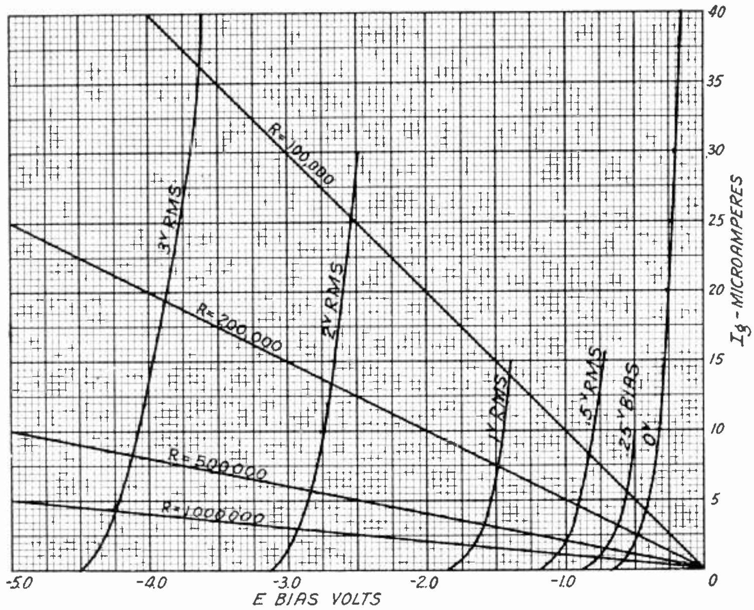

Fig. 1—$I_g=E_g$ characteristics of ER-227 tube with various a-c input voltages $E_b=180$ Volts, $R_p=10{,}000$ ohms.

by the intersections for zero and P in the following discussion. The peak voltage found above represents e_a in (19). P is known and $m\equiv 1$. e_a may be written as

$$e_a = \frac{Pm\dfrac{\sin\theta}{\theta}}{1+\dfrac{r}{R}} \tag{22}$$

where,

$$r \text{ is } \frac{\pi}{K\theta}\cdot$$

It is thus seen that as $\sin\theta$ and θ may be computed all the quantities are known so that r the internal resistance may be found in terms of R and as R is known r may be found in ohms for any input voltage.

Fig. I shows the I_g-E_g curves for various a-c input voltages of an

ER-227-type tube with 180 volts connected to the plate through 9000 ohms resistance. Four load lines are drawn in from the origin. The average input resistance for $m=100$ per cent using only the half, from P volts to zero volts, was computed by means of (22) for various a-c input voltages using Fig. 1 and another set of I_g-E_g curves taken with the same tube. The results are shown plotted in Fig. 2. It was necessary to take different values for K according to the input voltage and value of R which of course varies b. The value of b makes no appreciable difference for input voltages exceeding one volt but does for smaller

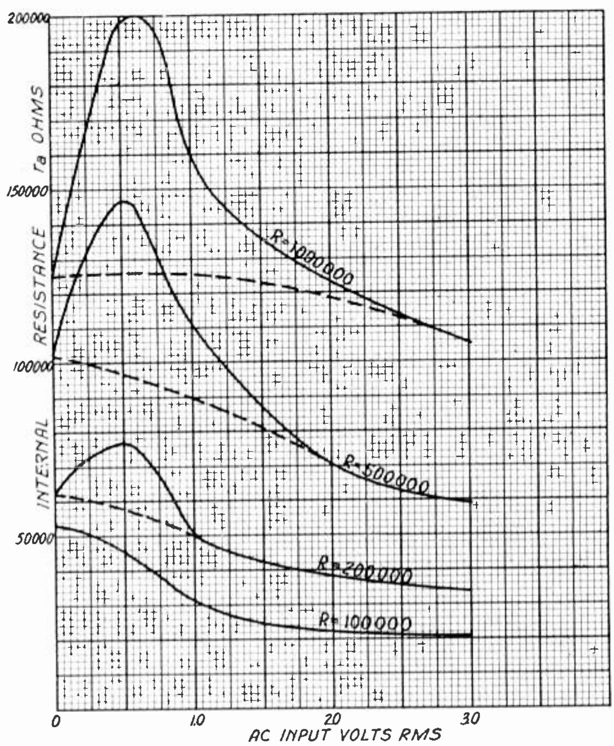

Fig. 2—Effective internal resistance ER-227 tube for various values of R calculated from formula $r_a=\pi/K\theta$. Dashed lines probable internal resistance.

input voltages. The rise in r_a occurs because the theory does not hold except for fairly large input voltages and the input voltage necessary for the theory to hold increases as R is increased. The probable value of r_a is shown plotted in dotted lines. Even the curve for R equal to 100,000 ohms had a rise in it for smaller values of carrier voltage. The values of r_a as calculated from the reciprocal of (10) agrees fairly closely with the given results for input voltages greater than the values at which the dotted curves join the full curves.

Colebrook[2] also shows that the effective input resistance to the carrier frequency may be taken as

$$R_e = \frac{\pi}{K} \frac{1}{\theta - \cos\theta \sin\theta} \cdot \tag{23}$$

This equation may be written as

$$R_e = \frac{\pi}{K\theta}\left(\frac{1}{1 - \cos\frac{\theta \sin\theta}{\theta}}\right) = r_a\left(\frac{1}{1 - \cos\frac{\theta\sin\theta}{\theta}}\right) \cdot \tag{24}$$

The value of R_e is the equivalent resistance which could be shunted across the tuned circuit to absorb the same power as is taken by the

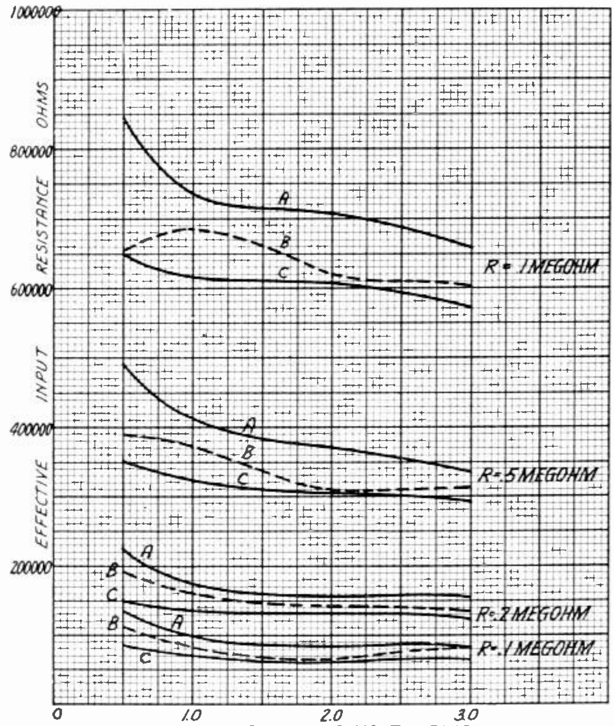

Fig. 3—Effective input resistance of grid resistor and condenser in series with ER-227 tube. A calculated from $R_e = R/2\cos^2\theta$, $B - R_e = r_a/(1\text{-}\cos\theta\ (\sin\theta)/\theta)$, $C - R_e = R/2\cos\theta$.

grid leak and rectifier. In the actual rectifier there are many other frequencies present including zero frequency yet the energy to maintain them comes from the energy given by the current of the fundamental frequency. The values of R_e calculated by (24) are shown by curves B in Fig. 3.

It has been shown before, although the writer cannot locate the first reference, that the effective input resistance is greater than $R/2$. Terman and Morgan[3] modify this by taking into account the fact that the current is only BE/R during the part of the cycle so that the resistance should be $R/2B$ where B is the effectiveness of rectification or $\cos\theta$ in the preceding notation. The values of R_e for various values of R are shown by curves C in Fig. 3 using the above equation. The writer feels that this equation should be still further modified as the average voltage is only $E\cos\theta$ during the part of the cycle when the grid is not drawing current. The power dissipated is equal to the power supplied and this power is

$$P = E^2 \cos\theta^2/R. \tag{25}$$

In effective values this becomes

$$P = \frac{2E^2\cos\theta^2}{R} = \frac{E^2}{R/2\cos^2\theta} \text{ and } R_e = \frac{R}{2\cos^2\theta}. \tag{26}$$

The values of R_e obtained using (26) are shown by curves A in Fig. 3. It is to be noted that the values given by curves B are intermediate between those given by A and C.

Terman and Morgan also conclude that $X/R \geqq m/\sqrt{1-m^2}$ for good quality. They reach this conclusion by considering the relations that the change of voltage across a condenser C discharging through a resistor R is E/RC and that the change of the envelope of the modulated wave $E(1+m\cos at)$ is Em at $\sin at$. They assume the rate of change of the voltage across the condenser to be equal to or greater than that given by the rate of change of the modulated wave, and obtain the above result.

The following analysis yields results more in line with those expected from a physical study of rectification, indicating that under correct conditions it would be possible to obtain good results even with 100 per cent modulation.

The rate of change of the condenser voltage $Ee^{-t/RC}$ is $-E/RC$ $e^{-t/RC}$. The value of $e^{-t/RC}$ is practically unity. The voltage E may be considered to be $P(1+m\cos at)$ although the condenser is not quite charged up to this value. The value of $\partial E/\partial t$ is then $P/RC(1+m\cos at)$. The rate of change of the input voltage $P(1+m\cos at)$ is $-P\,am\sin at$. The rate of change will be a maximum when $\partial(-P\,am\sin at)/\partial t$ is zero, which occurs when $-\cos at$ is equal to zero or $\sin at = 1$. Hence, $P/RC\,(1+m\cos at_0) = P\,am\sin at_0$

or,

$$1/RC_a \geqq m \text{ or } x/R \geqq m. \tag{27}$$

Where t_0 is the value of t which makes $\partial^2E/\partial t^2$ a maximum.

Experimental Results

A. Experimental Equipment

A General Radio signal generator was used to supply the radio frequency voltage modulated with 400 cycles. The generator voltages were changed somewhat so that up to 50 per cent modulation could be obtained with fair quality. It was necessary to amplify the output of the signal generator to obtain sufficient voltage for the test. At first very erratic results were obtained with the two stage r-f amplifier used and the distortion measured varied considerably depending upon tuning. The results were much better when the amplifier tuning was broadened by shunting the secondaries with a 100,000-ohm resistor. The results are given for the tuning giving the maximum detector output. The exact reasons for the erratic results obtained with two sharply tuned circuits are not known but it is believed that the detuning caused by the loading of the tuned circuit changed the input wave form due to unequal amplification of the carrier and side bands.

Preliminary checks showed that the distortion was about the same whether measured in the detector plate or in the output of the amplifier used. The distortion in the detector plate could only be measured for about 2 volts input with fair accuracy. It was desired to use voltages ranging from 0.12 to 20 volts or voltages ranging from the small signal detection theory to the range of voltages covered by the power detection theory in this article so the a-f amplifier was used. The detector output voltage was amplified to give only 300 milliwatts output from a push-pull 245-stage so that the distortion introduced by the amplifier was negligible.

B. Triode Results

An ER-227 tube with 180 volts applied through 10,000 ohms was used in all the triode measurements. The 10,000-ohm resistor was used as a potentiometer so that any desired fraction of the voltage developed across it in the detector plate could be applied to the audio amplifier. A preliminary study of plate rectification curves similar to those shown in a preceding article[4] showed that about a three-volt carrier would be all that could be used without bad overloading because of plate overload under the above conditions and that about 4.5 per cent second harmonic should be obtained with a three-volt carrier modulated 33 per cent. This study also showed that a smaller percentage of second harmonic should be obtained as this input voltage is decreased until the square-law range is reached when it should again increase and approach about 8 per cent.

In Fig. 4 the per cent second harmonic is plotted versus input voltage for various combinations of R and C. The carrier frequency used was 1000 kc and the modulating frequency was 400 cycles. The results are indicative of what may be expected in practice using a tuned input. The values of X/R calculated for the various values of grid condenser and resistor are shown with the data on the curves. It was also assumed here that varying the size of grid condenser and keeping the modulation frequency constant would give the same results as varying

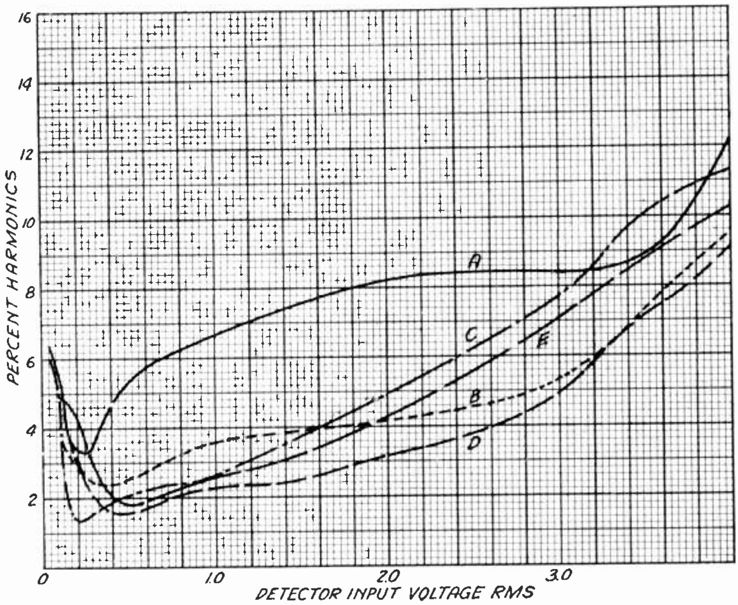

Fig. 4—Per cent second harmonic 227 grid circuit detector with tuned input measured with carrier frequency of 1000 kc modulated 33 per cent with 400 cycles, $E_b = 180$ volts, load resistance 10,000 ohms.

$A - R_g = 1{,}000{,}000$ ohms and $C_g = 2100$ $\mu\mu$f $X/R = 0.19$
$B - R_g = 1{,}000{,}000$ ohms and $C_g = 1100$ $\mu\mu$f $X/R = 0.36$
$C - R_g = 100{,}000$ ohms and $C_g = 2100$ $\mu\mu$f $X/R = 1.9$
$D - R_g = 1{,}000{,}000$ ohms and $C_g = 100$ $\mu\mu$f $X/R = 2.86$
$E - R_g = 100{,}000$ ohms and $C_g = 1100$ $\mu\mu$f $X/R = 3.63$

the modulation frequency and keeping the size of the condenser constant.

It is to be noted that the second harmonic increases rapidly due to plate rectification for all conditions when the input voltage is made more than three volts. Curve A has a value of X/R equal to 0.19 and hence the second harmonic should be high because this is less than the value of m which was 30 per cent. Curve B has a value of X/R equal to 0.36 and hence should be satisfactory. There is still some second harmonic being introduced by the small value of X/R as curve D having only 1/11 of the capacity follows very closely the second harmonic to be expected from the rectification curve taken in the plate circuit.[4] Curves C and E follow the theory up to about one volt input as each has a sufficient value of X/R for good quality. Beyond one volt input, however, the distortion increases much faster than any theory developed thus far, covering the process of rectification, would explain. The second harmonic is probably higher than the theory indicates because of the loading effect in the tuned circuit. The curves for small input give values of second harmonic to be expected from the square-law detector theory.

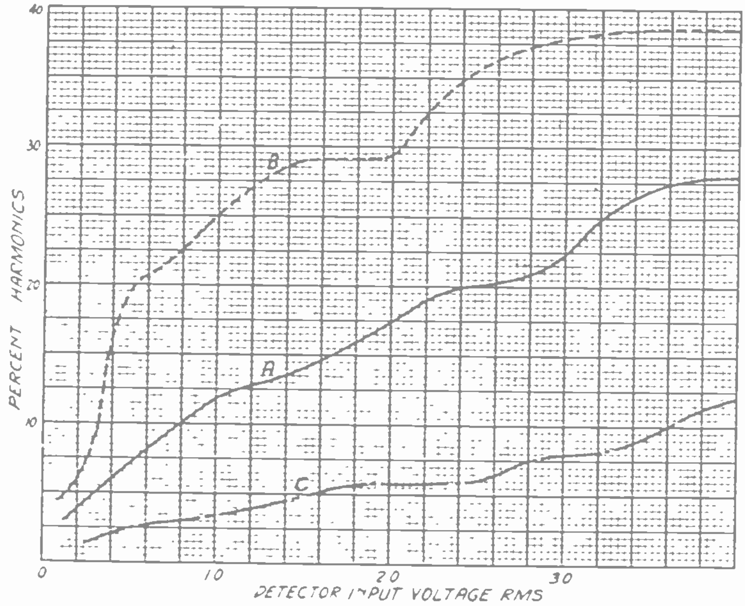

Fig. 5—Per cent second harmonic 227 grid circuit detector tuned input measured with a carrier frequency of 1000 kc modulated 33 per cent with 400 cycles, $E_b = 180$ volts, load resistance 10,000 ohms.

$R_g = 2{,}000{,}000$ ohms and $C_g = 2100\ \mu\mu f$ $X/R = 0.095$
$A - M = 30$ per cent
$B - M = 50$ per cent
$C - M = 20$ per cent

The value of resistance for condition A in Fig. 4 was increased to two megohms so that the value of X/R was 0.095 a condition particularly bad for distortion according to theory. The values of second harmonic for three values of m are shown plotted in Fig. 5. There is over twice as much second for A, Fig. 5, as for B, Fig. 5, for 2.5 volts input, although the ratio decreases as the input voltage is decreased. There is no constant ratio between the various percentages of second harmonic and percentage modulation as the ratio varies with the input voltage.

The effect of plate overload or plate rectification cannot be eliminated in the triode for large values of input voltage. A study of the

227 as a diode was next made. In this case any fraction of the a-f developed could be applied to the amplifier and analyzer and the r-f and d-c voltages could be removed so that the mechanism of grid circuit alone could be studied. The results of this study are given in the next section.

Before leaving the triode it may be of some interest to estimate the maximum values of R and C that may be used in practice. Curve D of Fig. 4 is reasonably close to B. The capacity across the grid leak is the value of C plus the input and distributed capacities. It is believed that 30 $\mu\mu$f would cover the total additional parallel capacity so that the total value of C would be 130 $\mu\mu$f. The ratio of the capacities for D and B is then 1130/130 or 8.7. A frequency of 8.7 times 400 or 3480

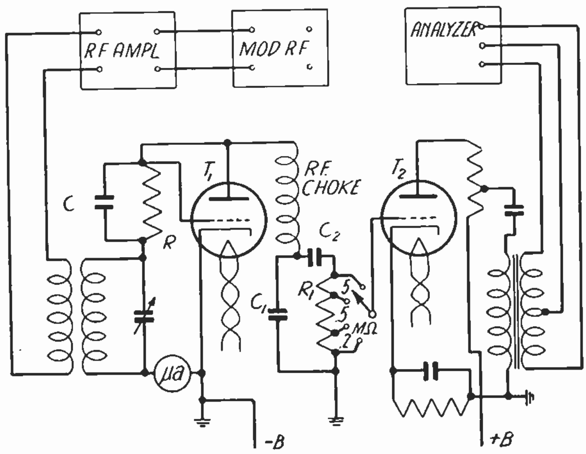

Fig. 6—Schematic diagram of circuit used to study diode detector.

could then be used to give the same distortion curve as given by B. From here on any assumption made involves the audio amplifier. If the audio amplifier passed 2×3480 or 6960 cycles with very little attenuation the value of R would have to be decreased if the percentage modulation was above 35 per cent. Most of the present-day amplifiers would attenuate the second harmonic or 6960 cycles so that the above constants would be satisfactory. If the amplifier passed frequencies up to 10,000 cycles a value of R equal to 0.5 megohm would be all that should be used with 100 $\mu\mu$f. It is better to keep the value of C down and the value of R fairly high due to the harmful effects of the low input resistance shunting the tuned circuit as evidenced by curves C and E of Fig. 4.

C-Diode Detector

Fig. 6 shows the circuit used for studying the diode detector. An ER-227 tube T_1 was used as a diode with the plate and grid tied together. The microammeter shown was used to indicate the average current in the grid circuit and hence indicated the carrier voltage when the modulation was zero. T_2 was also an ER-227 tube and the input to this tube was tapped so as to avoid the introduction of distortion in this stage when large input voltages to the diode were used. The taps were always chosen so that an audio-frequency voltage between the cathode connection of R_1 and ground with T_1 removed introduced less than one per cent second harmonic. The values of C_1 and R_1 used did not appreciably reduce the second harmonic due to frequency discrimination.

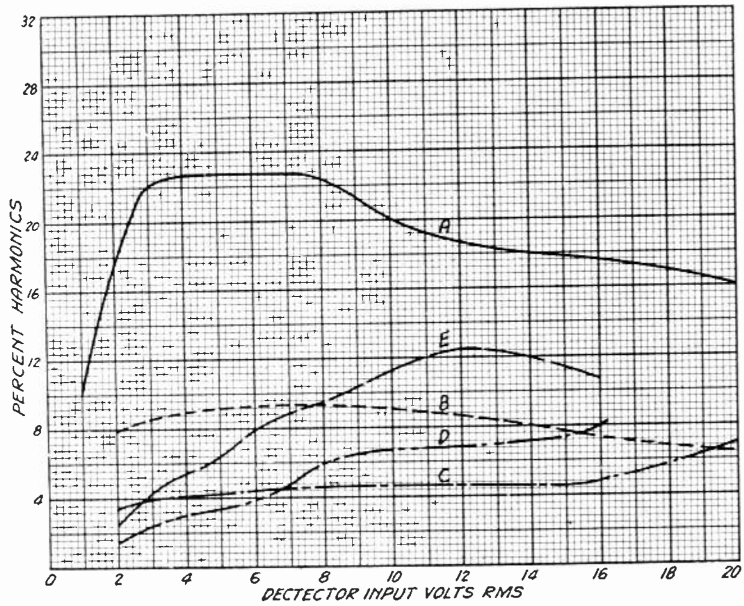

Fig. 7—Per cent second harmonic obtained from 227 tube used as a diode with plate and grid tied together using same tuned input and modulation radio-frequency voltage as used for Figs. 4 and 5.

$A - R = 2{,}000{,}000$ ohms and $C = 2000\ \mu\mu f$
$B - R = 2{,}000{,}000$ ohms and $C = 1000\ \mu\mu f$ and $R = 1{,}000{,}000$ ohms and $C = 2000\ \mu\mu f$
$C - R = 1{,}000{,}000$ ohms and $C = 1000\ \mu\mu f$
$D - R = 500{,}000$ ohms and $C = 2000\ \mu\mu f$
$E - R = 100{,}000$ ohms and $C = 2000\ \mu\mu f$

Fig. 7 shows the experimental results obtained with various combinations of R and C. The effect of plate rectification due to bias shifting which enters in the case of the triode previously studied is no longer present so that these results indicate better than those given previously just what occurs in the diode portion. The curves in general flatten out as the input voltage is increased thus indicating that a constant percentage second will be introduced as the input voltage is varied for any given combination of R and C.

It is to be noted that the second for R and C equal to two megohms and 2000 $\mu\mu$f, respectively, is about the same for the case of the diode that it is for the triode as shown by the full-line curve A in Fig. 5. It is also to be noted that the combination of one megohm and 2100 $\mu\mu$f, curve B, Fig. 7, is about the same as for the triode, curve A, Fig. 4. Curve B, Fig. 7, is for two combinations of the same X/R ratio. Curves C and D, Fig. 7, are for the same value of X/R although the curves have somewhat different values. Here again it is to be noted that curve E has a sufficient value of X/R to give good quality but the second rises considerably with input voltage. The same tendency appears also in curve D using 500,000 ohms.

Here again any estimates made on the maximum sizes of grid leak and condenser which may be used must be based on the characteristics of the audio amplifier. Curve B is too high for good quality. The reactance of a 2000-$\mu\mu$f condenser at 400 cycles corresponds to the reactance of a 200-$\mu\mu$f condenser at 4000 cycles so that if the audio-frequency amplifier passed 8000 cycles or more, either the value of R or C should be decreased from one megohm or 200 $\mu\mu$f, respectively. Curve C is satisfactory for a fundamental of 4000 cycles if the capacity shunting leak were 100 $\mu\mu$f. In general there will be considerable capacity to ground from the high side of the grid leak so that the value of R should not exceed 0.5 or 0.75 of a megohm and the capacity of C should not exceed 100 $\mu\mu$f.

Conclusions

1. The various theoretical methods of computing the input resistance of the grid leak and condenser in parallel with the combination in series with the input of a 227 tube give results reasonably close.

2. The experimentally determined distortion curves for a triode used as a grid circuit detector show the desirability of keeping the detector voltage within certain values; otherwise plate circuit overloading increases the distortion if the input voltage is made too great and square-law rectification increases it if the input voltage is made too small.

3. Although an equivalent generator and internal resistance may be derived for a diode or grid-cathode portion of a triode this equivalent internal resistance plays a very small part in discharging the grid condenser when the input voltage is above several volts. The grid leak resistance R should be used in calculating the X/R ratio.

4. Good results may be obtained using a resistor and condenser as the a-f impedance in either a diode or in the grid circuit of a triode provided the ratio X/R is not too great. The ratio of X/R may be slightly greater in the case of a triode than for a diode because less input voltage is used in the triode.

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CIRCUIT RELATIONS IN RADIATING SYSTEMS AND APPLICATIONS TO ANTENNA PROBLEMS*

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Summary—*Expressions for the self and mutual impedances within a radiating system are developed by the use of the generalized reciprocity theorem. These expressions are given in terms of the distributions of the electric field intensities along the radiators.*

A method for the determination of the field intensities is outlined. Formulas for the self and mutual impedances in several types of directional antennas are given.

Questions of practical interest in connection with arrays of half-wave dipoles, long parallel wires, and "V" type radiators are discussed. Different types of reflector systems are considered. Curves of the more important relations are shown.

The mathematical development is shown in an appendix.

IN THE design and the adjustment of antenna systems a knowledge of certain characteristics and relations is of great assistance. We should know the theoretical directivity, that is, the ratio of the intensity of radiation in a desired direction to the mean intensity in all directions. The contribution of each radiating element to the total radiated power and the interactions between elements are important. In a good system the ratio of heat losses to radiated power must be low.

The intensity of radiation in the desired direction is relatively easy to obtain. To determine the total power we may, for mathematical purposes, imagine the system placed at the center of a very large sphere and compute the power flow through each element of area on the sphere. A summation gives the total. The average intensity is then this total divided by the number of units of solid angle contained in the sphere. The application of this method to long linear radiators and several types of directional antenna systems has been shown by the writer in detail.[1] Upon completion of this process we have a complete knowledge of the power flow in every direction in space but are left in entire ignorance as to the portions of this power contributed by the various antenna elements and as to the interactions between these elements.

To the communications engineer, who is quite familiar with the use of impedance operators in connection with ordinary circuit calcula-

* Decimal classification: R116. Original manuscript received by the Institute, March 1, 1932. Presented before Twentieth Anniversary Convention of the Institute, Pittsburgh, Pa., April 9, 1932.

[1] Carter, Hansell, Lindenblad, "Development of directive transmitting antennas by R.C.A. Communications, Inc.," Proc. I.R.E., vol. 19, pp. 1773–1842; October, (1931).

tions, the question may arise "Why not determine the power at the circuit itself rather than at a great distance?" As a matter of fact, except for the distribution of the radiated power in space, we may determine everything we need to know at the wires. Indeed, we must work directly at the antenna system if we wish to determine what is happening in it.

In the following discussion an attempt is made to reduce problems in connection with radiation systems to such a form that they may be handled by the ordinary circuit methods of engineering and to show the results of certain applications of importance to directional antennas.

PART I—GENERAL PRINCIPLES

1. Circuit Laws and Reciprocity in Radiating Systems

Assume that, inside of a closed box, we have a circuit network consisting of inductances, capacities, and resistances (vacuum tubes, iron core inductances, and other nonlinear devices excluded) connected in an unknown manner but having two pairs of terminals, a and b, at opposite ends of the box. Now suppose we apply an a-c voltage at a and measure the current through an ammeter connected to terminals b. Then let us reverse the process, placing the ammeter at a and applying the voltage at b. The current is alike in both cases both in magnitude and phase angle. This is the reciprocity theorem for ordinary circuits. If we call the ratio between the voltage at a and current at b, Z_{ab} and the ratio under the reverse conditions, Z_{ba}, the reciprocity law then states that $Z_{ab}=Z_{ba}$. This impedance is generally known as the transfer impedance.

Carson[2] and Ballantine[3] have given proofs of a more generalized reciprocity theorem which holds without any restrictions in all cases to be considered in this discussion.

Consider a linear radiator as shown in Fig. 1. We know from experiment that, to a fair degree of approximation, the current is sinusoidally distributed. We wish to know what voltage we must impress at a current loop in order to produce a given current. Assume that we know the distribution of the parallel component of the electric force E_z along the radiator due to the sine wave distribution of current I_A sin mZ where $m=2\pi/\lambda$. Since the e.m.f. or voltage is the line integral of electric force, the voltage induced in an element dz due to the current

[2] Carson, "A generalization of the reciprocal theorem," *Bell Sys. Tech. Jour.*, July, (1924); "Reciprocal theorems in radio communication," Proc. I.R.E. June, (1929).

[3] Ballantine, "Reciprocity in electromagnetic and other systems," Proc. I.R.E., June, (1929).

I_A at the loop position A must be $E_z dz$. By the reciprocity law a current I_A in the element dz would induce a voltage $E_z dz$ at A. However, the actual current in the element dz is $I_A \sin mz$. Calling the voltage induced at A, dV, we then have the relation:

$$\frac{E_z dz}{I_A} = \frac{dV}{I_A \sin mz} \tag{1}$$

or,

$$dV = E_z \sin mz \, dz. \tag{2}$$

The total voltage at A, due to current in all elements of the wire, is then:

$$V = \int_0^l E_z \sin mz \, dz. \tag{3}$$

The impressed voltage must be equal and opposite to the induced e.m.f. Let us define the self-impedance of a radiator as the ratio be-

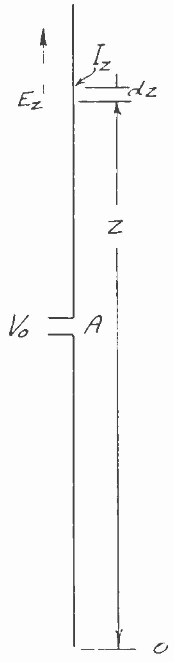

Fig. 1

tween the impressed voltage and current at a current loop position when this radiator is under no influence from other radiators. We then have the relation:

$$\dot{Z}_{11} = \frac{\dot{V}_1}{\dot{I}_1} = -\frac{\dot{V}_{11}}{\dot{I}_1} \tag{4}$$

where $\dot{Z}_{11}$ is the self-impedance of radiator No. 1 due to its own current. $\dot{V}_1$ is the impressed e.m.f., $\dot{V}_{11}$ the induced e.m.f., and $\dot{I}_1$ the loop current, the dots indicating that the phase must be taken care of by the standard complex algebra method of electrical engineering.

Assume that we have a second radiator No. 2 at any distance and oriented in any manner with respect to radiator No. 1. Assume we know the current in No. 1 and that this produces a known distribution of electric force along No. 2. Assuming that the current in wire No. 2 must be sine wave distributed, the effective induced e.m.f. at a current loop of wire No. 2 will then be:

$$V_{21} = \int_0^l E_{21} \sin mz \, dz. \tag{5}$$

Let us define the mutual impedance as the negative ratio of the induced e.m.f. at a current loop of radiator No. 2 to the loop current of radiator No. 1. Because of the reciprocity law this mutual impedance is the same in the reversed direction and we have the relation:

$$Z_{12} = Z_{21} = \frac{-V_{21}}{I_1}. \tag{6}$$

Provided we know the values of the self and mutual impedances we can now determine the relations in any system having n linear radiators and impressed voltages $V_1, V_2, \cdots, V_n$ at the current loops. The resulting relations are the same as for ordinary circuit networks, the difficulties in the way of the solution in the more complex cases being the same. The general relations then are:

$$\begin{aligned} V_1 &= I_1 Z_{11} + I_2 Z_{12} + \cdots + I_n Z_{1n} \\ V_2 &= I_1 Z_{12} + I_2 Z_{22} + \cdots + I_n Z_{2n} \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ &\cdots\cdots\cdots\cdots\cdots\cdots \\ V_n &= I_1 Z_{1n} + I_2 Z_{2n} + \cdots + I_n Z_{nn}. \end{aligned} \tag{7}$$

As an example, consider the case of two like radiators 1 and 2, where a voltage V_1 is impressed in radiator No. 1 only. We then have the relations:

$$\begin{aligned} V_1 &= I_1 Z_{11} + I_2 Z_{12} \\ 0 &= I_1 Z_{12} + I_2 Z_{22}. \end{aligned} \tag{8}$$

If no impedance is placed in series with either, $Z_{11} = Z_{22}$ and the relations giving the currents become:

$$I_1 = V_1 \frac{Z_{11}}{Z_{11}^2 - Z_{12}^2}, \qquad I_2 = -I_1 \frac{Z_{12}}{Z_{11}}. \tag{9}$$

If we disregard heat losses, the power radiated from the nth radiator in any system is $V_n I_n \cos \phi$, where ϕ is the phase angle, or $I^2 R$ where R is the real part of the complex impedance operator Z. In most cases in short-wave practice we are justified in neglecting heat losses within a radiator but in the feeding system they may be considerable.

Before we can apply the method outlined to any actual cases, we must know the impedances and, as already shown, the values of these impedances are determined by the field conditions in the vicinity of the radiators.

2. Field Conditions in the Vicinity of a Radiator

In the determination of the field conditions in the vicinity of a radiator, the writer has used an extension of the method outlined by Pistolkors.[4] During this work a paper by Bechman[5] appeared in which he gives an excellent method of determining the fields. At the conclusion of this work a second paper by Bechmann[6] was published. The latter covers a considerable part of the theory underlying the discussion to follow. Bechmann derives his electric and magnetic forces from a Hertz vector while the writer has used the scalar and vector potentials but, of course, both methods become identical in the results.

Faraday's law of induction and Maxwell's revised form of Ampere's law, which form the foundation of electromagnetic theory, are:

(a) The line integral of the electric force around any complete circuit is equal to the negative rate of change of magnetic induction through the circuit.

(b) The line integral of the magnetic force around any complete circuit is equal to the total current, conduction, and displacement, through the area bounded by the circuit.

The six partial differential equations known as "Maxwell's equations" are the differential form of these laws. We cannot directly determine the forces from these equations as they are in an implicit form. In the quasi-static, or low-frequency case, the magnetic force may be derived from a vector function called the vector potential. The reason for the name vector potential is that this vector is derived for a given current distribution in a manner similar to that used in deriving the scalar potential for a given charge distribution. To determine the electric force we need both the vector and scalar potentials.

[4] Pistolkors, "The radiation resistance of beam antennas," Proc. I.R.E., March, (1929).

[5] Bechmann, "Calculation of electric and magnetic field strengths of any oscillating straight conductors," Proc. I.R.E., March, (1931).

[6] Bechmann, "On the calculation of radiation resistance of beam antennas and antenna calculations," Proc. I.R.E., August, (1931).

In free space Maxwell's laws result in the "wave equation." Hence, at a distance r from the source, the electric and magnetic field intensity vectors E and H must be functions of $(t-r/c)$, c being the velocity of light, in addition to satisfying the particular conditions at the source. $(t-r/c)$ is commonly called the retarded time. It is the time at which a disturbance, reaching the distance r at the time t, originated at the source. The method of deriving the electric and magnetic intensities mentioned above can be generalized so as to hold for all frequencies if the retarded time is used in forming the potentials. Potentials formed in this manner are known as "retarded potentials."

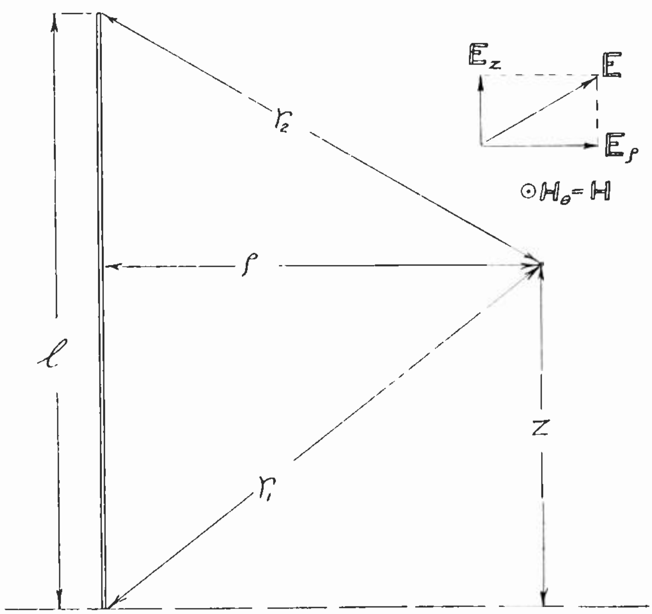

Fig. 2

For wires an integral number of half waves long the process described gives us the formulas shown below. These give H and the perpendicular and parallel components of E in terms of the cylindrical coördinates as shown in Fig. 2. The power and quadrature terms are given by the real and imaginary parts of these expressions after expanding the exponentials. The derivation is shown in Appendix I.

$$E_z = +j30I\left[\frac{\epsilon^{-jmr_2}}{r_2}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\right] \text{ volts per cm.} \quad (10)$$

$$E_\rho = -j30I\left[\frac{\epsilon^{-jmr_2}}{r_2}\,\frac{(z-l)}{\rho}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\,\frac{z}{\rho}\right] \text{ volts per cm.} \quad (11)$$

$$H_\theta = +j\frac{I}{10}\left[\frac{\epsilon^{-jmr_2}}{\rho}(-1)^n - \frac{\epsilon^{-jmr_1}}{\rho}\right] \text{ Gauss} \quad (12)$$

where I is the current in amperes, $m=2\pi/\lambda$, $r_2=\sqrt{\rho^2+(l-z)^2}$, $r_1=\sqrt{\rho^2+z^2}$, n = the number of half waves on the wire, and $\epsilon^{-jmr}=\cos mr - j \sin mr$.

From these relations we may determine the self and mutual impedances for the several conditions of interest which we wish to investigate. From the definitions of impedance given we have as general relations for the self and mutual impedances of any linear radiators whose lengths are multiples of a half wavelength:

$$Z_{11} = \frac{-1}{I_1}\int_0^l E_{11} \sin mz \, dz \tag{13}$$

$$Z_{12} = \frac{-1}{I_1}\int_0^l E_{12} \sin mz \, dz \tag{14}$$

where E_{11} is the component of the electric intensity parallel to radiator No. 1 due to the current I_1 in No. 1 and E_{12} is the component of the electric intensity parallel to radiator No. 2 due to the current I_1 in No. 1.

The conditions of interest and the corresponding impedance formulas are as follows. The derivation is shown in Appendix II.

(*a*) *Self-Impedance of a Linear Radiator*

$$Z_{11} = 30[\tau + \log_\epsilon 2ml - Ci2ml + jSi2ml] \text{ ohms} \tag{15}$$

where,

$$m = \frac{2\pi}{\lambda}, \quad Ci(u) = \int_\infty^u \frac{\cos x}{x} dx, \quad Si(u) = \int_0^u \frac{\sin x}{x} dx$$

$$\tau = \text{Euler's constant} = 0.5772 \cdots.$$

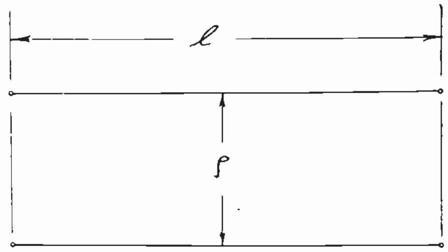

Fig. 3

Tables of the sine integral and cosine integral functions Si (u) and Ci (u) are given in Steinmetz' "Transient Electric Phenomena and Oscillations" and in Jahnke and Emde "Funktionentafeln mit Formeln und Kurven."

(*b*) *Parallel Wires of Equal Length* (*Not Staggered*) (*See Fig. 3.*)

$$Z_{21} = +30\{2Ei(-jm\rho) - Ei[-jm(\sqrt{\rho^2+l^2}+l)]$$
$$- Ei[-jm(\sqrt{\rho^2+l^2}-l)]\} \text{ ohms} \qquad (16)$$

where,
$$Ei(-jx) = Ci(x) - jSi(x).$$

(c) *Parallel Wires in Echelon (Fig. 4)*

$$Z_{21} = -15\cos mh[-2\,Ci\bar{\bar{h}} - 2\,Ci\overline{\overline{-h}} + Ci\overline{\overline{h-l}} + Ci\overline{\overline{-(h-l)}}$$
$$+ Ci\overline{\overline{h+l}} + Ci\overline{\overline{-(h+l)}}] + 15\sin mh\,[2\,Si\bar{\bar{h}} - 2\,Si\overline{\overline{-h}}$$
$$- Si\overline{\overline{h-l}} + Si\overline{\overline{-(h-l)}} - Si\overline{\overline{h+l}} + Ci\overline{\overline{-(h+l)}}]$$
$$- j15\cos mh[2Si\bar{\bar{h}} + 2Si\overline{\overline{-h}} - Si\overline{\overline{h-l}} - Si\overline{\overline{-(h-l)}}$$
$$- Si\overline{\overline{h+l}} - Si\overline{\overline{-(h+l)}}] + j15\sin mh[2Ci\bar{\bar{h}} - 2Ci\overline{\overline{-h}} \qquad (17)$$
$$- Ci\overline{\overline{h-l}} + Ci\overline{\overline{-(h-l)}} - Ci\overline{\overline{h+l}} + Ci\overline{\overline{-(h+l)}}] \text{ ohms.}$$

where,

$$\bar{\bar{h}} = m(\sqrt{\rho^2+h^2}+h), \quad \overline{\overline{-(h-l)}} = m[\sqrt{\rho^2+(h-l)^2} - (h-l)], \text{etc.}$$

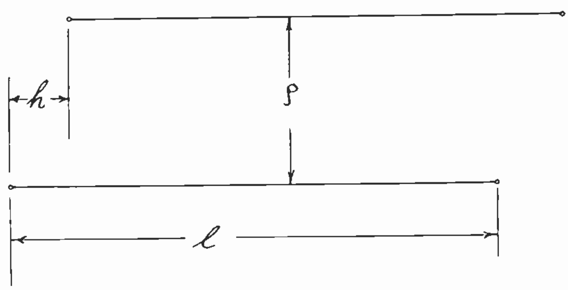

Fig. 4

(d) *Colinear Wires (Fig. 5)*

This is a special case of (c) in which ρ = zero where the formula fails due to giving rise to the indeterminate form $\infty - \infty$. However, by taking the limit as ρ approaches zero,

$$Z_{12} = -15\cos mh\left[-2Ci(2mh) + Ci(2m(h-l)) + Ci(2m(h+l))\right.$$
$$\left.- \log_\epsilon\left(\frac{h^2-l^2}{h^2}\right)\right] + 15\sin mh\left[2Si(2mh) - Si(2m(h-l))\right.$$
$$\left.- Si(2m(h+l)) - \right] j15\cos mh\left[2Si(2mh) - Si(2m(h-l))\right.$$
$$\left.- Si(2m(h+l))\right] + j15\sin mh\left[2Ci(2mh) - Ci(2m(h-l))\right.$$
$$\left.- Ci(2m(h+l)) - \log_\epsilon\left(\frac{h^2-l^2}{h^2}\right)\right] \text{ohms} \qquad (18)$$

when, $h > l$.

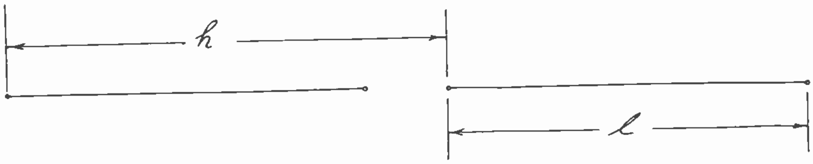

Fig. 5

(e) Two Wires Forming a "V" (Fig. 6)

In this case the electric intensity along the second wire, due to the current in the first, depends upon both the parallel and perpendicular components with reference to the first wire. This is given by:

$$E_s = j30I \frac{l}{s} \frac{\epsilon^{-jmr_2}}{r_2}(-1)^n \text{ volts per cm} \tag{19}$$

where,

$$r_2 = \sqrt{l^2 + s^2 - 2ls \cos \theta}$$

and s is the distance along the second wire as shown in the figure. The mutual impedance is:

$$Z_{21} = -30(-1)^n l \left[\int_0^l \frac{\sin mr_2}{r_2} \frac{\sin ms}{s} ds + j \int_0^l \frac{\cos mr_2}{r_2} \frac{\sin ms}{s} ds \right] \text{ ohms.} \tag{20}$$

The integrals in this equation cannot be expressed in the form of any known tabulated functions and therefore are best evaluated mechanically in each particular case.

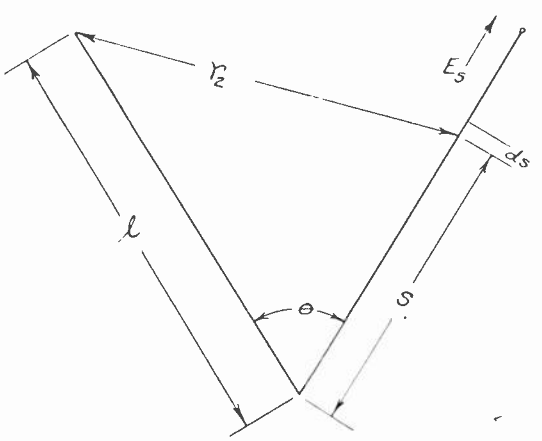

Fig. 6

PART II—APPLICATIONS

1. Field Conditions Near Radiators

It is not possible to build a model which will accurately show the field conditions near a radiator. If two forces, both of which are sinusoidal functions of time and which differ both in direction and in time phase are combined, the terminus of the vector representing the resultant force will describe an ellipse during a cycle. This is the condition which generally exists in the vicinity of a radiator with respect to the field forces. In general, the parallel and perpendicular components of the electric field intensity differ in time phase. Such a condition makes it quite difficult to get a clear physical picture of the phenomena existing.

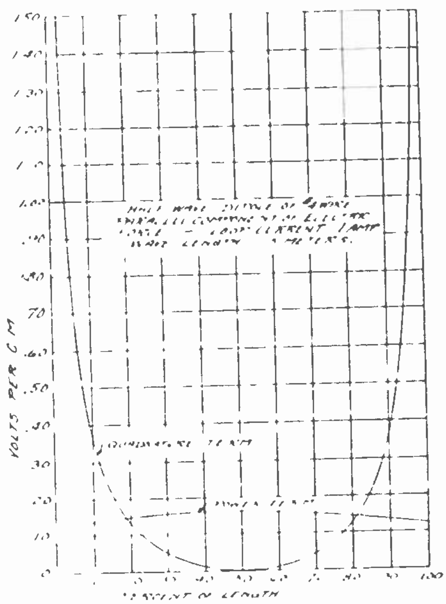

Fig. 7

At positions of interest we might plot the ellipses of polarization but to connect these pictures properly is a laborious procedure. However, in the case of a single linear radiator we may take any line in space parallel to the radiator, and plot curves of the power and quadrature terms of both the parallel and perpendicular components of the electric force along this line. A collection of such pictures gives us all the information necessary in a study of radiation phenomena.

In Fig. 7 are shown curves of the power and quadrature terms of the parallel component of the electric force along a half-wave dipole of No. 4 wire for a wavelength of 15 meters, while in Fig. 8 are shown curves of the quadrature terms in both the parallel and perpendicular components of the electric force. The only forces which can do any work on the conductor current are the parallel components. The average work per cycle done by the quadrature term is, of course, zero. Since we have assumed the wire to have no ordinary resistance, the work done by the power term represents energy radiated.

It will be noted that the curve of the reactive term in the parallel electric intensity rises to infinity at the wire ends. In practice, this cannot be true. This result is due to the assumption of a filamentary wire

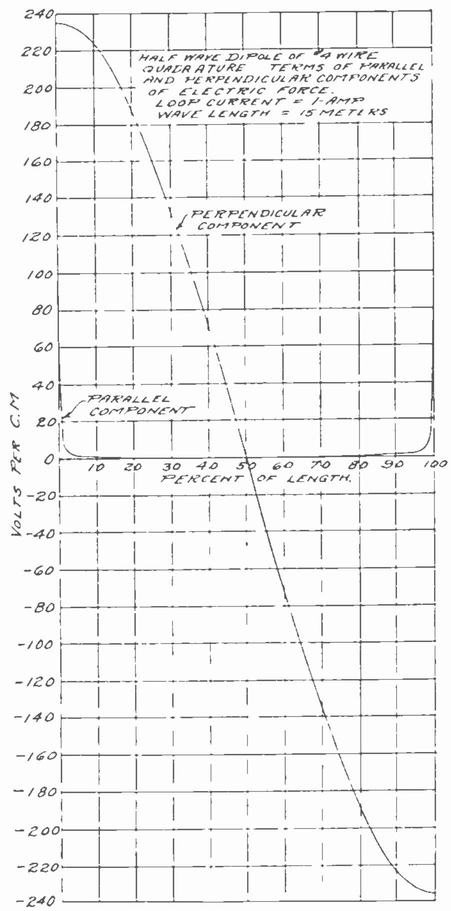

Fig. 8

having no end effects. In practice, the length of such a radiator is about 6 per cent less than a half wavelength, the insulator cap capacity being equivalent to the remaining length, necessary to complete the tuning. Thus in the practical case it is seen from the curves that the maximum electric force parallel to the wire is only about 0.28 per cent of that in the perpendicular direction.

It may be of practical interest to note the value of maximum electric force to be expected with 50 kw in a half-wave dipole at a wavelength of, say, 15 meters. From the curve it is seen that the maximum electric force is 236 volts per centimeter for a current of 1 ampere. At 50 kw the current would be $\sqrt{50,000/73.2}=26.2$ amperes. This will

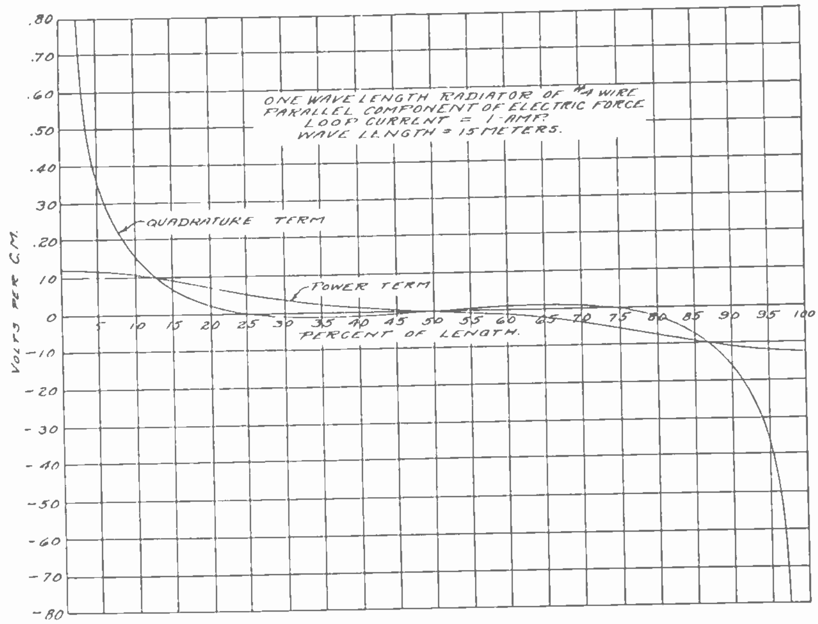

Fig. 9

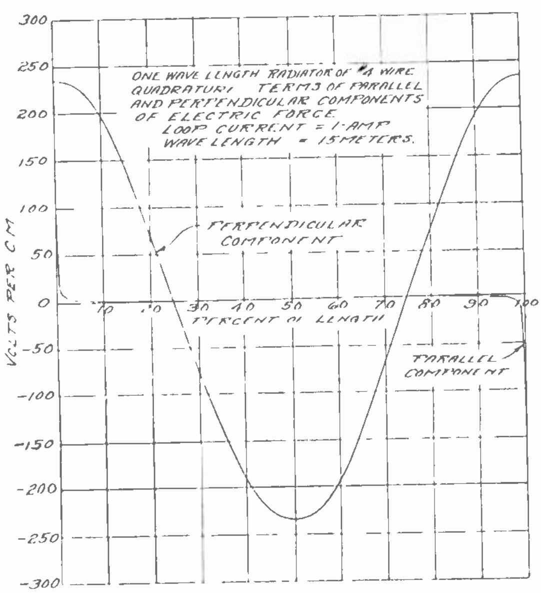

Fig. 10

result in a force of 6200 volts per centimeter or 15,700 volts per inch.

In Figs. 9 and 10 are shown similar curves for a radiator one wave long. It will be noted that the power term of the parallel component of the electric force is greatest towards the ends of the wire. For wires several wavelengths long the resulting curves would be very similar to these for the one-wave wire and therefore have not been shown.

2. Half-Wave Radiators

From (16) we obtain for the self-impedance of a half-wave radiator:

$$Z_{11} = 73.2 + j42.5 = 84.5 \underline{/+30.15°} \text{ ohms.}$$

Thus, at the current antinode the radiator is the equivalent of a resistance of 73.2 ohms (the radiation resistance) and an inductive re-

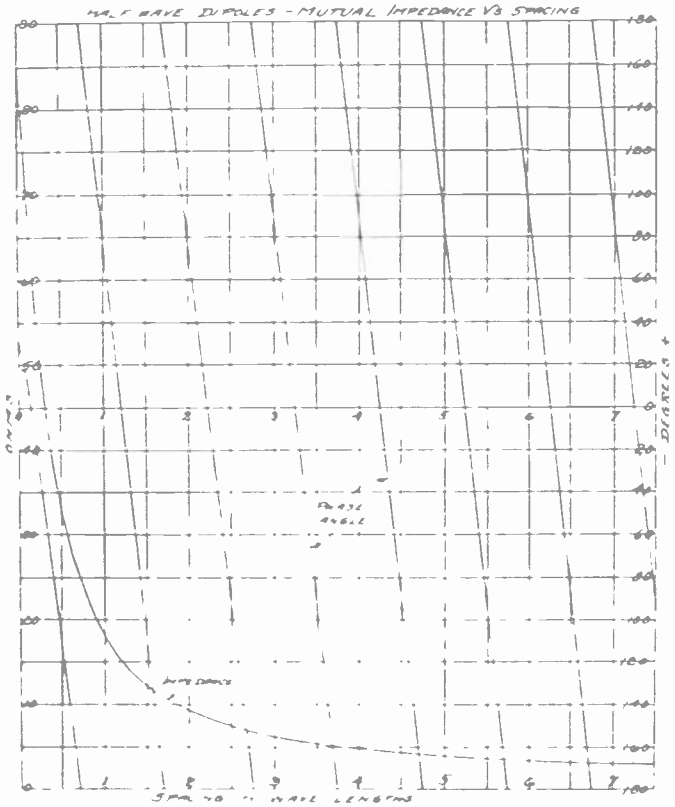

Fig. 11

actance of 42.5 ohms. This result indicates the necessity of decreasing the length a little in order to obtain a nonreactive load.

The curves in Figs. 11 and 12 show the manner in which the mutual impedance and its phase angle vary with the spacing of two parallel half-wave dipoles when the ends remain upon a common perpendicular line.

In the past there has been considerable controversy as to the best spacing for a free reflecting half-wave dipole from its antenna. By making use of the curves of mutual impedance we may answer this question. For zero radiation directly backwards the currents must be of equal amplitude and in quarter-phase relation and the spacing exactly equal to an odd multiple of a quarter wavelength. It is evident that such a condition is impossible to obtain when a free reflector is used. For best addition of the wave amplitudes in the forward direction the phase angle between the currents should be equal to $2\pi S/\lambda$ where S is the spacing. In Fig. 13 are shown curves of current and of actual and

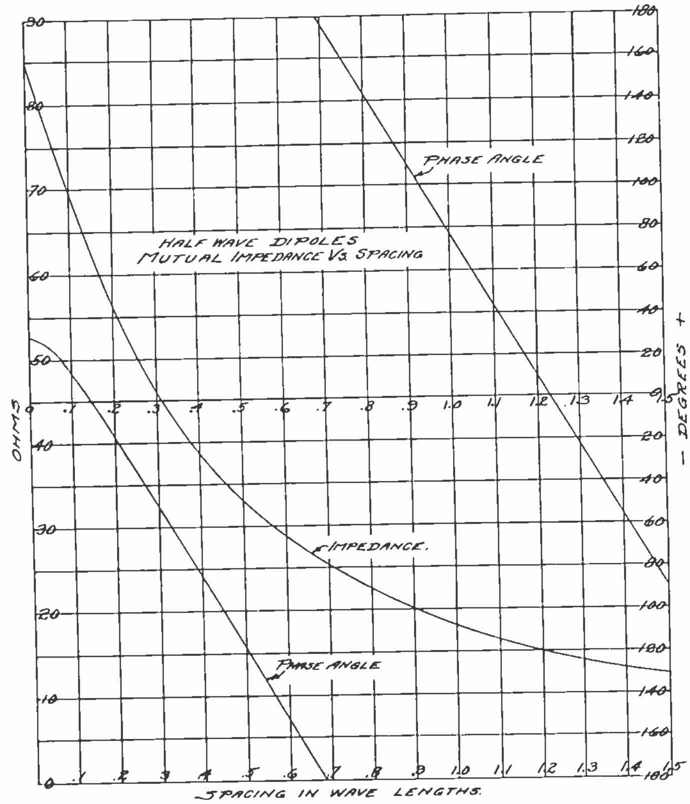

Fig. 12

desired phase angles as a function of the spacing. It is seen that the phase angle curves cross at about 0.29-wavelength spacing but that the current is rapidly decreasing. At a quarter-wave spacing the phase angle is incorrect by about 28 degrees. This may be made zero by a slight change in the reflector tuning with little effect upon the current amplitude. Consequently, to the writer, there appears to be little basis to the arguments for the use of other spacings. With R.C.A. Communications it has not been the practice to use free reflecting systems. When a reflector is fed by a transmission line it is no more a reflector in the strict sense of the word and the problem is quite different. This condition will be discussed later.

Consider the question "What is the best spacing for two parallel half-wave dipoles?" If the currents are held equal and constant as the spacing is varied, the intensity of radiation perpendicular to the array will remain constant, but, due to the variation in the mutual impedance, the total power will vary. It is apparent that at zero spacing the directivity is the same as for one radiator alone. At a very great spacing the mutual impedance is negligible and the power just twice that for one wire. At a great distance perpendicular to the array the electric

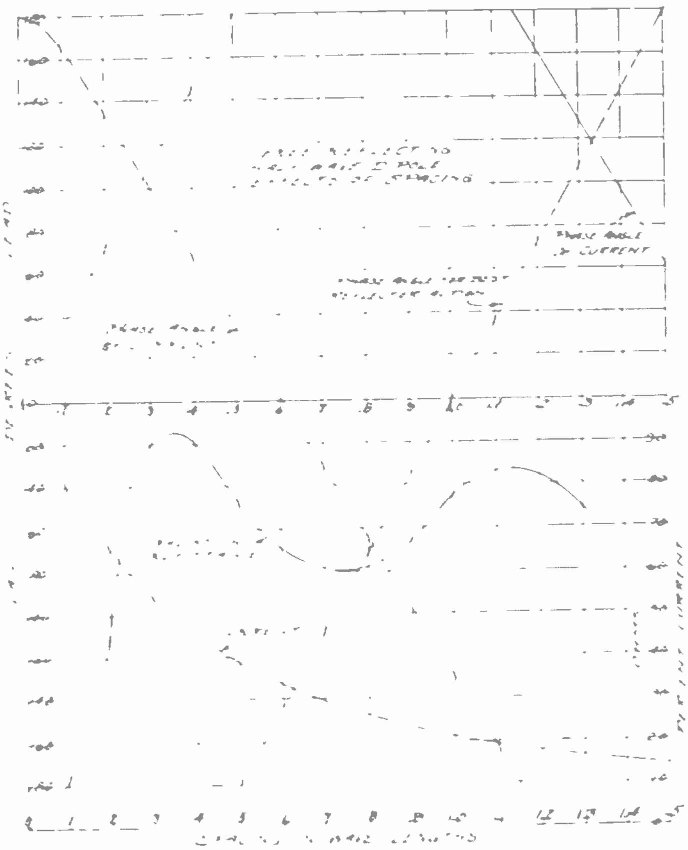

Fig. 13

intensity is doubled, thus quadrupling the intensity of radiation. The directivity is then exactly twice that for a single wire.

For a finite spacing the power in either wire is:

$$W = I_1^2 R_{11} + I_1^2 R_{12} \text{ where } R_{11} = Z_{11}\cos\varphi_{11} \text{ and } R_{12} = Z_{12}\cos\varphi_{12}.$$

The total power is $2W$. For one ampere in each dipole the total power is then $2(R_{11}+R_{12})$. The directivity is proportional to $1/W$. Fig. 14 shows the relative gain as the spacing is varied. The same reasoning may be extended to include any number of radiators. Fig. 15 is a similar curve for three radiators.

In treating radiation phenomena the assumption of a perfectly conducting ground is usually far from justified. A curve of radiation

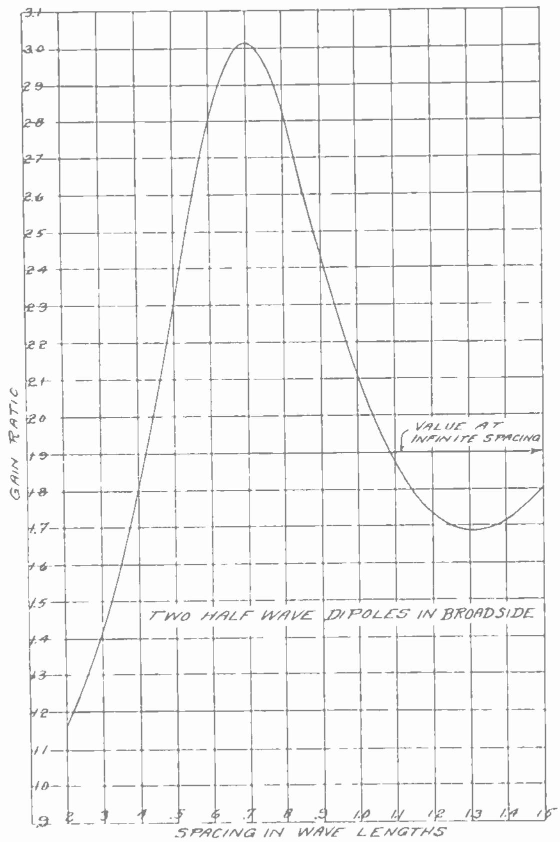

Fig. 14

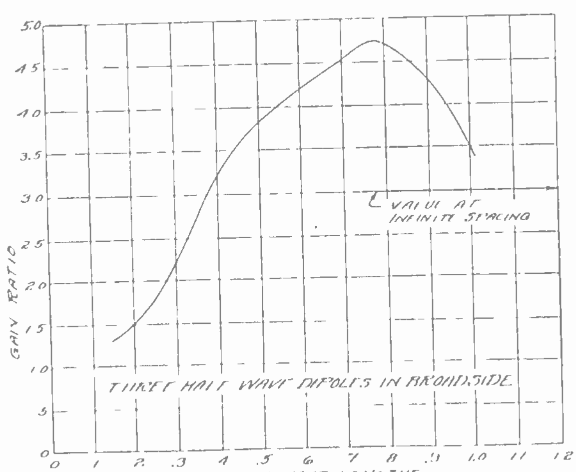

Fig. 15

resistance for a horizontal dipole above an ideal ground is shown in Fig. 16. This should, in this case, give a fair idea in a qualitative way,

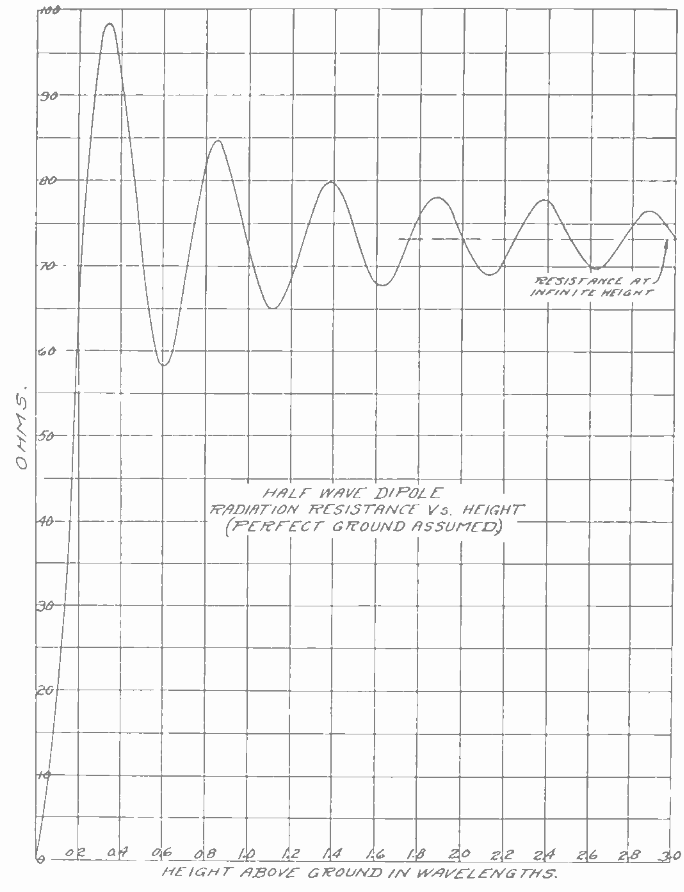
HALF WAVE DIPOLE
RADIATION RESISTANCE Vs. HEIGHT
(PERFECT GROUND ASSUMED)
RESISTANCE AT INFINITE HEIGHT
OHMS.
HEIGHT ABOVE GROUND IN WAVELENGTHS.

Fig. 16

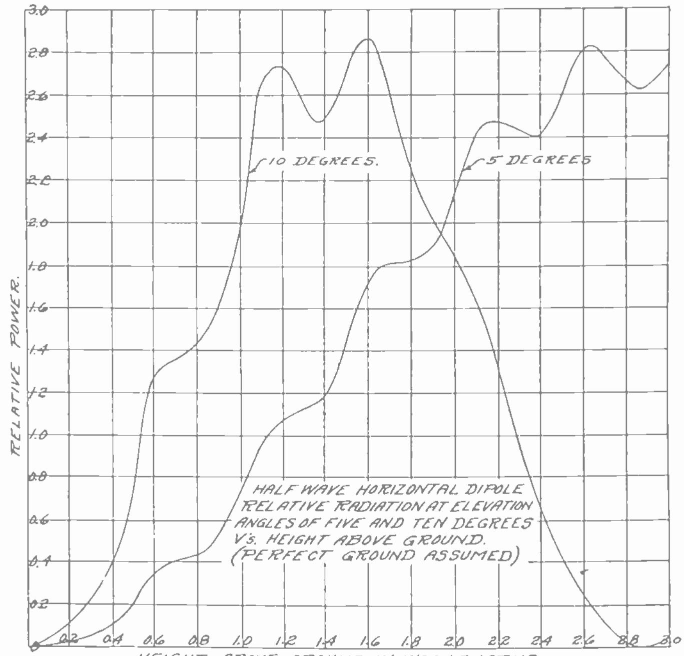
10 DEGREES.
5 DEGREES
HALF WAVE HORIZONTAL DIPOLE
RELATIVE RADIATION AT ELEVATION
ANGLES OF FIVE AND TEN DEGREES
Vs. HEIGHT ABOVE GROUND.
(PERFECT GROUND ASSUMED)
RELATIVE POWER.
HEIGHT ABOVE GROUND IN WAVELENGTHS

Fig. 17

of the variation with height over an actual ground. In practice, if we add a few feet to the actual height, the results will approach those for the ideal case even though such a procedure has little theoretical justification.

In Fig. 17 are shown curves of relative radiation per unit power input at elevation angles of 5 and 10 degrees for a horizontal dipole as the height is changed. Experience indicates the radiation most effective at a distant receiver to be that which leaves the transmitting antenna at angles in the vicinity of 10 degrees. If such is the case, a horizontal dipole should be placed at a height of between one and two wavelengths.

The most common simple type of radiator is a half-wave dipole connected to a transmission line in the manner shown in Fig. 18. The

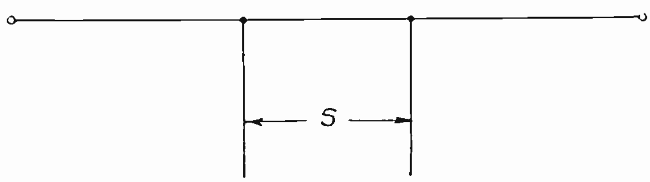

Fig. 18

length of the dipole and the spacing of the connections are then adjusted so that the characteristic impedance of the transmission line is matched. Such an arrangement is approximately equivalent to the sketch of Fig. 19 as the larger portion of the radiated power is contributed by the outer ends of the dipole. The effective characteristic impedance of the dipole is assumed equal to that of its feed line. The equivalent resistance load is then made equal to the ratio m of the char-

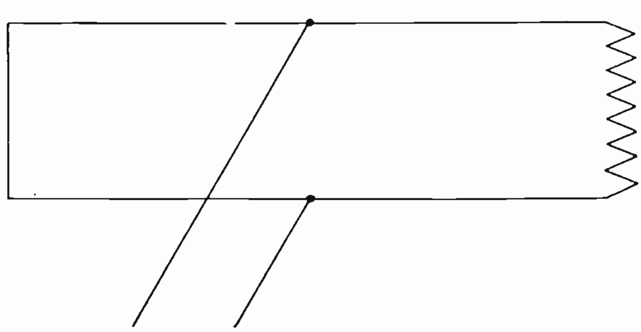

Fig. 19

acteristic impedance squared to the radiation resistance. It can be shown from transmission line theory that, in order to match the equivalent resistance of such a system to the characteristic impedance of the feed line, the total length of wire in the short-circuited line branch must be equal to $\lambda/2\pi \tan^{-1} (\sqrt{m}/(m-1))$ meters.

Fig. 20 shows the manner in which the distance between feed-line terminals varies with height for a horizontal dipole over perfectly conducting ground. Under actual conditions the variation follows a quite

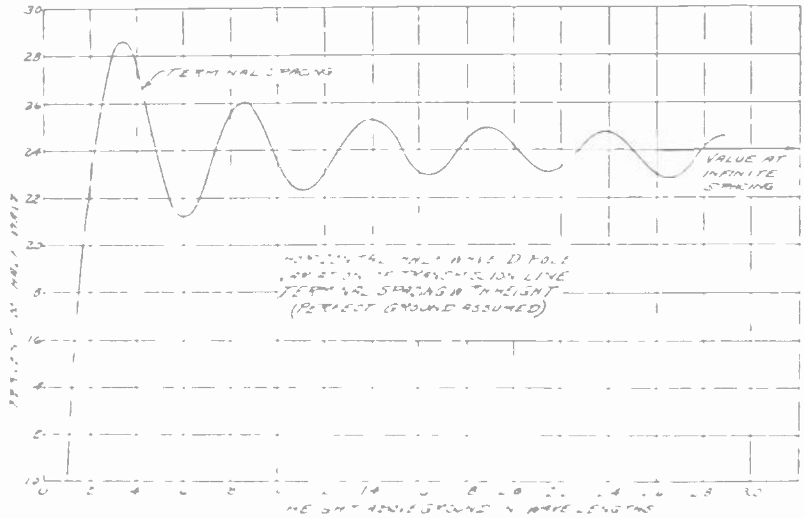

Fig. 20

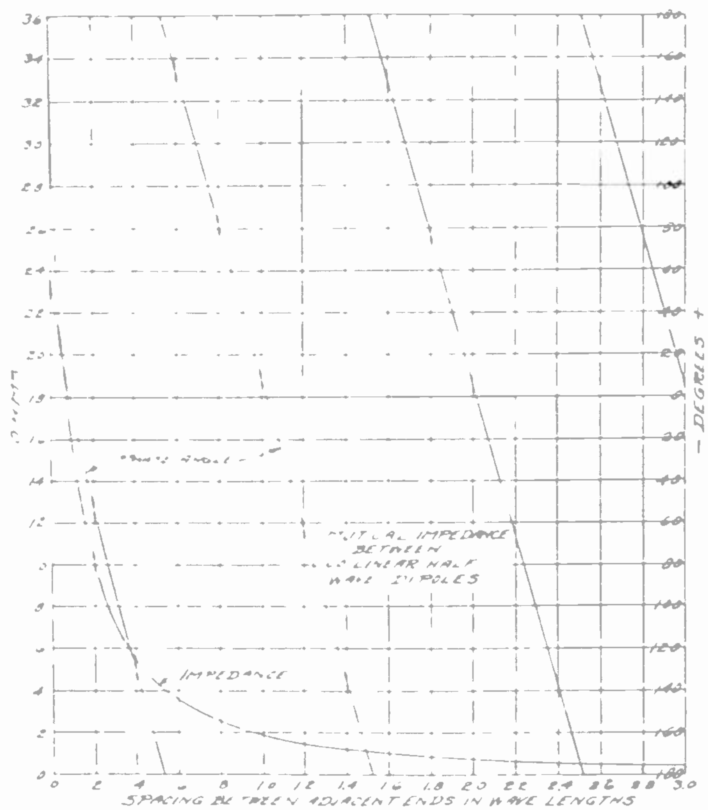

Fig. 21

similar curve. The total theoretical length also varies with height in a similar manner, but in practice the actual length is less than the theoretical by an amount depending upon the type of insulator and size wire and must be determined by trial for each condition.

In order to make the most economical use of supporting structures, it is often desirable in practice to arrange several horizontal dipoles end to end in the same span. Some of these are often operated at frequencies differing by less than one per cent. This raises the question as to what minimum spacing should be allowed when two dipoles in such an arrangement are operated with small frequency differences. The curve in Fig. 21 shows the variation in mutual impedance with spacing for two colinear dipoles. To obtain the per cent coupling the values given must be divided by 84.5.

There are many more conditions in connection with arrays of half-wave dipoles which might be investigated by means of the methods under discussion but, due to the recent developments in directional antennas which we have made, arrays of half-wave dipoles have become of minor importance in R.C.A. Communications.

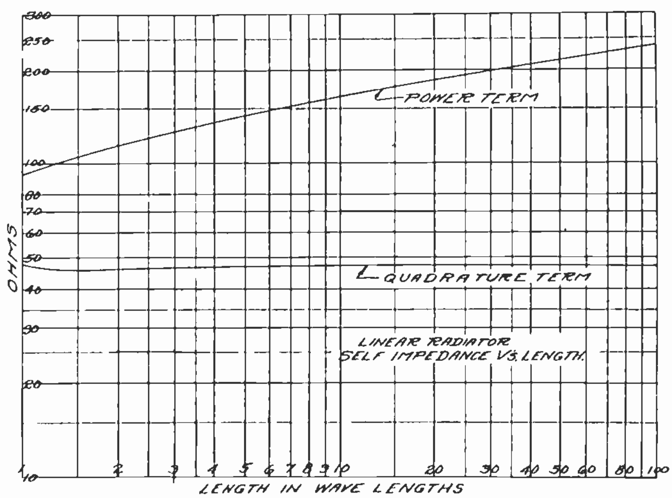

Fig. 22

3. Long Parallel Wires (Not Staggered)

From (15) we may compute the self-impedance for a wire having a length equal to any integral number of half wavelengths. Fig. 22 is a curve of impedance versus length. The values shown are correct only for multiple half wavelengths. The power term of the impedance is identical with the value of radiation resistance as shown in the I.R.E. paper already referred to, when computed by the Poynting's vector method. Curves of the power term in the mutual impedance for wires

4, 8, and 16 waves long, plotted as a function of the spacing, are shown in Fig. 23. By the same method as was used in connection with half-wave dipoles we may determine the relative directivity for two or more long wires in broadside as the spacing is varied. In Fig. 24 are shown

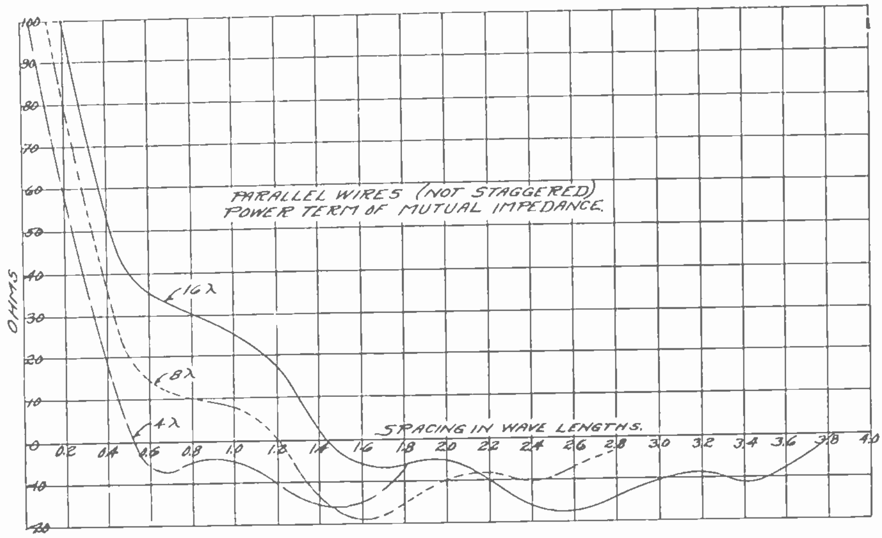

Fig. 23

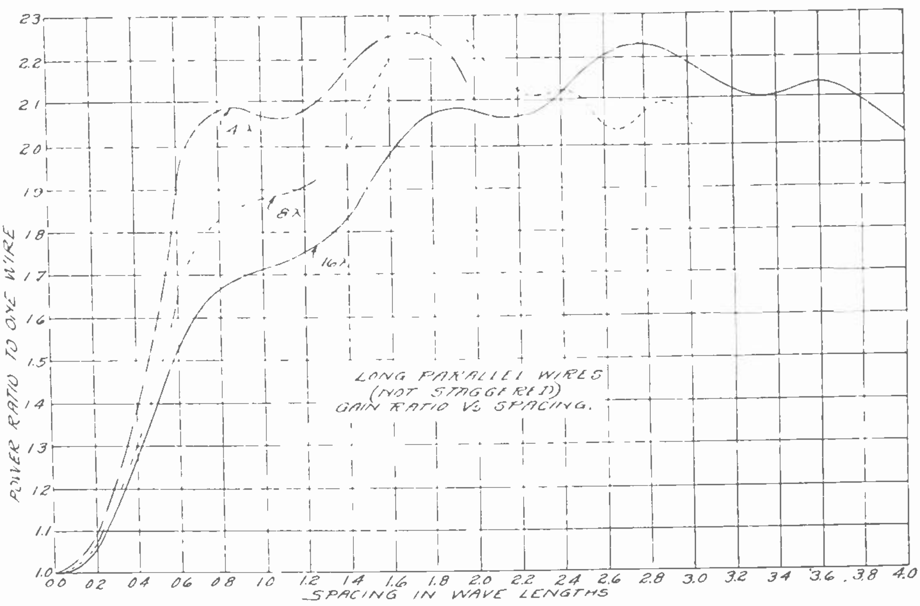

Fig. 24

curves for a pair of wires 4, 8, and 16 waves long. The 8-wave curve is of particular interest in connection with the broadsiding of two sections of the R.C.A. Type B antenna, often spoken of as the vertical harmonic wire antenna. It will be noted that the optimum spacing is

$1\frac{3}{4}$ wavelengths. This also was the result obtained experimentally by Lindenblad for two bays each without a reflector. Analysis by the Poynting vector method, subject to more or less error because of the large number of curves plotted, resulted in an optimum value of 2 wavelengths for 2 bays complete with reflectors. It is apparent that the spacing should be a little greater for a system with reflectors than without. Therefore, we can state with certainty that the spacing should lie within the range of $1\frac{3}{4}$ to 2 wavelengths.

4. Long Parallel Wires in Echelon

From (17) we may calculate the transfer impedance between two wires of any length in echelon. As this expression is rather tedious to evaluate, we shall here treat only one case, the calculation of the theoretical directivity for the Model B harmonic wire antenna, as a check upon the conclusions from the Poynting vector method of analysis. In a commercial model the dimensions are: length = 8 wavelengths, spacing $(\rho) = 0.416\lambda$, stagger (or echelon distance) $= 0.1311\lambda$.

Since the current in each succeeding wire leads that in the preceding by 90 degrees, the total impressed voltage in No. 1 wire for a current of 1 ampere in each wire must be:

$$V_1 = Z_{11} + jZ_{12} + j^2Z_{13} + j^3Z_{14} = Z_{11} + jZ_{12} - Z_{13} - jZ_{14}.$$

Since $Z_{ab} = R_{ab} + jX_{ab}$, the power term of V_1, or the power for one ampere, in No. 1 wire becomes:

$$W_1 = R_{11} - X_{12} - R_{13} + X_{14}.$$

In a similar manner we obtain for the power in the other three wires:

$$W_2 = R_{22} + X_{21} - X_{23} - R_{24}$$

$$W_3 = R_{33} - R_{31} + X_{32} - X_{34}$$

$$W_4 = R_{44} + X_{43} - R_{42} - X_{41}.$$

Each of the R's in the above relation are equal to one of the four values, R_{11}, R_{12}, R_{13}, R_{14}. A similar relation is also true for the X's. Upon substitution of these equivalent values and addition of the W's, we obtain for the total power: $W = 4R_{11} - 4R_{13}$. Having previously calculated R_{11} we have remaining only R_{13} to determine. From (17) we get $R_{13} = -11.48$ ohms. Therefore, $W = 4 \times 167.1 = 668.4$ watts per ampere.

For one ampere in each wire the radiation in the direction of maximum is increased 16 times over that for one ampere in one wire alone. The power for one wire alone is 155.6 watts per ampere. Therefore, the gain ratio is $16 \times 155.6/668.4 = 3.71$. The gain ratio for one wire to a half-wave dipole is 4.42. Hence, the ratio for the one-bay harmonic wire antenna to the half-wave dipole is $4.42 \times 3.71 = 16.4$.

The above result is nearly the same as that obtained by the Poynting vector method as well as by actual tests.

5. V-Wire Radiators

In the Model D antenna the radiating unit is a wire in the shape of a V. Several lengths have been used but we shall first consider a unit having sides 8 waves in length. The self-impedance of one side of a V, as obtained from (20), is $155.6+j\,46.9$ ohms. For the mutual impedance we get from (20), after changing the variable from S to ms

$$Z_{12} = -30 \cdot ml \left[\int_0^{16\pi} \frac{\sin mr_2}{mr_2} \cdot \frac{\sin ms}{ms}\, d(ms) + j \int_0^{16\pi} \frac{\cos mr_2}{mr_2} \cdot \frac{\sin ms}{ms}\, d(ms) \right] \text{Ohms} \tag{22}$$

where,

$$mr_2 = \sqrt{(16\pi)^2 + (ms)^2 - 32\pi ms \cos \theta}.$$

By graphical evaluation of the above expression we obtain $Z_{12} = 37.2 - j\,48.3$ ohms.

Since the current in the second wire is in phase opposition to that in the first, the total effective impedance of one side of the V is 155.6

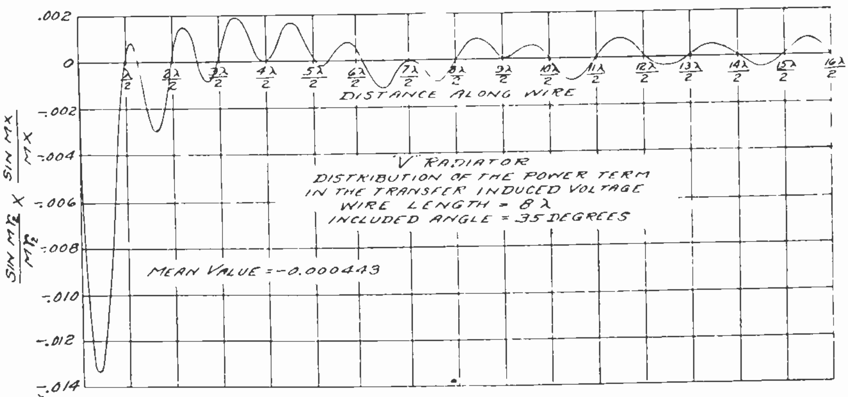

Fig. 25

$+j\,46.9 - (37.2 - j\,48.3) = 108.4 + j\,95.2$ ohms. In the determination of the mutual impedance, curves of the integrands were plotted to a large scale. In addition to knowing the total effect of one wire of a V upon the other it is of value to know just how this effect is distributed

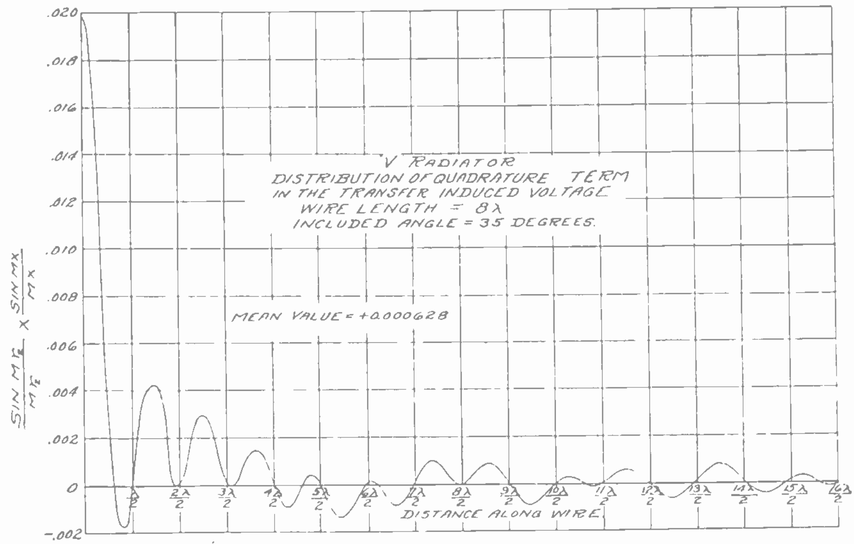

Fig. 26

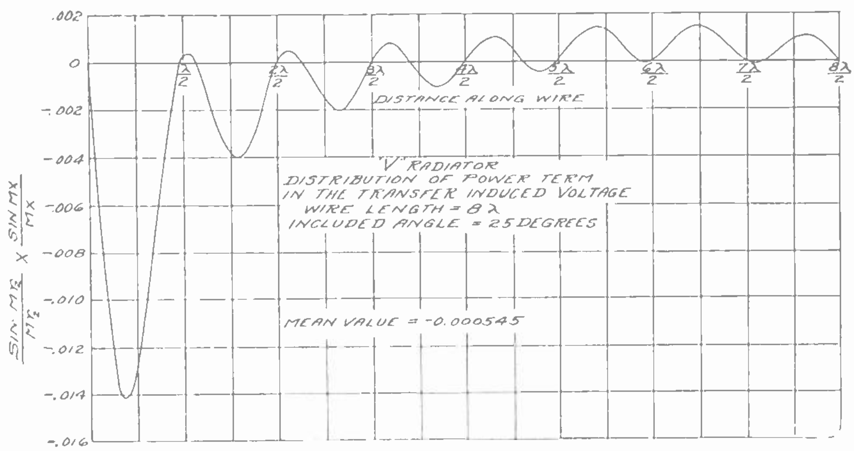

Fig. 27

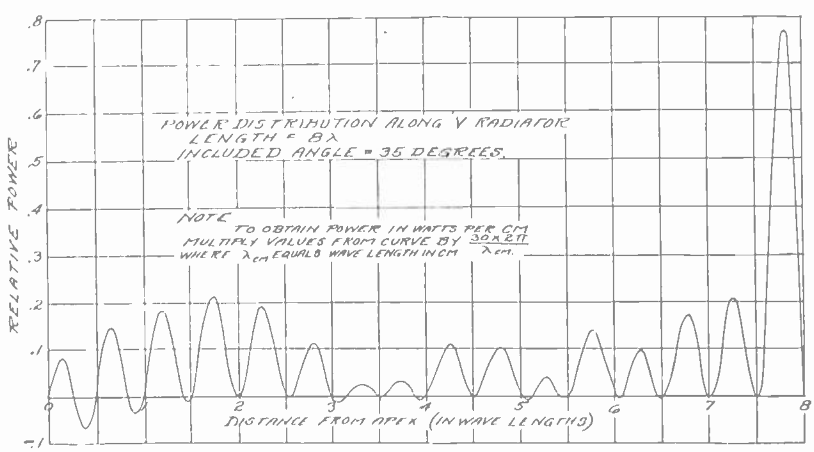

Fig. 28

along the wire. For this reason, rough copies, drawn to a small scale, of these curves are shown in Figs. 25 and 26.

The effect of decrease in the included angle of the V to 25 degrees is shown in Fig. 27.

In certain cases we wish to know not only the total power radiated from a V unit but also the contribution of each element of the wire to this total power. The total power radiated from an element is deter-

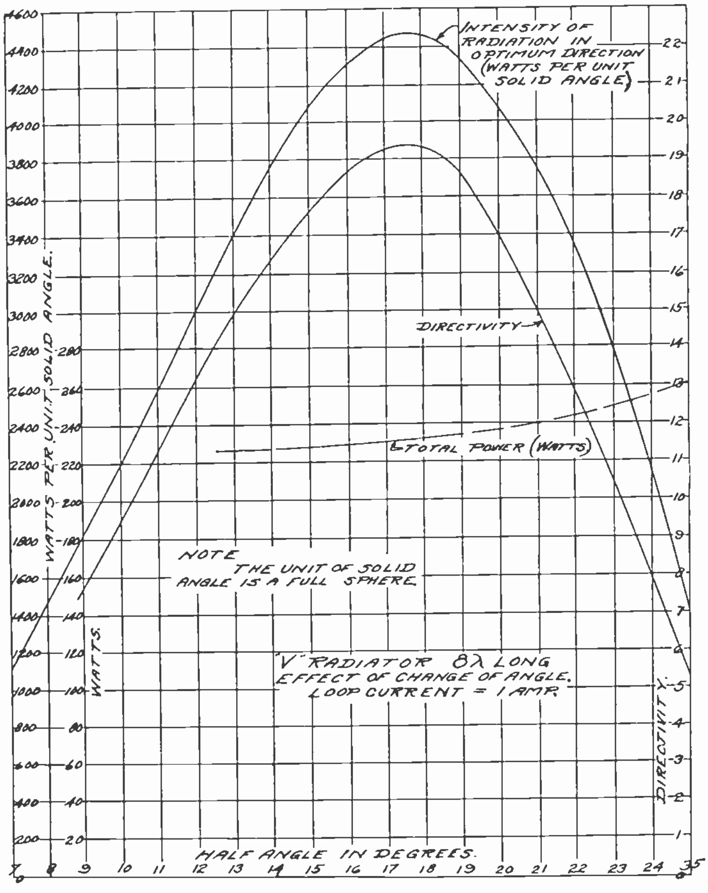

Fig. 29

mined by the sum of the self-induced and mutual electric forces. A curve showing the relative power distribution along an 8-wave, 35-degree V is shown in Fig. 28. Although each element of the wire takes part in determining the directional distribution of radiation, its contribution to the power may, in some cases, even be negative. It will be noted from the curve that the larger portion of the power is contributed by the elements toward the diverging ends of the V.

It was shown in the I.R.E. paper previously referred to that, if the current is held constant, maximum radiation along the bisector of an

8-wave V takes place when the included angle is 35 degrees. However, it does not necessarily follow that this angle results in the maximum directivity as the directivity depends upon the ratio of the intensity of radiation along the bisector to the total power radiated. In general, constant currents do not represent a constant total power when the conditions in a radiating system are changed. An investigation of the

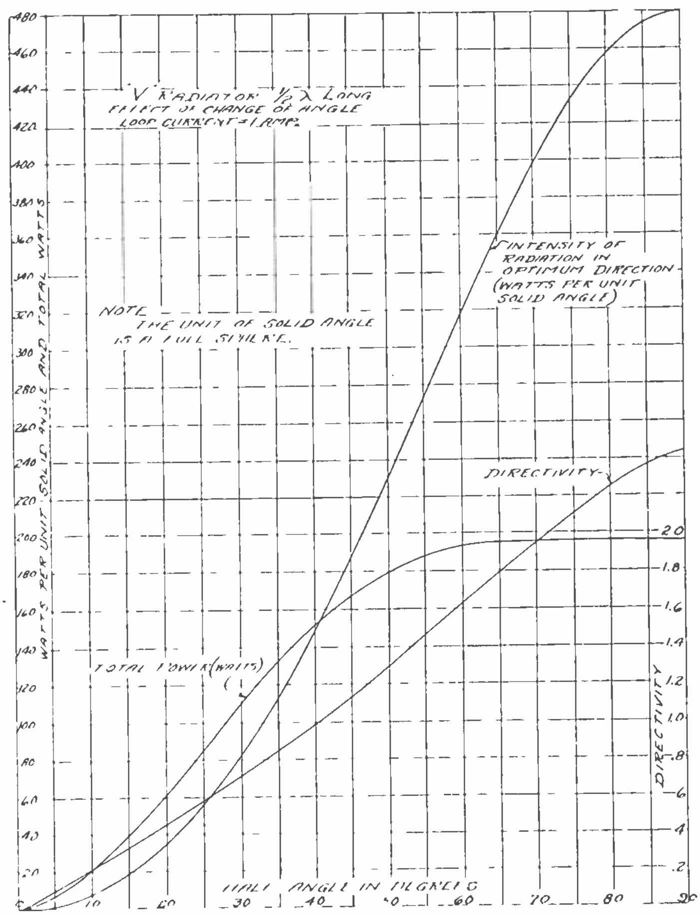

Fig. 30

effect of angle upon directivity was therefore made in connection with V wires of several different lengths.

The total power radiated is, in each case, I^2R, where R is the power term in the total impedance of the V. The power per unit solid angle radiated along the bisector can be obtained by the method shown in the same I.R.E. paper referred to. Curves of radiation in the optimum direction, total power radiated, and directivity, plotted as a function of the included angle of an 8-wave V, are shown in Fig. 29. The unit of solid angle has been taken here as a full sphere rather than a solid

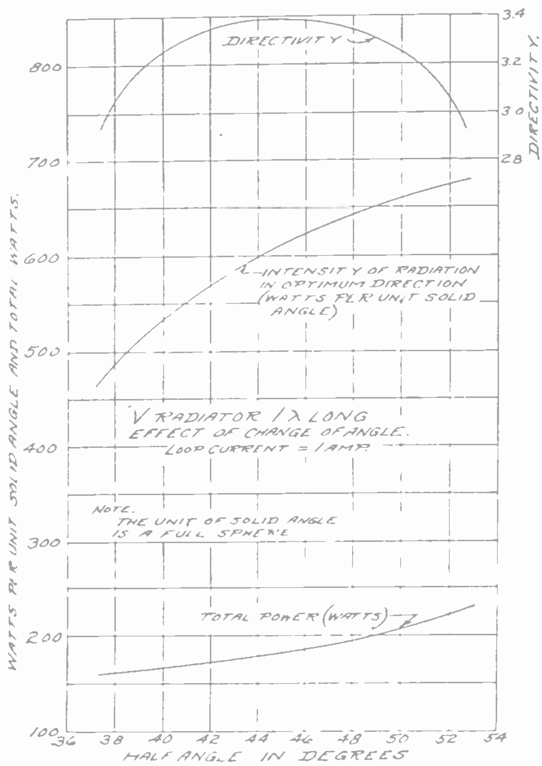
DIRECTIVITY
INTENSITY OF RADIATION IN OPTIMUM DIRECTION (WATTS PER UNIT SOLID ANGLE)
V RADIATOR 1λ LONG
EFFECT OF CHANGE OF ANGLE.
LOOP CURRENT = 1 AMP.
NOTE. THE UNIT OF SOLID ANGLE IS A FULL SPHERE
TOTAL POWER (WATTS)
WATTS PER UNIT SOLID ANGLE AND TOTAL WATTS.
DIRECTIVITY.
HALF ANGLE IN DEGREES

Fig. 31

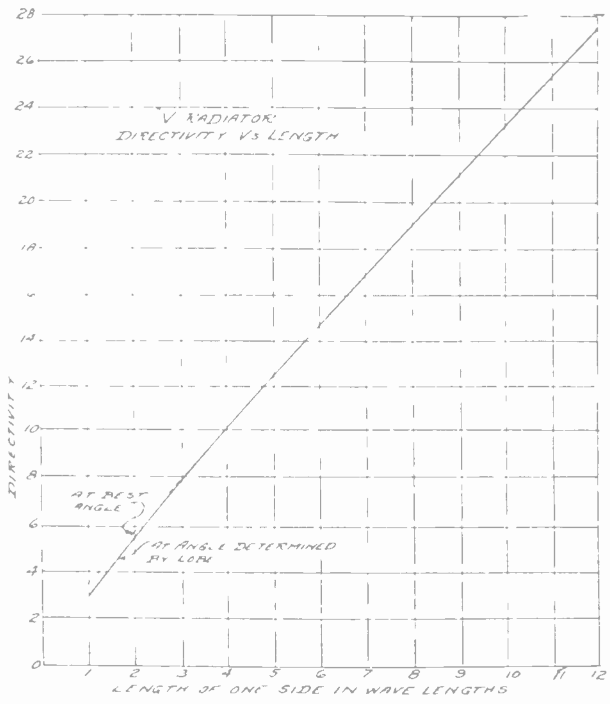
V RADIATOR
DIRECTIVITY Vs LENGTH
AT BEST ANGLE
AT ANGLE DETERMINED BY LOBE
DIRECTIVITY
LENGTH OF ONE SIDE IN WAVE LENGTHS

Fig. 32

radian. The directivity then becomes the ratio of the watts-per-unit solid angle in the optimum direction to the total power radiated.

In Figs. 30 and 31 are shown similar curves for one-half and one-wave V's. It will be noted that the optimum directivity for a one-wave V is obtained when the angle is 90 degrees rather than 105 degrees as determined from the field amplitude patterns alone.

In Fig. 32 is shown a curve of directivity vs. length of wire where the best angle is used in each case.

The included angle of a V wire may be made obtuse such that maximum radiation takes place in a direction perpendicular to the bisector as shown in Fig. 33.

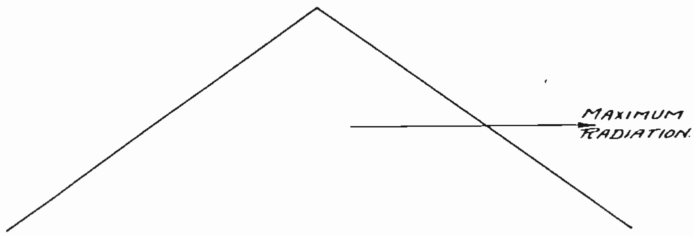

Fig. 33

It is of interest to find the gain ratio for such a system and compare it with an acute angle V having maximum radiation along its bisector. This has been done for a V having an angle of 140 degrees and sides equal to 8 wavelengths. In this case the mutual impedance is such as to increase the power for a given current in each leg over the value when the wires are at a great distance. This results in a gain ratio of

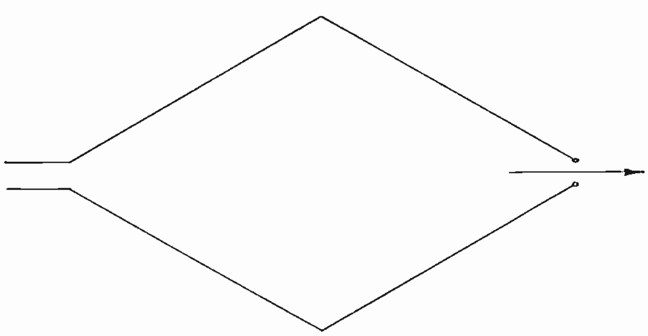

Fig. 34

considerably less than 2 over that of a single wire. The actual value obtained was 1.68. Therefore, this combination is quite inferior to a system where maximum radiation is along the bisector.

If we form a diamond system (Fig. 34), we have a combination of the effects just considered. Maximum radiation takes place along one diagonal. The gain ratio is less than twice that for a single acute angle

V but greater than twice that for a single obtuse angle V. The usual broadside arrangement used in the Model D antenna is thus seen to be superior to the diamond.

A rough copy of the curve of the mutual voltage distribution for a V wire having an included angle of 140 degrees is shown in Fig. 35.

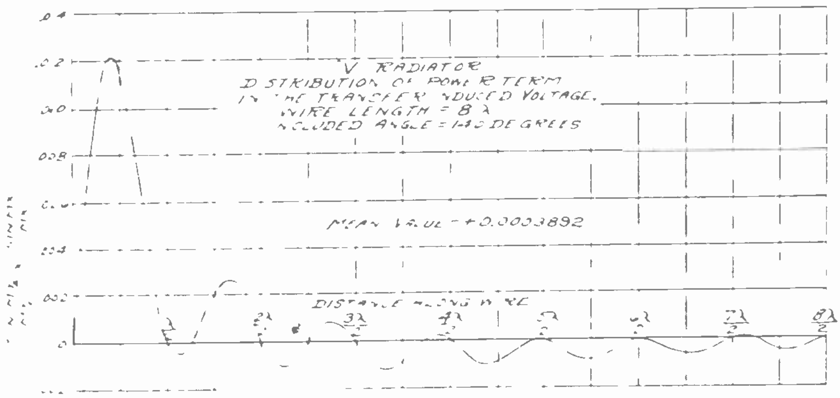

Fig. 35

6. Antenna Systems with Fed Reflectors

In all the directional antenna systems in use in R.C.A. Communications, it has been the practice to feed the energy directly to the reflector by means of a transmission line, and several different spacings have been used between the antenna and reflector units. Several times the question has arisen as to what is the best spacing.

If two like radiating systems are spaced in the desired direction of radiation by a distance equal to any odd number of quarter waves and the currents in the two units are equal and in quarter-phase relation, the directivity will be exactly twice that for one system acting alone, provided the distribution of currents within either system remains unchanged by proximity of the other. This statement can be proved by the methods under discussion.

First it can be shown that so long as the currents in the antenna and reflector systems are equal and in quarter-phase relation, the total power input is exactly twice that for one system alone when remote from any other, regardless of the spacing. This statement should not be taken to mean that the portions of the power contributed by the antenna and reflector are equal. As a matter of fact, with ordinary spacings the larger portion of the power is always contributed by the antenna. When the spacing is an odd quarter wavelength the electric intensity at some remote point along the continuation of the spacing line between the two systems, due to both systems, is either twice that due to one alone, or zero. Calling the electric intensity due to one system alone E, that due to both is $2E$ and the corresponding intensity of the radiation $4E^2$. Since the power input is twice that of one wire alone, the directivity ratio is 2 and the statement is proved. The same conclusion is roughly obtained in any particular case by the integration of Poynting's vector.

It is therefore clear that, in so far as directivity alone is concerned, the number of odd quarter wavelengths used for the spacing of an energized reflector is immaterial. However, small spacings result in a

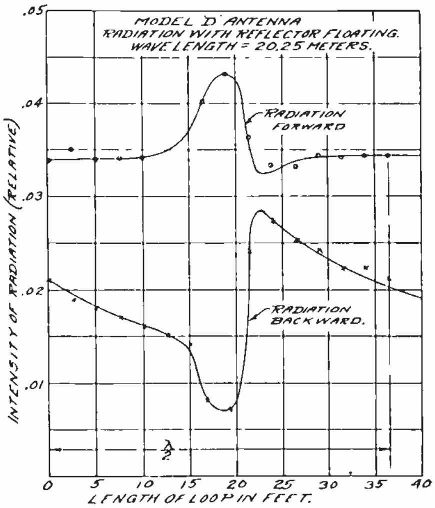

Fig. 36

much greater difficulty of adjustment due to the higher values of mutual impedance obtained. In some instances radiation at some undesirable angle may be appreciable and by properly spacing the reflector this may be made a minimum.

In practice, where the antenna and reflector each may consist of a rather complex arrangement of radiators, the mutual impedance may be determined from experimental curves of intensity of radiation vs. tuning of the reflector when free. In making such a test the coupling to the transmitter is kept low so that the impressed voltage on the antenna can be considered constant.

An example of such curves, taken in both forward and backward directions, is shown in Fig. 36. These were taken during the process of adjustment of a V antenna system in which both antenna and reflector units each consisted of 2 V wires one above the other.

V but greater than twice that for a single obtuse angle V. The usual broadside arrangement used in the Model D antenna is thus seen to be superior to the diamond.

A rough copy of the curve of the mutual voltage distribution for a V wire having an included angle of 140 degrees is shown in Fig. 35.

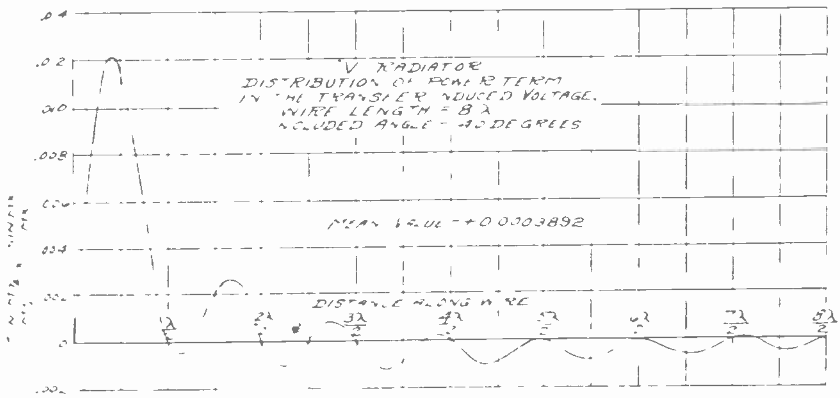

Fig. 35

6. Antenna Systems with Fed Reflectors

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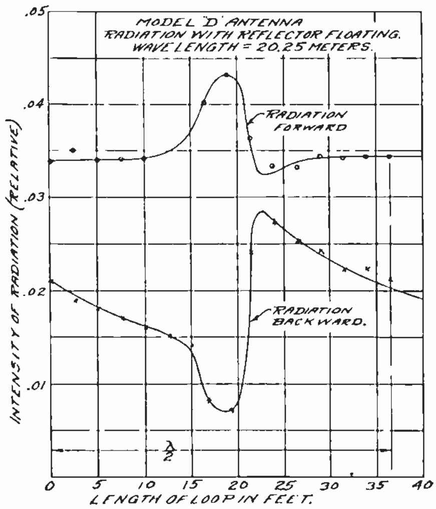

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APPENDIX I

I. Field Conditions in the Vicinity of a Radiator

In Fig. 37 let AB be a radiator whose length l is an integral number n of half waves. Call the distance along the wire z_0 and let the cylindrical coördinates of the point P, at which we wish to determine the field strengths, be: (ρ, θ, z)

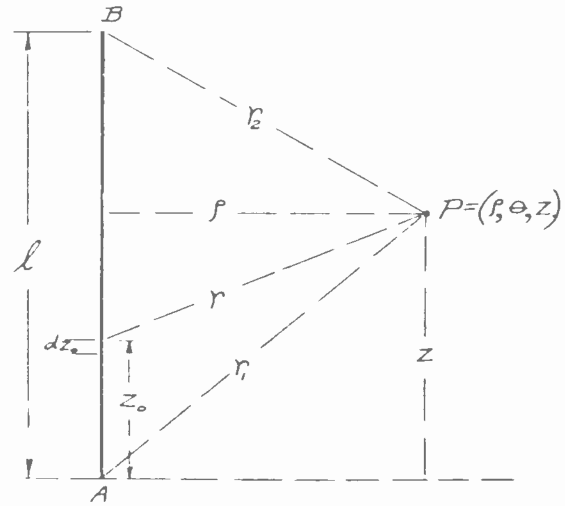

Fig. 37

If the current at an antinodal point is represented by the real part of $I\epsilon^{j\omega t}$, the current at any point z_0 along the wire is then given by the relation:

$$i = I\epsilon^{j\omega t} \sin mz_0. \tag{23}$$

where $m = 2\pi/\lambda = \omega/c$, c being the velocity of light.

Because of the law of continuity, the time rate of decrease of charge density, σ, along the wire must equal the space rate of change of current, or:

$$\frac{\delta\sigma}{\delta t} = -\frac{\delta i}{\delta z_0}. \tag{24}$$

where σ and i are both in electrostatic units, from which

$$\sigma = j\frac{I}{c}\epsilon^{j\omega t} \cos mz_0. \tag{25}$$

The electric and magnetic field forces may be determined from the retarded scalar and vector potentials ψ and A where:

$$\psi = \int_0^l \frac{[\sigma]}{r} dz_0. \tag{26}$$

$$A = \frac{K}{c}\int_0^l \frac{[i]}{r}\,dz_0, \tag{27}$$

in which $[\sigma]$ and $[i]$ indicate the charge and current taken at the retarded time $(t-r/c)$, and K is unit vector in the z direction.

Upon substituting the values of "retarded" charge and current in these relations and changing the sine and cosine functions to exponential form, the potentials become:

$$\psi = j\frac{I}{2c}\epsilon^{j\omega t}\int_0^l\left[\frac{\epsilon^{-jm(r+z_0)}}{r}+\frac{\epsilon^{-jm(r-z_0)}}{r}\right]dz_0 \tag{28}$$

$$A = -jK\frac{I}{2c}\epsilon^{j\omega t}\int_0^l\left[\frac{\epsilon^{-jm(r+z_0)}}{r}-\frac{\epsilon^{-jm(r-z_0)}}{r}\right]dz_0 \tag{29}$$

where,

$$r = \sqrt{\rho^2+(z_0-z)^2}.$$

The above integrals may be expressed in terms of the sine integral and cosine integral functions but this serves no useful purpose as the potentials are of no value to us except as a means of deriving the field forces.

To form the components of E and H we have the relations:

$$E = -\operatorname{grad}\psi - \frac{1}{c}\frac{dA}{dt} \tag{30}$$

$$H = \operatorname{curl} A. \tag{31}$$

Since A has the direction of the wire axis $A_z = A$ and $A_\rho = A_\theta =$ zero.

$$\text{Grad}_z\,\psi = \frac{\delta\psi}{\delta z}\cdot\ \text{grad}_\rho\,\psi = \frac{\delta\psi}{\delta\rho},\ \text{and grad}_\theta\,\psi = 0$$

$$\text{Curl}_\theta\,A = -\frac{\delta A}{\delta\rho}\cdot\ \text{curl}_\rho\,A = 0,\ \text{curl}_z\,A = 0$$

$$\text{Hence, } H_\theta = H = -\frac{\delta A}{\delta\rho},\ \text{and } H\rho = Hz = 0.$$

However, from Faraday's law, $dH/dt = -c$ curl E, from which we get

$$H = \frac{j}{m}\operatorname{curl}_\theta E = \frac{j}{m}\left[\frac{\delta E\rho}{\delta z}-\frac{\delta Ez}{\delta\rho}\right], \tag{32}$$

so that, once we have derived E_z and E_ρ we may just as well obtain H from the electric force components as from the vector potential.

From (30) we have for the parallel component (E_z) of the electric force:

$$\begin{aligned} E_z &= -\operatorname{grad}_z \psi - \frac{1}{c}\frac{dA}{dt} \\ &= -j\frac{I}{2c}\epsilon^{j\omega t}\int_0^l \frac{\delta}{\delta z}\left[\frac{\epsilon^{-jm(r+z_0)}}{r} + \frac{\epsilon^{-jm(r-z_0)}}{r}\right]dz_0 \\ &\quad + \frac{\omega I}{2c^2}\epsilon^{j\omega t}\int_0^l \left[\frac{\epsilon^{-jm(r+z_0)}}{r} - \frac{\epsilon^{-jm(r-z_0)}}{r}\right]dz_0. \end{aligned} \tag{33}$$

From the diagram it is apparent that $\delta r/\delta z = -\delta r/\delta z_0$. If we make use of this relation and integrate by parts, after some manipulation we get:

$$E_z = +j\frac{I}{2c}\left[(\epsilon^{jml} + \epsilon^{-jml})\frac{\epsilon^{-jm\sqrt{\rho^2+(l-z)^2}}}{\sqrt{\rho^2+(l-z)^2}} - \frac{\epsilon^{-jm\sqrt{\rho^2+z^2}}}{\sqrt{\rho^2+z^2}}\right] \tag{34}$$

but $(\epsilon^{jml}+\epsilon^{-jml})/2 = \cos ml = (-1)^n$ where n is the number of half waves on the radiator.

If we let $r_1 = \sqrt{\rho^2+z^2}$ and $r_2 = \sqrt{\rho^2+(l-z)^2}$

$$E_z = j\frac{I}{c}\epsilon^{j\omega t}\left[\frac{\epsilon^{-jmr_2}}{r_2}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\right] \tag{35}$$

electrostatic cgs units.

If I is the r-m-s current in amperes this becomes:

$$E_z = j30I\left[\frac{\epsilon^{-jmr_2}}{r_2}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\right] \text{ volts per cm (r-m-s.)} \tag{36}$$

To obtain E_ρ we have, since $A_\rho = 0$

$$E_\rho = -\operatorname{grad}_\rho \psi = -\frac{\delta\psi}{\delta\rho} \tag{37}$$

$$E_\rho = j\frac{I}{2c}\epsilon^{j\omega t}\int_0^l \frac{\delta}{\delta\rho}\left[\frac{\epsilon^{-jm(r+z_0)}}{r} + \frac{\epsilon^{-jm(r-z_0)}}{r}\right]dz_0. \tag{38}$$

After considerable manipulation this becomes:

$$E_\rho = -j\frac{I}{c}\epsilon^{j\omega t}\left[\frac{\epsilon^{-jmr_2}}{r_2}\cdot\frac{z-l}{\rho}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\cdot\frac{z}{\rho}\right] \text{esu} \tag{39}$$

or in practical units where I is the r-m-s current in amperes:.

$$E_\rho = -j30I\left[\frac{\epsilon^{-jmr_2}}{r_2}\cdot\left(\frac{z-l}{\rho}\right)(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\cdot\frac{z}{\rho}\right] \text{volts per cm.} \tag{40}$$

To determine H we may use the relation:

$$H = \frac{j}{m} \operatorname{curl}_\theta E = \frac{j}{m}\left[\frac{\delta E\rho}{\delta z} - \frac{\delta Ez}{\delta \rho}\right] \tag{41}$$

After performing the operations indicated and combining terms we get, for the current in amperes (r-m-s):

$$H = j\frac{I}{10}\left[\frac{\epsilon^{-jmr_2}}{\rho}(-1)^n - \frac{\epsilon^{-jmr_1}}{\rho}\right] \text{Gauss (r-m-s).} \tag{42}$$

These relations give us a complete knowledge of the field conditions at any point in space.

APPENDIX II

1. Self-Impedance of a Linear Radiator

The self-impedance has been defined by the relation:

$$Z_{11} = -\frac{1}{I_1}\int_0^l E_z \sin mz\, dz. \tag{43}$$

Substituting the value of E_z from (10) into this expression and noting that, in this case, $r_1 = z$ and $r_2 = l - z$ we obtain:

$$Z_{11} = -j30\int_0^l \left(\frac{\epsilon^{-jm(l-z)}}{l-z}(-1)^n - \frac{\epsilon^{-jmz}}{z}\right)\sin mz\, dz. \tag{44}$$

Since $ml = n\pi$, $\epsilon^{-jml} = (-1)^n$ and this expression, after replacing $\sin z$ by its exponential equivalent, becomes:

$$\begin{aligned} Z_{11} &= -15\int_0^l \left(\frac{\epsilon^{-j2mz} - 1}{l-z} + \frac{\epsilon^{-j2mz} - 1}{z}\right)dz \\ &= -30\int_0^{2ml} \frac{\epsilon^{-ju} - 1}{u}\, du \end{aligned} \tag{45}$$

or,

$$Z_{11} = 30\{[\tau + \log_\epsilon 2ml - Ci2ml] + j[Si2ml]\} \text{ ohms,} \tag{46}$$

where $\tau = 0.5772 \ldots$ (Euler's constant).

2. Transfer Impedance for Parallel Wires (Not Staggered)

The transfer impedance was defined as :

$$Z_{21} = \frac{-1}{I}\int_0^l E_{21} \sin mz\, dz. \tag{47}$$

Substituting the value of E_z from (10) into this expression it becomes, after replacing sin mz by its exponential form:

$$Z_{21} = -15\int_0^l \left[\frac{\epsilon^{-jm(r_2-z)} - \epsilon^{-jm(r_2+z)}}{r_2}(-1)^n - \frac{\epsilon^{-jm(r_1-z)} - \epsilon^{-jm(r_1+z)}}{r_1}\right] dz. \quad (48)$$

Changing the variable in the integrals by substitutions of which $U = m(r_2 - z + 1)$ is typical, we get:

$$Z_{21} = +15\left[(-1)^n \int_{m(\sqrt{\rho^2+l^2}+l)}^{m\rho} \frac{\epsilon^{-j(u-ml)}}{u} du + (-1)^n \int_{m(\sqrt{\rho^2+l^2}-l)}^{m\rho} \frac{\epsilon^{-j(u+ml)}}{u} du - \int_{m\rho}^{m(\sqrt{\rho^2+l^2}-l)} \frac{\epsilon^{-ju}}{u} du - \int_{m\rho}^{m(\sqrt{\rho^2+l^2}+l)} \frac{\epsilon^{-ju}}{u} du\right]. \quad (49)$$

Since $ml = n\pi$, $\epsilon^{-jml} = (-1)^n$ and $\epsilon^{+jml} = (-1)^n$

$$Z_{21} = +30\left[2Ei(-jm\rho) - Ei\{-jm(\sqrt{\rho^2+l^2}+l)\} - Ei\{-jm(\sqrt{\rho^2+l^2}-l)\}\right]. \quad (50)$$

3. Mutual Impedance for Parallel Wires in Echelon

By reference to Fig. 4 it is seen that if we consider Z as the distance along wire No. 1, the distance along the second wire becomes $(z-h)$. Taking this into account, the expression for the mutual impedance becomes:

$$Z_{21} = -j30\int_h^{l+h}\left[\frac{\epsilon^{-jmr_2}}{r_2}(-1)^n - \frac{\epsilon^{-jmr_1}}{r_1}\right]\sin m(z-h)dz. \quad (51)$$

Changing the sine term to exponential form this becomes:

$$Z_{12} = -15\epsilon^{-jmh}\left[(-1)^n\int_h^{l+h}\frac{\epsilon^{-jm(r_2-z)}}{r_2}dz - \int_h^{l-h}\frac{\epsilon^{-jm(r_1-z)}}{r_1}dz\right] + 15\epsilon^{+jmh}\left[(-1)^n\int_h^{l+h}\frac{\epsilon^{-jm(r_1+z)}}{r_1}dz - \int_h^{l+h}\frac{\epsilon^{-jm(r_1-z)}}{r_1}dz\right]. \quad (52)$$

By changing the variables in a manner similar to that in the preceding development and remembering that $\epsilon^{jml} = \epsilon^{-jml} = (-1)^n$, we get:

$$
\begin{aligned}
Z_{21} = &-15\epsilon^{-jmh}\{-2Ei[-jm(\sqrt{\rho^2+h^2}-h)]\\
&+Ei[-jm(\sqrt{\rho^2+(h-l)^2}-(h-l))]\\
&+Ei[-jm(\sqrt{\rho^2+(h+l)^2}-(h+l))]\}\\
&-15e^{+jmh}\{-2Ei[-jm(\sqrt{\rho^2+h^2}+h)]\\
&+Ei[-jm(\sqrt{\rho^2+(h-l)^2}+(h-l))]\\
&+Ei[-jm(\sqrt{\rho^2+(h+l)^2}+(h+l))]\}\text{ ohms.}
\end{aligned}
\tag{53}
$$

Expanding this expression into its power and quadrature terms it becomes:

$$
\begin{aligned}
Z_{21} = &-15\cos mh[-2Ci\bar{\bar{h}}-2Ci\overline{\overline{-h}}+Ci\overline{\overline{h-l}}+Ci\overline{\overline{-(h-l)}}\\
&+Ci\overline{\overline{h+l}}+Ci\overline{\overline{-(h+l)}}]+15\sin mh[2Si\bar{\bar{h}}-2Si\overline{\overline{-h}}\\
&-Si\overline{\overline{h-l}}+Si\overline{\overline{-(h-l)}}-Si\overline{\overline{h+l}}+Si\overline{\overline{-(h+l)}}]\\
&-j15\cos mh[2Si\bar{\bar{h}}+2Si\overline{\overline{-h}}-Si\overline{\overline{h-l}}-Si\overline{\overline{-(h-l)}}\\
&-Si\overline{\overline{h+l}}-Si\overline{\overline{-(h+l)}}]+j15\sin mh[2Ci\bar{\bar{h}}-2Ci\overline{\overline{-h}}\\
&-Ci\overline{\overline{h-l}}+Ci\overline{\overline{-(h-l)}}-Ci\overline{\overline{h+l}}+Ci\overline{\overline{-(h+l)}}]\text{ ohms}
\end{aligned}
\tag{54}
$$

where,

$$\bar{\bar{h}} = m(\sqrt{\rho^2+h^2}+h),\ \overline{\overline{-(h-l)}} = m(\sqrt{\rho^2+(h-l)^2}-(h-l)),\text{ etc.}$$

4. Mutual Impedance for Colinear Wires

This is a special case of wires in echelon where the spacing (ρ) is zero. However, if zero is substituted for ρ in (54) we get the indeterminate form $\infty - \infty$. This difficulty is overcome by taking the limit of the expression as ρ approaches zero in the following manner:

For small values of ρ we have by the binomial law:

$$\sqrt{\rho^2+h^2}-h = \frac{1}{2}\frac{\rho^2}{h} \tag{55}$$

$$\sqrt{\rho^2+(h-l)^2}-(h-l) = \frac{1}{2}\frac{\rho^2}{h-l}, \tag{56}$$

$$\sqrt{\rho^2+(h+l)^2}-(h+l) = \frac{1}{2}\frac{\rho^2}{h+l}. \tag{57}$$

For small values of x,

$$Ci(x) = r + \log_\epsilon x \tag{58}$$

and,

$$\lim_{\rho\to 0}\left[2Ci\frac{m\rho^2}{2h} - Ci\frac{m\rho^2}{2(h-l)} - Ci\frac{m\rho^2}{2(h+l)}\right] = \log_\epsilon\left(\frac{h^2-l^2}{h^2}\right) \tag{59}$$

and,

$$
\begin{aligned}
Z_{21} = & -15 \cos mh\Big[-2Ci2mh + Ci2m(h-l) + Ci2m(h+l) \\
& - \log_e\left(\frac{h^2-l^2}{h^2}\right)\Big] + 15 \sin mh\big[2Si2mh - Si2m(h-l) \\
& - Si2m(h+l)\big] - j15 \cos mh\big[2Si2mh - Si2m(h-l) \\
& - Si2m(h+l)\big] + j15 \sin mh\big[2Ci2mh - Ci2m(h-l) \\
& - Ci2m(h+l) - \log_e\left(\frac{h^2-l^2}{h^2}\right)\Big] \text{ ohms}
\end{aligned} \tag{60}
$$

when,

$$h > l.$$

5. Mutual Impedance for V Wires

In Fig. 38 are two wires of equal length $n(\lambda/2)$, where n is an integer, and having an included angle θ between them. The distance along (2)

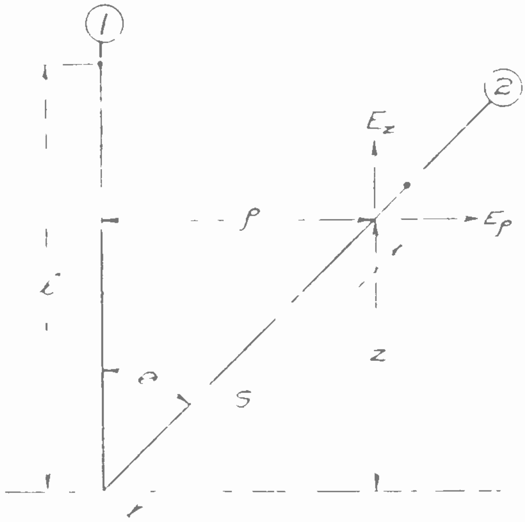

Fig. 38

is measured from the apex as origin. In order to determine the voltage induced in wire (2) by the current in wire (1) it is first necessary to determine the component of the electric force E in the direction of wire (2).

The component of E_z in the direction along s in $E_z \cos\theta$.

The component of E_ρ in the direction along s is $E_\rho \sin\theta$.

Therefore, $E_s = E_z \cos\theta + E_\rho \sin\theta$.

But $z = s\cos\theta$ and $\rho = s \sin\theta$.

Substituting these values of E_z, E_ρ, z, and ρ in (36) we obtain:

$$E_s = j30\left[\frac{\epsilon^{-jmr_2}}{r_2}(-1)^n - \frac{\epsilon^{-jms}}{s}\right]\cos\theta$$

$$-j30\left[\frac{\epsilon^{-jmr_2}}{r_2}\cdot\frac{s\cos\theta - l}{s\sin\theta}(-1)^n\cdot - \frac{\epsilon^{-jms}}{s}\cdot\frac{s\cos\theta}{s\sin\theta}\right]\sin\theta \qquad (61)$$

$$= j30(-1)^n\frac{l}{s}\frac{\epsilon^{-jmr_2}}{r_2}\cdot \text{volts/cm where } r_2 = \sqrt{l^2+s^2-2ls\cos\theta} \qquad (62)$$

Substituting this value of Es in the general formula for mutual impedance, and separating the expression into its power and quadrature terms we get:

$$Z_{21} = -30l(-1)^n\left[\int_0^l \frac{\sin mr_2}{r_2}\cdot\frac{\sin ms}{s}ds + j\int_0^l \frac{\cos mr_2}{r_2}\cdot\frac{\sin ms}{s}\cdot ds\right] \text{ohms.} \qquad (63)$$

It is not possible to express these integrals in any form convenient for calculation. As r_2 is a function of l, s, and θ they must be evaluated mechanically for each specific condition.

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EQUIVALENT ELECTRICAL NETWORKS*

By

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(Washington, D. C.)

Summary—*The paper shows how to obtain, by a matrix multiplication, networks equivalent at all frequencies to a given network, as well as the networks with the least number of elements.*

THE problem of calculating the driving-point impedance function $Z(p)$ of a given two-terminal network is a familiar one in electric circuit theory. The usual method is to combine the impedances and admittances of the various branches in such manner as to give the total impedance between the two terminals. This impedance is, of course, the alternating-current impedance of the network, obtained by dividing the alternating-current voltage across the terminals of the network, by the resulting driving alternating-current. Another method, and in more complicated networks a better one, is the use of the determinant of the network. The determinant of the network is the determinant whose elements are the coefficients of the currents in the Kirchhoff equations of the network. The elements are of the form $\lambda p+\rho+\sigma/p$, where λ, ρ, and σ are positive constants and are the inductance, resistance, and elastance terms, and p is $2\pi\sqrt{-1}$ times the frequency. The determinant is symmetrical about the main diagonal, and consists essentially of two kinds of elements. The elements of the main diagonal are the *total* parameters, that is, they are terms of the form $\lambda_{jj}p+\rho_{jj}+\sigma_{jj}/p$, where λ_{jj}, ρ_{jj} and σ_{jj} are, respectively, the *total* inductance, resistance, and elastance of the mesh. All the other elements are the *mutual* parameters, that is, they are terms of the form $\lambda_{jk}p+\rho_{jk}+\sigma_{jk}/p$ where λ_{jk}, ρ_{jk}, and σ_{jk} are, respectively, the inductance, resistance, and elastance *mutual* or *common* to the two meshes j and k. The driving-point impedance of the network is obtained by dividing the determinant of the network by the minor of the element in the first row and first column. This amounts to applying Kirchoff's equations to the network and writing the determinant solution for the driving current. The form of the determinant of the network suggests matrix representation of the network used later. Thus, the impedance of a given network is a fraction, the numerator of which is the determinant of the network, and the denominator the minor of the element in the first row and first column of this determinant. The expansion of

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the determinant and its minor results in the following expression for the impedance function:

$$Z(p)=\frac{a_{2n}p^{n}+a_{2n-1}p^{n-1}+a_{2n-2}p^{n-2}+\cdots+a_2p^{-n+2}+a_1p^{-n+1}+a_0p^{-n}}{b_{2n-1}p^{n-1}+b_{2n-2}p^{n-2}+\cdots+b_2p^{-n+2}+b_1p^{-n+1}} \qquad (1)$$

where the a and b terms are real constants.

Multiplying the numerator and denominator by p^n, the impedance function becomes

$$Z(p)=\frac{a_{2n}p^{2n}+a_{2n-1}p^{2n-1}+a_{2n-2}p^{2n-2}+\cdots+a_2p^2+a_1p+a_0}{b_{2n-1}p^{2n-1}+b_{2n-2}p^{2n-2}+\cdots+b_2p^2+b_1p}. \qquad (2)$$

This, then, is the most general expression of the impedance function of a network of n meshes. Thus, the determination of the impedance function of a given two-terminal network of any number of meshes is not difficult, and results in an expression of the form (2). This expression is *unique* for a given network, that is, for a network with given elements, the coefficients of p are definite constants. To every given network therefore, there corresponds one and only one impedance function, which can be reduced to the form (2).

Conversely, however, it is not true that to every impedance function there corresponds one and only one network. To an impedance function determined from a *given* network, there may correspond an *infinite* number of other networks. That is, the impedance of every one of these networks, with its elements of inductance, resistance, and elastance different from those of the given network, is exactly the same as the impedance of the given network.

This fact seems, until recent years, to have been disregarded.[1] The terminal equipment of communication systems consists essentially of networks, such as wave filters, corrective networks, etc. These networks are designed to have desired characteristics which are obtained by giving a definite configuration to the network and by assigning proper magnitudes to the circuit elements. From the standpoint of good design, it is important to know that the network that has been designed to have the given characteristics is better and more economical than any other network having the same characteristics. This applies to any part of the network, for any part of a network must be so designed as to contribute in the best and most economical manner to

[1] *See* R. M. Foster, "Theorems regarding the driving-point impedance of two-mesh circuits," *Bell Sys. Tech. Jour.*, vol. 3, p. 651, (1924); R. M. Foster, "A reactance theorem," *ibid.*, p. 259; W. Cauer, "Die Verwirklichung von Wechselstromwiderständen vorgeschriebener Frequenzabhängikeit," *Archiv für Elek.*, Heft 4, Band 17, p. 355, (1926); W. Cauer, "Vierpole," *Elek. Nach. Tech.*, Heft 7, Band 6, p. 272, (1929).

the desired result. Thus, consider the mid-series equivalent m-derived band-pass type of filter shown in Fig. 1. The shunt arm *ab* is part of this network, and without being concerned about the rest of the network, this arm may be considered by itself as a network with terminals *a*, *b*. The voltage across this shunt arm is the voltage $e(t)$ across the terminals *a*, *b* when the filter is in operation. Now, since there exists an infinite number of other networks which have exactly the same impedance function, these networks may be substituted for the given shunt arm without in any way affecting the operation of the filter.[2] The important question, therefore, arises: Which is the best network to use? To answer this question, a knowledge of every one of the infinite number of networks having the same impedance as the given network is required. That is, it is necessary to be able to determine all the networks having the same impedance function as the given network.

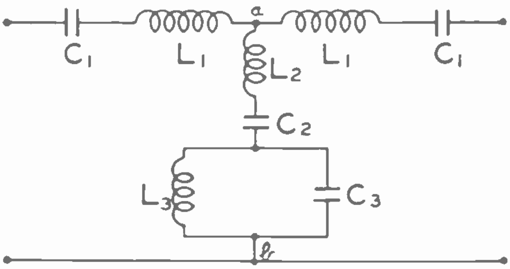

Fig. 1

When this has been accomplished the actual selection of the best network depends upon many factors, determined largely by experience and practical considerations. Small values of capacities are undesirable because they are difficult to measure accurately and because the capacity of the wiring may be large enough to be important, and large values of capacities are costly. Small values of inductances are difficult to measure accurately and large values of inductances are affected by shunt capacities between the windings. Obviously, networks with the smallest number of elements (the minimal networks) would in general be least expensive.[3]

It is not enough, therefore, to design a network, which, when finally built, performs its function satisfactorily. As long as there exists an infinite number of other networks which will perform identically the same function in a communication system, a given design is not necessarily the most desirable one, while a better and more economical network may be built.

[2] Networks having the same driving-point impedance functions have identical indicial currents. This follows from the infinite integral theorem. See V. Bush, "Operational Circuit Analysis," pp. 34–75, (1929).

[3] An excellent discussion of these factors appears in K. S. Johnson, "Transmission Circuits for Telephone Communication," p. 197, (1927).

The purpose of this paper, therefore, will be to show by a matrix multiplication how to obtain networks equivalent at all frequencies to a given network, as well as the minimal networks, that is, the networks with the least number of elements.

Consider, for example, the simple two-mesh network containing only inductance and resistance elements shown in Fig. 2. The parameters of this network are, of course,

$$\lambda_{11} = 2, \quad \lambda_{22} = 1, \quad \lambda_{12} = 1; \quad \rho_{11} = 2, \quad \rho_{22} = 2, \quad \rho_{12} = 1.$$

As has been indicated above λ_{11} and λ_{22} are, respectively, the total inductances of meshes 1 and 2, and λ_{12} is the inductance common to the two meshes. Similarly ρ_{11} and ρ_{22} are, respectively, the total resistances of meshes 1 and 2, and ρ_{12} is the resistance common to both meshes.

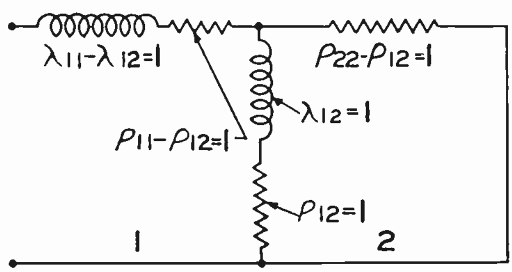

Fig. 2

The network of Fig. 2 may be represented by two matrices, the elements of which are, respectively, the inductance and resistance parameters of the network. These matrices are

$$\left\| \begin{matrix} 2 & 1 \\ 1 & 1 \end{matrix} \right\|, \quad \left\| \begin{matrix} 2 & 1 \\ 1 & 2 \end{matrix} \right\| \tag{3}$$

A two-mesh network, containing inductance, resistance, and capacitance elements, is represented by three matrices. Thus, the network of Fig. 3 is represented by the matrices

$$\left\| \begin{matrix} 3 & 1 \\ 1 & 4 \end{matrix} \right\|, \quad \left\| \begin{matrix} 6 & 2 \\ 2 & 4 \end{matrix} \right\|, \quad \left\| \begin{matrix} 7 & 4 \\ 4 & 8 \end{matrix} \right\| \tag{4}$$

These are, respectively, the inductance, resistance, and elastance matrices, from which, by an obvious rule of formation, the network of Fig. 3 can be constructed.

For the general case of a network containing n meshes with inductance, resistance, and capacitance elements, the following matrices represent the network.

$$\left\| \begin{matrix} \lambda_{11} & \cdots & \lambda_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \lambda_{1n} & \cdots & \lambda_{nn} \end{matrix} \right\| \qquad \left\| \begin{matrix} \rho_{11} & \cdots & \rho_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \rho_{1n} & \cdots & \rho_{nn} \end{matrix} \right\| \qquad \left\| \begin{matrix} \sigma_{11} & \cdots & \sigma_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \sigma_{1n} & \cdots & \sigma_{nn} \end{matrix} \right\| \tag{5}$$

Thus, in general, there is a one-to-one correspondence between an electrical network and a system of three matrices. Given the network, the matrices can be constructed, and conversely, given the matrices, it is not difficult to construct the network. These matrices need not have

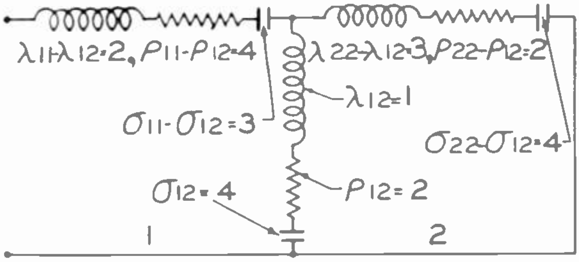

Fig. 3

any mathematical connotation. They may be considered a shorthand way of easily cataloging or pigeonholing the electrical elements which make up a network.

Proceeding with the simple two-mesh network shown in Fig. 2, perform the following matrix multiplications on the matrices (3), which represents this network.[4]

$$\left\| \begin{matrix} 1 & a_{21} \\ 0 & a_{22} \end{matrix} \right\| \times \left\| \begin{matrix} 2 & 1 \\ 1 & 1 \end{matrix} \right\| \times \left\| \begin{matrix} 1 & 0 \\ a_{21} & a_{22} \end{matrix} \right\| \tag{6a}$$

$$\left\| \begin{matrix} 1 & a_{21} \\ 0 & a_{22} \end{matrix} \right\| \times \left\| \begin{matrix} 2 & 1 \\ 1 & 2 \end{matrix} \right\| \times \left\| \begin{matrix} 1 & 0 \\ a_{21} & a_{22} \end{matrix} \right\| \tag{6b}$$

The quantities a_{21} and a_{22} are any real numbers. Performing the multiplications of the matrices in (6) we have, respectively,[5]

$$\left\| \begin{matrix} 2 + 2a_{21} + a_{21}^2 & a_{22} + a_{21}a_{22} \\ a_{22} + a_{21}a_{22} & a_{22}^2 \end{matrix} \right\| \tag{7a}$$

$$\left\| \begin{matrix} 2 + 2a_{21} + 2a_{21}^2 & a_{22} + 2a_{21}a_{22} \\ a_{22} + 2a_{21}a_{22} & 2a_{22}^2 \end{matrix} \right\| \tag{7b}$$

[4] For the transformations which represent these matrix multiplications, see N. Howitt, "Group theory and the electric circuit," *Phys. Rev.*, vol. 37, no. 12, p. 1583, June, (1931).

[5] It is not difficult to multiply matrices, once the rule is known. For this rule see, for example, M. Bocher, "Introduction to Higher Algebra." Thus,

$$\left\| \begin{matrix} a_1 a_2 \\ b_1 b_2 \end{matrix} \right\| \times \left\| \begin{matrix} c_1 c_2 \\ d_1 d_2 \end{matrix} \right\| = \left\| \begin{matrix} a_1c_1 + a_2d_1 & a_2c_2 + a_1d_2 \\ b_1c_1 + b_2d_1 & b_1c_2 + b_2d_2 \end{matrix} \right\|$$

The matrices (7) represent networks which are equivalent to the network of Fig. 2. That is, by assigning different real values to a_{21} and a_{22}, networks are obtained which have the same impedance at *all* frequencies as that of Fig. 2. The matrices of (7), therefore, represent not one network but an infinite number of *equivalent* networks. These networks may be said to form a group, since all of them are contained in the matrices (7), and any one can be obtained from any other by a matrix multiplication similar to (6).

Thus, for example, by assigning the values $-\frac{1}{2}$ and $+1$, respectively, to a_{21} and a_{22} the matrices (7) become

$$\begin{Vmatrix} 5/4 & 1/2 \\ 1/2 & 1 \end{Vmatrix}, \qquad \begin{Vmatrix} 3/2 & 0 \\ 0 & 2 \end{Vmatrix}. \tag{8}$$

From these matrices, the network shown in Fig. 4 is readily constructed. It is a simple matter to verify the fact that the networks of Figs. 2 and 4 have the same impedance at *all* frequencies.

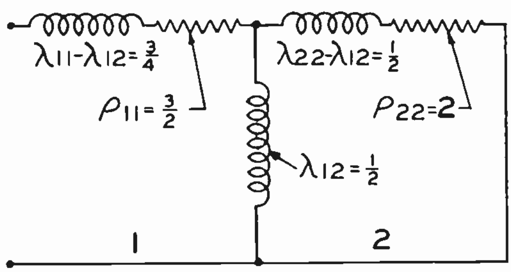

Fig. 4

Fig. 5 shows a number of networks represented by the matrices (7) and obtained from them by assigning different real values to a_{21} and a_{22}. Note that the networks a' and g' are respectively electrically identical with the networks a-g, except that the branches in mesh 2 are interchanged. The former networks may be considered images of the latter. Two networks with their branches in mesh 2 interchanged represent different matrices, and to exhaust all the networks represented by the matrices (7), networks and their images must be included. Note, too, that the networks d-g and their respective networks d'-g' are minimal networks. That is, they are the networks of the group containing the least number of network elements. They are, in general, the most economical networks of the group and are, therefore, to be preferred in a communication or other electrical system.

These minimal networks are obtained from the matrices (7). These matrices show by the number of arbitrary constants, namely, a_{21} and a_{22} that we can eliminate at most two elements, thus leaving four elements as the number for the minimal forms. This is very useful, since the least number of elements that a network of the group may have is apparent from the matrices. If λ_{11}, λ_{22}, λ_{12}; ρ_{11}, ρ_{22}, ρ_{12} represent the parameters of the infinite set of networks having a given impedance function, the corresponding matrices would, of course, be

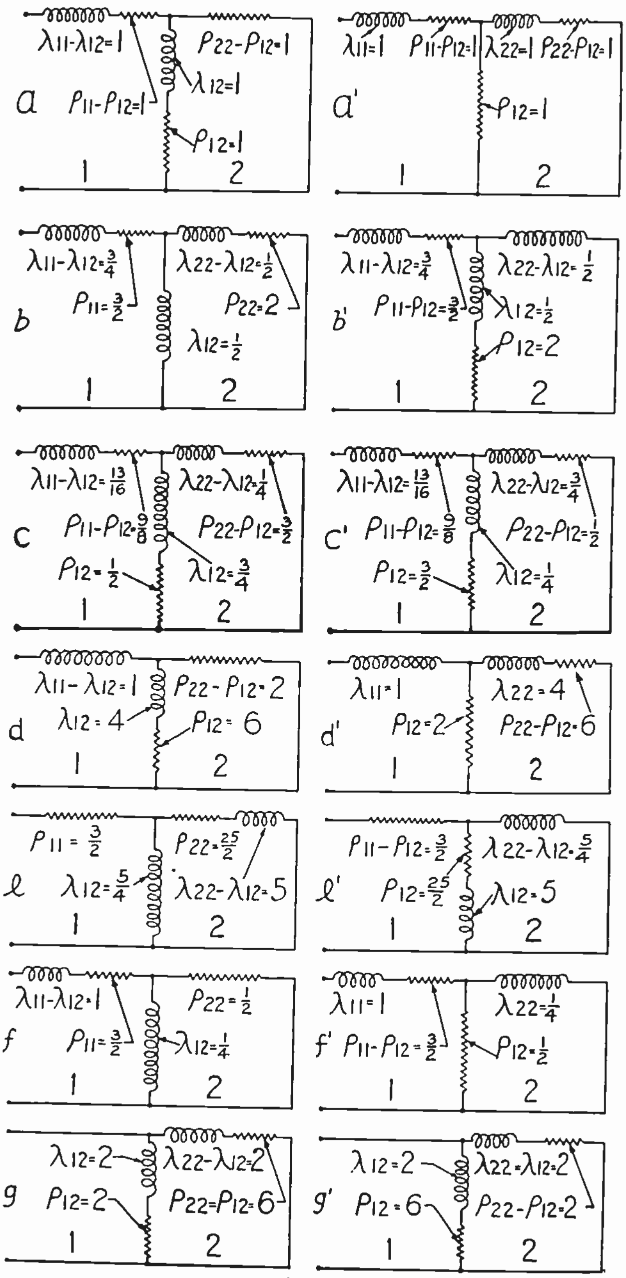

Fig. 5

$$\begin{Vmatrix} \lambda_{11} & \lambda_{12} \\ \lambda_{12} & \lambda_{22} \end{Vmatrix} \qquad \begin{Vmatrix} \rho_{11} & \rho_{12} \\ \rho_{12} & \rho_{22} \end{Vmatrix}. \tag{9}$$

The minimal forms are then obtained by eliminating two elements in all possible ways, without changing the impedance function. In this way there result eight minimal forms, obtained by making the parameters take on values so that the following equations are satisfied.

$$\left.\begin{array}{llll}
(a) & \lambda_{12} = 0, & \rho_{12} = \rho_{11} \\
(b) & \lambda_{12} = 0 & \rho_{12} = \rho_{22} \\
(c) & \rho_{12} = 0 & \lambda_{12} = \lambda_{11} \\
(d) & \rho_{12} = 0 & \lambda_{12} = \lambda_{22} \\
(e) & \lambda_{12} = \lambda_{11} & \rho_{12} = \rho_{11} \\
(f) & \lambda_{12} = \lambda_{11} & \rho_{12} = \rho_{22} \\
(g) & \lambda_{12} = \lambda_{22} & \rho_{12} = \rho_{11} \\
(h) & \lambda_{12} = \lambda_{22} & \rho_{12} = \rho_{22}
\end{array}\right\} \quad (10)$$

Applying these conditions to (7), we see that a_{21} and a_{22} must satisfy the following equations for the minimal networks.

$$\left.\begin{array}{ll}
(a) & a_{22} + a_{21}a_{22} = 0 \\
 & a_{22} + 2a_{21}a_{22} = 2 + 2a_{21} + 2a_{21}^2 \\
(b) & a_{22} + a_{21}a_{22} = 0 \\
 & a_{22} + 2a_{21}a_{22} = 2a_{22}^2 \\
(c) & a_{22} + 2a_{21}a_{22} = 0 \\
 & a_{22} + a_{21}a_{22} = 2 + 2a_{21} + a_{21}^2 \\
(d) & a_{22} + 2a_{21}a_{22} = 0 \\
 & a_{22} + a_{21}a_{22} = a_{22}^2 \\
(e) & a_{22} + a_{21}a_{22} = 2 + 2a_{21} + a_{21}^2 \\
 & a_{22} + 2a_{21}a_{22} = 2 + 2a_{21} + 2a_{21}^2 \\
(f) & a_{22} + a_{21}a_{22} = 2 + 2a_{21} + a_{21}^2 \\
 & a_{22} + 2a_{21}a_{22} = 2a_{22}^2 \\
(g) & a_{22} + a_{21}a_{22} = a_{22}^2 \\
 & a_{22} + 2a_{21}a_{22} = 2 + 2a_{21} + 2a_{21}^2 \\
(h) & a_{22} + a_{21}a_{22} = a_{22}^2 \\
 & a_{22} + 2a_{21}a_{22} = 2a_{22}^2
\end{array}\right\} \quad (11)$$

Each equation from (a) to (h) will give a minimal form.

Let us actually obtain some of the minimal networks. Finding the values of a_{21} and a_{22}, which satisfy (a), we obtain

$$a_{21} = -1$$

$$a_{22} = -2.$$

Substituting these values of a_{21} and a_{22} in the matrices (7), these become,

$$\begin{Vmatrix} 1 & 0 \\ 0 & 4 \end{Vmatrix}, \quad \begin{Vmatrix} 2 & 2 \\ 2 & 8 \end{Vmatrix}. \tag{12}$$

The corresponding network is readily constructed from these matrices, and is shown in d', Fig. 5.

Let us now obtain the minimal form given by the equations (b). The values of a_{21} and a_{22} for this case are, respectively, -1 and $-1/2$. Substituting these values in the matrices (7), we have for the matrices of the network

$$\begin{Vmatrix} 1 & 0 \\ 0 & \frac{1}{4} \end{Vmatrix}, \quad \begin{Vmatrix} 2 & \frac{1}{2} \\ \frac{1}{2} & \frac{1}{2} \end{Vmatrix} \tag{13}$$

The parameters of the network are then

$$\lambda_{11} = 1, \quad \lambda_{22} = \tfrac{1}{4}, \quad \lambda_{12} = 0; \quad \rho_{11} = 2, \quad \rho_{22} = \tfrac{1}{2}, \quad \rho_{12} = \tfrac{1}{2}$$

and the network is shown in Fig. 5,f'. It is not difficult to proceed in this manner and to obtain the other minimal forms and their respective images. It is necessary only to satisfy, for each minimal form, one of the equations (a) to (h).

For the general case of networks of any number of meshes, the infinite set of networks equivalent to the given network is obtained by the following equations

$$\begin{Vmatrix} \lambda'_{11} & \cdots & \lambda'_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \lambda'_{1n} & \cdots & \lambda'_{nn} \end{Vmatrix} = \begin{Vmatrix} 1 & a_{21} & \cdots & a_{n1} \\ 0 & a_{22} & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ 0 & a_{2n} & \cdots & a_{nn} \end{Vmatrix} \times \begin{Vmatrix} \lambda_{11} & \cdots & \lambda_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \lambda_{1n} & \cdots & \lambda_{nn} \end{Vmatrix} \times \begin{Vmatrix} 1 & 0 \cdots & 0 \\ a_{21} & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ a_{n1} & \cdots & a_{nn} \end{Vmatrix}$$

$$\begin{Vmatrix} \rho'_{11} & \cdots & \rho'_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \rho'_{1n} & \cdots & \rho'_{nn} \end{Vmatrix} = \begin{Vmatrix} & \text{``} & \end{Vmatrix} \times \begin{Vmatrix} \rho_{11} & \cdots & \rho_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \rho_{1n} & \cdots & \rho_{nn} \end{Vmatrix} \times \begin{Vmatrix} & \text{``} & \end{Vmatrix} \qquad (14)$$

$$\begin{Vmatrix} \sigma'_{11} & \cdots & \sigma'_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \sigma'_{1n} & \cdots & \sigma'_{nn} \end{Vmatrix} = \begin{Vmatrix} & \text{``} & \end{Vmatrix} \times \begin{Vmatrix} \sigma_{11} & \cdots & \sigma_{1n} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \cdot & & \cdot \\ \sigma_{1n} & \cdots & \sigma_{nn} \end{Vmatrix} \times \begin{Vmatrix} & \text{``} & \end{Vmatrix}$$

where λ, ρ, and σ are the elements of the given network, and λ', ρ' and σ' represent the elements of the system of equivalent networks. The minimal networks for the general case may be obtained in a manner similar to that of the two-mesh example, although it may be possible to arrive at simplifying rules for obtaining the equivalent minimal networks.

Extensions of this theory may be made to networks of an infinite member of degrees of freedom, such as lumped or continuous lines and by the principle of superposition, to networks of any number of terminals. The equivalence of networks may also be generalized to include equivalence of transfer impedance as well as the driving-point impedance, and by suitable restrictions on the a elements of the transformation matrix to equivalence with respect to more than one mesh. Finally, as in the solution of three-phase alternating-current problems, simplification results by transforming from Y to Δ or vice versa, so in the solution of the transient currents of networks, simplification may result by transformation to an equivalent network. And the solution for the transient mesh current in one network gives, of course, the corresponding transient mesh current in the infinite set of equivalent networks, the other transient mesh currents being obtained by a linear transformation.[4]

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THE NONUNIFORM TRANSMISSION LINE*

BY

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Summary—*The problem of transmission of periodic waves along a transmission line, whose series impedance and shunt admittance per unit length vary as any powers of the distance from some point, is solved. The solution is given in terms of Bessel functions. A length of such a line is considered as a four-terminal network, and the more important parameters of the network are given. From these parameters one derives immediately the attenuation of current and voltage along the line. The solution is given for a line consisting of a number of parts, each of which is of the form described above. The line constants (so-called) need not vary continuously from one part to the next. The results can be applied to the cases of a tapered submarine cable, an overhead line with a pronounced sag, and end effects in a high tension line.*

INTRODUCTION

THE theory of the nonuniform line has been treated by various people. A general solution was obtained by Ravut,[1] who obtained the solution in the form of an infinite series. Ravut assumed that the line constants were differentiable with respect to distance along the line. This is, of course, an important restriction. It follows that the line constants must vary continuously.

Later J. R. Carson[2] obtained the solution of the general case in the form of an infinite series of integrals. This solution is more unrestricted than the solution of Ravut, in that the only assumption made is that the line constants are integrable. Discontinuities are permissible. In fact, it is difficult to imagine a physical transmission line, in which the line constants are not integrable.

Ballantine[3] solved the case of a transmission line in which the series and shunt impedances per unit length were both proportional to the same power of the distance from the origin, the solution being found in Bessel functions.

Arnold and Bechberger[4] found the solution, in the form of an in-

* Decimal classification: 621.319.2. Original manuscript received by the Institute, February 16, 1932.

[1] C. Ravut, "Propagation des courants sinusoidaux sur des lignes quelconques, "*Révue Générale de l'Eléctricité,*" vol. 7, no. 19, p. 611–615; May 8, (1920).

[2] J. R. Carson, "Propagation of periodic currents over non-uniform lines," *Electrician*, vol. 86, no. 10, p. 272–273; March 4, (1921).

[3] S. Ballantine, "Non-uniform lumped electric lines," *Jour. Frank. Inst.*, vol. 203, p. 561–582; April, (1927); discussion p. 849–853.

[4] Arnold and Bechberger, "Sinusoidal currents in linearly tapered loaded transmission lines," PROC. I.R.E., vol. 19, p. 304–310; February, (1931).

finite series, for the case when the series impedance varied linearly, but the shunt admittance is constant.

M. E. Federici[5] solved this last case, but found the solution in the more convenient form of Bessel functions.

The author found the same solution for the linearly tapered line, but it transpires that a much more general case can be solved in terms of Bessel functions, which includes the solutions of Ballantine and the linearly tapered line as particular cases. This paper solves this more general case, when the series impedance and shunt admittance vary as any powers of the distance from a point. Also the more important parameters of such a line are found from the solution.

A General Type of Nonuniform Transmission Line

In a transmission line, let all distances be measured from an origin, the distance of any point from the origin being designated x, the series impedance per unit length at any point be Z, and the shunt admittance be Y, the line current and voltage at the point be i and v, respectively. The equations for i and v are

$$-\frac{di}{dx} = Yv \tag{1}$$

and,

$$-\frac{dv}{dx} = Zi. \tag{2}$$

Substituting in (1) for i from (2) we obtain

$$Yv = \frac{d}{dx}\left(\frac{1}{Z}\frac{dv}{dx}\right),$$

giving,

$$\frac{d^2v}{dx^2} - \frac{Z'}{Z}\frac{dv}{dx} - YZv = 0. \tag{3}$$

This is the differential equation for v, and it assumes that Z has a differential coefficient with respect to x, which we have written Z'. It may be noted here that Carson's solution does not assume this restriction on Z, and hence is much more general than any solution based on (3), which holds only for a part of a line in which Z is differentiable and, in consequence, continuous. By the symmetrical form of (1) and (2), it is clear that the equation for i is

[5] M. E. Federici, "Su di un nuovo tipo di cavo elettrico disunforme," *Rendiconti della R. Accad. Naz. dei Linzei*, vol. XIII, 6a, p. 128–132; gennaio 1931–IX.

$$\frac{d^2i}{dx^2} - \frac{Y'}{Y}\frac{di}{dx} - YZi = 0. \tag{4}$$

Let,

$$Z = zx^\alpha \tag{5}$$

and,

$$Y = yx^\beta, \tag{6}$$

equation (3) becomes

$$\frac{d^2v}{dx^2} - \frac{\alpha}{x}\frac{dv}{dx} - (yzx^{\alpha+\beta})v = 0. \tag{7}$$

Put,

$$v = x^p u \tag{8}$$

and,

$$w = x^q, \tag{9}$$

substituting from (8) and (9) in equation (7) we derive

$$\begin{aligned} \frac{d^2u}{dw^2} &+ \frac{2p+q-\alpha-I}{q}\frac{Idu}{wdw} \\ &+ \left[\frac{p(p-\alpha-I)}{q^2w^2} - \frac{yz}{q^2}x^{\alpha+\beta+2-2q}\right]u = 0. \end{aligned} \tag{10}$$

On making,

$$\frac{2p+q-\alpha-I}{q} = I$$

and,

$$\alpha+\beta+2-2q = 0$$

viz,

$$p = (I+\alpha)/2, \tag{11}$$

and,

$$q = (\alpha+\beta+2)/2, \tag{12}$$

equation (10) reduces to

$$\frac{d^2u}{dw^2} + \frac{I}{w}\frac{du}{dw} + \left[\frac{-4yz}{(2+\alpha+\beta)^2} - \left\{\frac{1+\alpha}{2+\alpha+\beta}\right\}^2\frac{1}{w^2}\right]u = 0. \tag{13}$$

The solution of (13) is

$$u = J_{(\pm I+\alpha)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta}w\right].$$

From (8), (9), (11), and (12) we get

$$v = x^p u$$

$$= x^{(1+\alpha)/2} J_{(\pm 1+\alpha)/(2+\alpha+\beta)} \left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2} \right]. \tag{14}$$

By symmetry we find

$$i = x^{(1+\beta)/2} J_{(\pm 1+\beta)/(2+\alpha+\beta)} \left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2} \right]. \tag{15}$$

When $(1+\alpha)/(2+\alpha+\beta)$ is an integer, m say, the Bessel's functions of plus and minus order are not independent and the functions are then J_m and Y_m, Y_m being the Bessel function of the second kind.

Having obtained v in (14), there are two arbitrary constants. Equation (15) then gives the form of i, but not its arbitrary constants, which must be obtained from the arbitrary constants of v by use of (2). This will now be done for the case when $(1+\alpha)/(2+\alpha+\beta)$ is not an integer.

Let,

$$f_1(x) = x^{(1+\alpha)/2} J_{(1+\alpha)/(2+\alpha+\beta)} \left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2} \right] \tag{16a}$$

and,

$$f_2(x) = x^{(1+\alpha)/2} J_{(-1+\alpha)/(2+\alpha+\beta)} \left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2} \right]. \tag{16b}$$

Then,

$$v = Af_1(x) + Bf_2(x) \tag{17a}$$

A *and* B being arbitrary constants.

Equation (2) then gives

$$i = -\frac{1}{Z}\frac{dv}{dx}$$

$$= -\frac{1}{zx^\alpha}[Af_1'(x) + Bf_2'(x)].$$

It is clear that,

$$f_1(x) = w^{(1+\alpha)/(2+\alpha+\beta)} J_{(1+\alpha)/(2+\alpha+\beta)} \left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w \right],$$

so that,

$$f_1'(x) = \frac{df_1(x)}{dw}\frac{dw}{dx}$$

$$= w^{(1+\alpha)/(2+\alpha+\beta)} J_{(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w\right] x^{(2j\sqrt{yz})/(2+\alpha+\beta)} \cdot \frac{dw}{dx},$$

because,

$$\frac{d}{dw}[w^n J_n(kw)] = kw^n J_{n-1}(kw),$$

and thus,

$$f_1'(x) = j\sqrt{yz}\, x^{(1+2\alpha+\beta)/2} J_{(-(1+\beta))/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w\right],$$

Similarly,

$$f_2'(x) = -j\sqrt{yz}\, x^{(1+2\alpha+\beta)/2} J_{(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w\right],$$

and hence,

$$i = -Aj\sqrt{\frac{y}{z}}\, x^{(1+\beta)/2} J_{-(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w\right]$$

$$+ Bj\sqrt{\frac{y}{z}}\, x^{(1+\beta)/2} J_{(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} w\right].$$

Writing,

$$f_3(x) = -j\sqrt{\frac{y}{z}}\, x^{(1+\beta)/2} J_{-(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2}\right] \quad (16c)$$

and,

$$f_4(x) = j\sqrt{\frac{y}{z}}\, x^{(1+\beta)/2} J_{(1+\beta)/(2+\alpha+\beta)}\left[\frac{2j\sqrt{yz}}{2+\alpha+\beta} x^{(2+\alpha+\beta)/2}\right] \quad (16d)$$

we have,

$$i = Af_3(x) + Bf_4(x). \quad (17b)$$

It is seen that $f_3(x)$ and $f_4(x)$ are of the forms given in (15). Equations (16) and (17) are the solution of the problem in terms of the two arbitrary constants.

Some Particular Cases

Case 1

$\alpha=0$, $\beta=0$. The line is uniform.

$$f_1(x) = x^{1/2} J_{\frac{1}{2}}[j\sqrt{yz}\,x]$$

$$= +\, x^{1/2} \sqrt{\frac{2}{\pi}} \sin(j\sqrt{yz}\,x)/\sqrt{j\sqrt{yz}\,x}$$

$$= \sqrt{\frac{2j}{\pi\sqrt{yz}}} \sinh(\sqrt{yz}\,x),$$

$$f_2(x) = x^{1/2} J_{-\frac{1}{2}}(j\sqrt{yz}\,x)$$

$$= \sqrt{\frac{2}{j\pi\sqrt{yz}}} \cosh(\sqrt{yz}\,x),$$

$$f_3(x) = -j\sqrt{\frac{y}{z}}\, f_2(x),$$

and,

$$f_4(x) = j\sqrt{\frac{y}{z}}\, f_1(x),$$

which on substitution in (17a) and (17b) give the ordinary solution in terms of hyperbolic series and cosines.

Case 2

$\beta=-\alpha$. Ballantine calls this the Bessel line.

$$f_1(x) = x^{(1+\alpha)/2} J_{(1+\alpha)/2}[j\sqrt{yz}\,x],$$

$$f_2(x) = x^{(1+\alpha)/2} J_{-(1+\alpha)/2}[j\sqrt{yz}\,x],$$

$$f_3(x) = -j\sqrt{\frac{y}{x}}\, x^{(1-\alpha)/2} J_{-(1+\alpha)/2}[j\sqrt{yz}\,x],$$

$$f_4(x) = j\sqrt{\frac{y}{z}}\, x^{(1-\alpha)/2} J_{(1-\alpha)/2}[j\sqrt{yz}\,x],$$

agreeing with the form given by Ballantine. In this case, if α is any even integer, the Bessel functions can be expressed simply in terms of sines and cosines. An example in Case 1, where $\alpha=0$, and another case is $\alpha=\pm 2$, when it can be shown that the functions f_1, f_2, f_3, f_4 are composed of terms like $x^{\pm 1}$, $e^{\pm kx}$, and $e^{\pm kx}$.

Case 3

$\alpha=1$, $\beta=0$. This is the linearly tapered line treated by Arnold and Bechberger and by Federici. The series impedance tapers, but the shunt admittance is constant.
Then,

$$\left.\begin{aligned} f_1(x) &= xJ_{2/3}\left[\tfrac{2}{3}j\sqrt{yz}\,x^{3/2}\right], \\ f_2(x) &= xJ_{-2/3}\left[\tfrac{2}{3}j\sqrt{yz}\,x^{3/2}\right], \\ f_3(x) &= -j\sqrt{\frac{y}{z}}\,x^{1/2}J_{-1/3}\left[\tfrac{2}{3}j\sqrt{yz}\,x^{3/2}\right], \\ \text{and,}\qquad & \\ f_4(x) &= j\sqrt{\frac{y}{z}}\,x^{1/2}J_{1/3}\left[\tfrac{2}{3}j\sqrt{yz}\,x^{3/2}\right]. \end{aligned}\right\} \tag{18}$$

If the shunt admittance tapers, but the series admittance is constant $\alpha=0$ and $\beta=1$. For this f_1 and f_2 have the forms of f_3 and f_4 just given, and f_3 and f_4 the forms of f_1 and f_2 just given. The constants are slightly different, and may be found from (16).

Case 4

$\alpha=-1$, $\beta=0$. This is a useful case and may be used for certain end effects in cable sheaths and similar problems.

$$\left.\begin{aligned} f_1(x) &= J_0\left[2j\sqrt{yz}\,x^{1/2}\right], \\ f_2(x) &= Y_0\left[2j\sqrt{yz}\,x^{1/2}\right], \\ f_3(x) &= -j\sqrt{\frac{y}{z}}\,x^{1/2}J_{-1}\left[2j\sqrt{yz}\,x^{1/2}\right] \\ \text{and,}\qquad & \\ f_4(x) &= j\sqrt{\frac{y}{z}}\,x^{1/2}Y_{-1}\left[2j\sqrt{yz}\,x^{1/2}\right]. \end{aligned}\right\} \tag{19}$$

Case 5

$\alpha+\beta=-2$. The order of the Bessel functions becomes infinite, and the problem reduces to a very simple case. Equation (7) is now

$$\frac{d^2v}{dx^2}-\frac{\alpha}{x}\frac{dv}{dx}-yz\frac{v}{x^2}=0.$$

which is a homogeneous equation. The substitution $x = e^w$ reduces this equation to

$$\frac{d^2v}{dw^2} - (1 + \alpha)\frac{dv}{dw} - yz\,v = 0,$$

of which the solution is

$$\begin{aligned} v &= Ae^{mw} + Be^{nw}, \\ &= Ax^m + Bx^n, \end{aligned}$$

where,

$$m = (1 + \alpha)/2 + \tfrac{1}{2}\sqrt{(1 + \alpha)^2 + 4yz}$$

and,

$$n = (1 + \alpha)/2 = \tfrac{1}{2}\sqrt{(1 + \alpha)^2 + 4yz}.$$

It is then seen that $i = -(1/z)\,[Amx^{m-\alpha-1} + Bnx^{n-\alpha-1}]$.

Case 6

$\alpha = \beta$. Both series impedance and shunt admittance taper linearly, both from the same point. The Bessel function are here again of order $\pm\frac{1}{2}$ and so they can be expressed in terms of hyperbolic sines and cosines.

The Line as a Four-Terminal Network

Consider that part of the line between the points $x = x_1$ and $x = x_2$, and let v_1, i_1, v_2, and i_2 be the voltages and currents at the ends. These are given by (17a) and (17b) on substituting the appropriate values of x.

$$\begin{aligned} v_1 &= Af_1(x_1) + Bf_2(x_1), \\ v_2 &= Af_1(x_2) + Bf_2(x_2), \\ i_1 &= Af_3(x_1) + Bf_4(x_1), \\ i_2 &= Af_3(x_2) + Bf_4(x_2). \end{aligned}$$

We can solve for A and B in terms of i_2, v_2, and functions of x_2, and on substituting these values in i_1 and v_1 we obtain

$$\begin{aligned} i_1 &= ai_2 + bv_2, \\ v_1 &= ci_2 + dv_2, \end{aligned} \tag{20}$$

where,

$$\left.\begin{aligned} a &= [f_4(x_1)f_1(x_2) - f_3(x_1)f_2(x_2)]/D, \\ b &= [f_3(x_1)f_4(x_2) - f_4(x_1)f_3(x_2)]/D, \\ c &= [f_2(x_1)f_1(x_2) - f_1(x_1)f_2(x_2)]/D, \\ d &= [f_1(x_1)f_4(x_2) - f_2(x_1)f_3(x_2)]/D, \\ \text{and,}\quad D &= f_2(x_2)f_3(x_2) - f_1(x_2)f_4(x_2). \end{aligned}\right\} \tag{21}$$

It can be shown that $ad-bc=1$. These four numbers a, b, c, d, of which only 3 are independent give the properties of the line between $x=x_1$ and $x=x_2$, which can be considered as a four-terminal network. The well-known image parameters, the image impedances and image transfer constant, can be immediately found from a, b, c, and d as follows.

Let the image impedances be called Z_1 and Z_2, and are such that the impedance looking in at x_1 is Z_1, when x_2 is terminated by Z_2, and the impedance looking in at x_2 is Z_2 when x_1 is terminated by Z_1.

This is equivalent to saying that

when,
$$\left.\begin{aligned} v_1 &= i_1 Z_1 \\ v_2 &= i_2 Z_2, \end{aligned}\right\} \tag{22}$$

and,

when,
$$\left.\begin{aligned} v_1 &= -\,i_1 Z_1 \\ v_2 &= -\,i_2 Z_2. \end{aligned}\right\} \tag{23}$$

Substituting for v_1 and v_2 from (22) in (20) we get

$$Z_1 = \frac{c + dZ_2}{a + bZ_2}. \tag{24}$$

Substituting from (23) in (20) we get

$$-Z_1 = \frac{c - dZ_2}{a - bZ_2}. \tag{25}$$

From (24) and (25) we get

$$Z_1 = \sqrt{\frac{cd}{ab}} \tag{26}$$

and,

$$Z_2 = \sqrt{\frac{ac}{bd}}. \tag{27}$$

There are two image transfer constants, one for each direction. Suppose an e.m.f. is applied at x_1, then $T_{12}=\log_e (i_1/i_2)$, provided x_2 is terminated by Z_2. This gives that

$$\begin{aligned} T_{12} &= \log_e (a + bZ_2) \\ &= \log_e \sqrt{\frac{a}{d}} (\sqrt{ad} + \sqrt{bc}). \end{aligned} \tag{28}$$

If an e.m.f. is applied at x_2, and x_1 is terminated by Z_1, $T_{21}=\log_e (i_2/i_1)$, giving

$$T_{21} = \log_e 1/(a - bZ_2)$$

$$= \log_e \sqrt{\frac{d}{a}} (\sqrt{ad} + \sqrt{bc}). \tag{29}$$

The image transfer constant, T, is the mean of T_{12} and T_{21}, so that,

$$T = \log_e (\sqrt{ad} + \sqrt{bc}). \tag{30}$$

It is easy to see from (28) and (29) that

$$Z_1\, e^{T_{12}} = Z_2\, e^{T_{21}},$$

which is in accordance with the reciprocal theorem for passive networks.

Voltage and Current Attenuation

Because the impedances vary along the length of the line, the voltage and current will suffer unequal attenuations, which will depend upon terminal conditions at the far end. If the line goes off to infinity, we proceed as follows.

Express $f_1(x)$ as $g_1(x)+h_1(x)$, where $g_1(x)$ becomes zero at infinity and $h_1(x)$ becomes infinite. In order that v should become zero at infinity, we must have

$$v = (A + B)[g_1(x) + g_2(x)]$$
$$= D[g_1(x) + g_2(x)], \text{ say},$$

and similarly,

$$i = D[g_3(x) + g_4(x)].$$

Then v is attenuated according to the law $g_1(x)+g_2(x)$, and i according to the law $g_3(x)+g_4(x)$.

The case of a finite line can be treated by the ordinary passive network theory, involving the image parameters.

Successive Nonuniform Lines

If any two or more lines are placed in tandem, the total can be considered as a four-terminal network, whose parameters can be easily found from the parameters of each part. If one part with parameters (a_1, b_1, c_1, d_1), is before a part with parameters (a_2, b_2, c_2, d_2), the combination has parameters $(a_1a_2+b_1c_2,\ a_1b_2+b_1d_2,\ c_1a_2+d_1c_2,\ c_1b_2+d_1d_2)$ according to the ordinary formula for the multiplication of matrices; viz., the parameters (A, B, C, D) of the combination is given by

$$\begin{Vmatrix} A, & B \\ C, & D \end{Vmatrix} = \begin{Vmatrix} a_1, & b_1 \\ c_1, & d_1 \end{Vmatrix} \times \begin{Vmatrix} a_2, & b_2 \\ c_2, & d_2 \end{Vmatrix}.$$

This can be continued for any number, and the parameters of any number of such lines in tandem is given by

$$\begin{Vmatrix} a_1, & b_1 \\ c_1, & d_1 \end{Vmatrix} \times \begin{Vmatrix} a_2, & b_2 \\ c_2, & d_2 \end{Vmatrix} \times \begin{Vmatrix} a_3 & ,b_3 \\ c_3 & ,d_3 \end{Vmatrix} \times \cdots$$

The parameters of each portion being found, the parameters of the combination can thus be calculated. Continuity of characteristics is unnecessary.

Applications

1. Tapered Submarine Cable

Long submarine cables, which are loaded, have been laid down, the loading tapering from the ends towards the middle. Each half can be considered as a four-terminal network with parameters (a, b, c, d), and these networks are placed back to back. If the network with parameters (a, b, c, d) is reversed, the new parameters are (d, b, c, a), provided the network is composed of passive elements so that $ad-bc=1$. The parameters of the resulting network are then seen to be $(ad+bc, 2ab, 2cd, ad+bc)$. We find (a, b, c, d) as follows.

R, G, and C are fixed, but $L=L_0\,(1+te)$, e being the distance from the shore end. Then,

$$Z = R + j\omega L_0(1 + te)$$

and,

$$Y = G + j\omega C.$$

This reduces to Case 3 and the parameters are given as Bessel's functions of $(2\sqrt{G+j\omega C}/3\omega L_0 t)\,(R+j\omega L)^{3/2}$ of orders $\pm\frac{2}{3}$ and $\pm\frac{1}{3}$. The image impedance at the shore ends is $\sqrt{[2cd(ad+bc)]/[(ad+bc)2ab]} = \sqrt{cd/ad}$, and this can be used for the determination of balancing for duplex working.

2. Sagging Overhead Line

If there were a single overhead wire with a pronounced sag, we should have a capacity variation, which we can consider as a linear taper from the poles towards the mid-pole point to a first approximation. This gives $\alpha=0$ and $\beta=1$ and the case is very much like that of the first application. Each half between two poles has parameters (a, b, c, d) and each pole length has parameters $(ad+bc, 2ab, 2cd, ad+bc)$, where (a, b, c, d) are given in Bessel functions of order $\pm\frac{1}{3}$, $\pm\frac{2}{3}$. Each pole length is a symmetrical four-terminal network with image impedance Z_1 at each end and propagation constant θ given by

$$Z_1 = \sqrt{\frac{cd}{ab}}.$$

and,

$$\theta = 2 \log_e (\sqrt{ad} + bc).$$

If there are n pole lengths, the image impedance of the whole is still Z_1, but the propagation constant is $n\theta$.

3. End Effect in a High Tension Line

When a cable end is opened and the sheath is stripped back from the dielectric, if a high voltage is applied between the core and the sheath, there is a high nonuniform potential gradient along the uncovered dielectric. This portion is sometimes wound with asbestos twine, a semiconductor, to equalize the potential gradient. In this case we can put R proportional to x^{-n}, x being the distance from the core towards the sheath and $L=0$. The potential between the outer surface of the dielectric and the core can be found in terms of Bessel functions of order $\pm(1+n)/(2+n)$, and the potential gradient in Bessel functions of order $\pm 1/(2+n)$. For an approximate and easy calculation, we can take R as proportional to the distance squared from the sheath, and then the potential gradient varies as a simple power of this distance.

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DISCUSSION ON "QUARTZ PLATE MOUNTINGS AND TEMPERATURE CONTROL FOR PIEZO OSCILLATORS"*

VINCENT E. HEATON AND E. G. LAPHAM

Victor J. Andrew:[1] The writer has used quartz plate mountings similar to those described in this article, and should like to add to the excellent material presented by the authors. 30-kc quartz plates vibrating in the "extensional mode" and with dimensions approximately 4 inches $\times$ 1 inch $\times$ 1/8 inch were used.

Electrodes were tried in the form of a thin metallic film on the surfaces of the quartz plate similar to the sputtered platinum film described by the authors. Sputtering apparatus not being available, the metallic film was applied by the much cruder method of rubbing a piece of soft metal on the rough ground surface of the quartz plate. The intimate contact between the electrodes and the quartz plate made the circuit particularly easy to start into oscillation. A quartz plate with a silver film and in a mounting similar to Fig. 4 of the paper had a constancy of frequency as great as similar uncoated quartz plates, which was several times as great as the 1 in 20,000 which the authors observed in a quartz plate with sputtered electrodes. It seems likely that their variation was due to something in the mounting or circuit other than the coating on the quartz plate. This form of electrodes seems to have possibilities worth further investigation.

A number of forms of clamps on the two largest surfaces of the quartz plate similar to Fig. 3 (three points of contact on each surface) and Fig. 4 (a line or narrow area across the 1 inch dimension of each surface) were tried. The motion of a quartz plate within half an inch of the center is small compared to that near the ends, so the location of the clamps within that area makes no great difference. A contact with the surface within 1 inch of either end, or any contact extending more than 1/16 inch along the length damps the quartz plate so much that it is difficult to obtain oscillation.

The pressure applied to the clamps has a large influence on the frequency, and consequently the holder must be so constructed that the pressure is constant, or varies consistently with temperature. A variation of pressure with temperature causes a change of frequency with temperature which is added algebraically to that inherent in the quartz plate. This principle might be applied to designing an oscillator with a zero frequency-temperature coefficient. Pressures up to at least 25 pounds on clamps which have a small area of contact do not damp the quartz plate too much to permit oscillation. Consequently the clamps may be held against the quartz plate by a very stiff spring when the oscillator is intended for portable use.

* PROC. I.R.E., vol. 20, p. 261, February, (1932).
[1] University of Chicago, Chicago, Ill. Formerly Westinghouse Electric and Manufacturing Company, Chiçopee Falls, Mass.

BOOK REVIEWS

The Federal Radio Commission (Service Monograph No. 65), by Laurence F. Schmeckebier. Published by The Brookings Institution, Washington, D. C. 159 pages, 8vo., 1932, cloth. Price $1.50.

This monograph is a concise survey of the functions of the Federal regulatory, administrative and legal bodies concerned in the administration of radio.

Included in this monograph is an interesting and valuable history of the early use and regulation of radio, illustrating very clearly the efforts made to substitute order for chaos in radio service.

The routine activities of the Federal Radio Commission are amply disclosed, including the relations members of Congress have had in the regulatory function of the Federal Radio Commission. There is also described the related activities of the Department of Commerce, the State Department and the general functions of the Court of Appeals of the District of Columbia, as well as those of the Supreme Court of the United States, with respect to the decisions and activities of the Federal Radio Commission.

An interesting description is given of the organization of the Federal Radio Commission, in which the duties of the various sections are outlined in such a manner as to be useful to those interested in securing franchises from the Commission.

Included in the volume are a transcript of the laws relating to the Federal control of radio, a bibliography of books and articles on that subject, and data with respect to information required by the Federal Radio Commission before a license is granted.

This book forms a very useful handbook for radio stations and a useful guide for applicants for radio facilities, as well as an instructive outline for the legal profession and others desiring a clear and concise digest of various factors involved in Federal radio regulation.

*T. A. M. Craven

* Consulting radio engineer, Washington, D.C.

Handbook of Chemistry and Physics, by Hodgman-Lange, Sixteenth Edition, 1545 pages. Price $5. Chemical Rubber Publishing Co., Cleveland, Ohio.

The book contains very complete tables for the mathematician, physicist, and chemist. Of particular interest to the radio engineer are the 18 pages of radio formulas and tables including the new tables of vacuum tube characteristics. There are over 130 pages of electrical tables in addition to the above. A table of trigonometric functions for decimal fractions of degrees will be found in this edition as well as the usual table for degrees and minutes, making a total of 178 pages of mathematical formulas and tables.

*K. A. Norton

* Bureau of Standards, Washington, D.C.

BOOKLETS, CATALOGS, AND PAMPHLETS RECEIVED

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

"Colloidal Graphite" is the name of the 24-page brochure issued by the Acheson Oildag Company of Port Huron, Mich., outlining the properties, uses, and advantages of colloidal graphite lubricants. A number of technical bulletins are also available dealing with the various phases of the use of colloidal graphite. Of these, perhaps the most interesting to radio engineers are Bulletin No. 31.2, entitled "Colloidal Graphite as a Retardant of Secondary Emission in Vacuum Tubes," and Bulletin No. 11.3, "The Use of Colloidal Graphite in the Manufacture of Electrical Resistances."

A loose-leaf binder issued by the Acme Wire Company of New Haven, Conn., contains a number of bulletins giving the properties and specifications of copper wires, varnished cambric insulations, and coil winding assemblies.

Several folders are available from the American Instrument Company, 774–776 Girard St., N.W., Washington, D. C., describing sensitive relays and thermostatic regulators which have important applications in temperature controlled quartz crystal oscillators.

The Bakelite Corporation, 247 Park Ave., New York, N. Y., has for distribution booklets describing various types of bakelite. "Bakelite Laminated" is the title of a 40-page booklet describing the manufacture and use of laminated fabrics impregnated with phenol resins. "Bakelite Molded" deals with bakelite molding materials and their uses with a brief description of the molding process and equipment required for the purpose. The booklet on "Bakelite Varnish" is concerned with the properties, uses, and methods of application of varnish, enamel, lacquer, and cement bakelite products.

Bulletin Q-202 of the Brush Development Company of Cleveland, Ohio, gives a general description and the operating principles of a piezo-electric microphone suitable for high-class broadcasting and recording. Another leaflet describes the electrical and physical characteristics of the Brush piezo-electric loud speaker.

A 48-page handbook on "Tungsten, Molybdenum, and Special Alloys" issued by the Callite Products Company, Union City, N. J., gives the history, properties, and uses of a number of metallurgical products and alloys for radio, incandescent lamp, and the electrical industries. Approximately half of the pages are devoted to tables giving the specifications of various metals and wires manufactured by Callite Products, Inc.

The advantages of fixed resistors manufactured by Continental Carbon, Inc., 13900 Lorain Ave., Cleveland, Ohio, are given in a folder entitled "Resistors for Radio Applications."

Catalog No. 30 describes solid and stranded wire manufactured for radio purposes by the Cornish Wire Company, Inc., 30 Church St., New York, N. Y. Radio hook-up wire manufactured by this concern is treated separately in catalog No. 25.

Several audio amplifiers and a radio-frequency tuner and amplifier as well as a complete line of fixed and variable resistors are described in "Electrad Products," a recent catalog of Electrad, Inc., 175 Varick St., New York, N. Y.

RADIO ABSTRACTS AND REFERENCES

THIS is prepared monthly by the Bureau of Standards,* and is intended to cover the more important papers of interest to the professional radio engineer which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the "Classification of Radio Subjects: An Extension of the Dewey Decimal System," Bureau of Standards Circular No. 385, obtainable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 10 cents a copy. The classification also appeared in full on pp. 1433–56 of the August, 1930, issue of the PROCEEDINGS of the Institute of Radio Engineers.

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

R000. RADIO (GENERAL)

R007 ×R550 A. D. Ring. Empirical standards for broadcast allocation. PROC. I.R.E., vol. **20**, pp. 611–625; April, (1932).

The method used by the Engineering Division of the Federal Radio Commission in determining empirical standards of reception, interference, and service area is explained, for consideration in connection with the engineering aspects of the allocation of radio broadcast facilities. The average good service areas of 100-watt local channel stations, 250 to 1000-watt regional channel stations, 5000 to 10,000-watt high power regional channel stations, and 5000 to 50,000-watt clear channel stations are defined with reference to the voltage intensity ratio of the desired signal to the undesired signal incidental to specified mileage and kilocycle separations between stations.

R100. RADIO PRINCIPLES

R113 R. K. Potter and H. T. Friis. Some effects of topography and ground on short-wave reception. PROC. I.R.E., vol. **20**, pp. 699–721; April, (1932).

This paper contains some results of an experimental study of the effects which ground and ground irregularities have upon short-wave signal reception. The results illustrate the signal strength advantage to be gained in the selection of suitable ground or topographical conditions and show the influence of antenna types, and vertical angle of signal arrival, upon such an advantage.

R113.2 L. W. Austin. Tables of North Atlantic radio transmission conditions for long-wave daylight signals for the years 1922–1930. PROC. I.R.E., vol. **20**, pp. 689–98; April, (1932).

Tables presenting daylight transmission conditions between Europe and the northeastern United States for frequencies of 15–23 kc. These are derived from signal intensity measurements made in Washington on a number of low frequency European transmitting stations averaged according to a method previously described.

R113.5 H. T. Stetson. Radio reception and sunspots. *Electronics*, vol **4**, pp. 122–123; April, (1932).

From an experimental study of radio reception, it is found that reception at a great distance from radio transmitter is best during a sunspot minimum. The local range, 30–50 miles, has best reception during sunspot maxima.

R113.61 H. Rukop and R. Wolf. Ein leistungsfähige Einrichtung für Messungen an den Heavisideschichten. (An efficient arrangement for

* This list compiled by Mr. A. H. Hodge and Miss E. M. Zandonini.

measuring the apparent heights of the Kennelly-Heaviside layers.) *Zeit. für Tech. Physik,* vol. **13**, pp. 132–134. No. 3; (1932).

The authors describe an automatic apparatus for continuously recording the virtual heights of ionized layers in the upper atmosphere.

R113.7 J. H. Dellinger, Distance ranges of radio waves. *Radio Engineering,* vol. **12**, pp. 18–19; April, (1932).

Approximate distance ranges of radio waves throughout the frequency range are shown graphically. A list of references is given.

R114 F. Schindelhauer. Über zwei verschiedene Arten von Atmosphärischen Störungen. (Two different types of atmospheric disturbances.) *Elekt. Nach. technik,* vol. **9**, pp. 41–45; February, (1932).

In an effort to determine the nature and origin of atmospheric disturbances, radio direction finding methods have been applied to record the incident direction of such disturbances. Observations are made with the following apparatus: A vertical loop antenna is caused to rotate at the rate of six revolutions per hour by means of a clock mechanism. The output of the antenna is connected to a radio receiver and drum recorder. The record gives the number, direction (with 180 ambiguity) and magnitude of received static impulses. Records of two such recording stations are required to obtain the absolute bearing of the disturbance source.

R120 ×R113.7 J. S. McPetrie. A method of determining the effect of the earth on the radiation from aerial systems. *Jour. I.E.E.* (London), vol. **70**, pp. 382–390; March, (1932).

A method of considering the image of the radiator in the earth is given. A formula is deduced for the field at any point near the earth's surface due to a given doublet, and it is shown how this formula may be extended in order to determine the field at various distances from an antenna carrying a current of known distribution. The field at any distant point may be found directly for any number of equal antennas and reflectors from a knowledge of the field at the same point due to one antenna and reflector alone.

R125 E. Siegel and J. Labus. Feldverteilung und Energiemission von Richtantennen. (Field distribution and energy emission of directional antennas.) *Hochfrequenztechnik und Elektroakustik.* vol. **39**, pp. 86–93; March, (1932).

Proceeding from the van der Pol solution for the electric field produced by a dipole antenna and the energy emitted by a dipole antenna, the field distribution and energy emission of a half-wave antenna and of a combination of equiphased dipoles are investigated. A formula for the calculation of field distribution in space and the radiation resistance is given.

R131 B. Giovanni. Étude des faibles oscillations des générateurs à lampes. (Study of weak oscillations of electron tube generators.) *L'Onde Electrique,* vol. **11**, pp. 89–100; February, (1932).

Study of circuits containing three-electrode tubes near the limit of generation of oscillations. The expression of the amplitude and frequency of oscillation as a function of the resistance of oscillating circuit. Conditions which determine whether generation builds up abruptly or slowly.

R134 G. S. C. Lucas. The graphical solution of detector problems. *Wireless Engineer and Experimental Wireless* (London), vol. **9**, pp. 202–207; April, (1932).

An approximate method which is applicable to problems in anode bend or grid detection with the diode, triode, screen-grid and pentode tubes is presented.

R134 H. A. Brown and C. T. Knipp. Power detection characteristics of pentode tubes. *Electronics,* vol. **4**, pp. 126–127; April, (1932).

Output and distortion tests were made on pentode tubes used as detectors. The pentode was found to have very desirable characteristics as a detector. It was found that as a power detector the pentode delivered 10 times as much power as other detectors noted.

R138 R. DeCola. Ionization in vacuum tubes. *Radio Engineering,* vol. **12**, pp. 15–16; April, (1932).

A physical explanation of blue glow within vacuum tubes. Interaction between liberated electrons and ions.

R139 G. A. Beauvais. Potentiel stable d'une électrode isolée dans une lampe triode (Stable potential of an isolated electrode in a three-electrode vacuum tube.) *L'Onde Electrique*, vol. **11**, pp. 83–88; February, (1932).

In this article the author points out that an isolated electrode of a triode can keep, in a stable manner, a potential different from zero on condition that the other electrode is brought to a high voltage; and discusses the explanation of this phenomena.

R143 R. Lee. Rectifier filter circuits. *Electric Journal*, vol. **29**, pp. 186–192; April, (1932).

Rectifier and filter circuits are discussed. Considerable data are presented. The Fourier method of analysis is used.

R161.1 R. H. Langley. An examination of selectivity. Proc. I.R.E., vol. **20**, pp. 657–673; April, (1932).

The present selectivity requirements are developed and a simple mathematical treatment is expanded to meet them. The criterion for uniform ability to reject undesired signals for both condenser and inductance tuning results from this calculation. The relation of the selectivity curve, as now taken and presented, to the actual performance of the receiver is discussed. Possible improvements in the definition, method of measurement, and presentation of data, are suggested.

R200. Radio Measurements and Standardization

R241 High-resistance measurements. *Electronics*, vol. **4**, p. 94; March, (1932).

An inexpensive portable arrangement which employs the General Electric low-grid current tube FP-54 enables one to measure high resistances. Circuits and constants are given.

R243.1 B. B. Bryant. Using the vacuum-tube voltmeter. *Radio Craft*, vol. **3**, p. 676; May, (1932).

Uses of the vacuum-tube voltmeter with particular reference to radio servicing and measurement.

R261 R. L. Smith-Rose and H. A. Thomas. Tests on five ultra-short wave receivers. *Wireless Engineer and Experimental Wireless* (London), vol. **9**, pp. 186–194; April, (1932).

Relative performance tests on five receiving sets, one a regenerative detector type, two super-regenerative types, and two supersonic heterodyne types are described. The supersonic heterodyne type shows best voltage amplification.

R282 W. Meyer and A. Schmidt. Über die elektrizitätsleistung von Bariumoxyd in zusammenhang mit der elektronenemission. (On the electrical conductivity of barium oxide in connection with electron emission.) *Zeit. für tech. Physik*, pp. 137–144; No. 3; (1932).

After describing the experimental work, the author discusses the results presenting the data in the form of curves.

R300. Radio Apparatus and Equipment

R325 E. Bruce. The horizontal diamond-shaped antenna. *Bell Laboratory Record*, vol. **10**, pp. 291–295; April, (1932).

A new type of directive antenna array is described which preserves the directional selectivity over a wider range of frequencies than the older type.

R325.1 R. Darbord. Reflecteurs et lignes de transmission pour ondes ultra courtes. (Reflectors and transmission lines for ultra-short waves.) *L'Onde Electrique*, vol. **11**, pp. 53–82; February, (1932).

The use of reflectors for concentrating short radio waves is discussed in detail. The physical principles encountered in developing a telephone connection on 18 cm waves between Calais, France, and Dover, England, are explained.

R330 A new high quality detector tube. *Radio Engineering*, vol. **12**, pp. 33–34; April, (1932).

Use and characteristics of Wunderlich tube.

R330 New tubes—Detectors, rectifiers, amplifiers. *Electronics*, vol. **4**, pp. 118–120; April, (1932).

The general operating characteristics of the following new tubes are given: '46, "Triple-twin," Wunderlich, '82. By a new circuit the "triple-twin" may be used in push-pull. Class B amplification using '46 tubes is emphasized.

R330 L. Martin. More new tubes. *Radio Craft*, vol. **3**, pp. 652–655; May, (1932).

A group of eight new tubes are described. A pentode with low hum level, an oscillating detector, a detector which may be used as detector or volume control, a two-volt pentode, a detector-amplifier, a diode, an automobile output pentode, and a low noise level tube, P.J.11.

R339 Lee Sutherlin. A new industrial amplifier tube for phototube circuits. *Radio Engineering*, vol. **12**, p. 24; April, (1932).

Characteristics of RJ-550.

R355.6 D. E. Replogle. Recent developments in precision frequency control. *Radio Engineering*, vol. **12**, pp. 29–32; April, (1932).

Description of the engineering of accurate frequency maintenance of radio transmitters.

R355.6 H. Martin. Selbsttätige frequenzregulierung. (Self-acting frequency regulation). *Phys. Zeit.* vol. **33**, pp. 239–242; March 15, (1932).

A simple optical system is described which is used in connection with two electrically driven tuning forks to produce Lissajous' figures. There is a further description of an automatic regulator for holding the frequency ratio of the two forks constant.

R357 E. G. Watts. Improvements in frequency multipliers for aircraft radio. *Electronics*, vol. **4**, pp. 124–125; April, (1932).

An improved frequency doubler may be obtained by the use of the Hazeltine or Rice circuits as described.

R361 H. Hill. How to build the tetradyne all-wave receiver. *Radio Craft*, vol. **3**, pp. 650–651; May, (1932).

Construction details.

R361 E. P. Hufragel and G. J. Herrscher. An ultra-short-wave super-regenerative 5-meter receiver. *Radio Craft*, vol. **3**, p. 675; May, (1932).

Circuit and construction details.

R363 P. Kapteyn. Über den verstärkungsgrad widerstandsgekoppelter Röhrenanordnungen. (On the amplification of resistance-coupled circuits.) *Hochfrequenztechnik und Elektroakustik*, vol. **39**, pp. 41–48; February, (1932); pp. 78–86; March, (1932).

A mathematical development is given. The optimum conditions for low and high frequency amplification are presented. The elimination of feedback and oscillations is discussed.

R363 H. M. Lane. Resistance-capacitance coupled amplifier in television. Proc. I.R.E., vol. **20**, pp. 722–733; April, (1932).

This paper presents a method of obtaining the transient or complete solution of the amplifier performance under the excitation of typical television signal impulses.

R363.2 J. R. Nelson. Output amplifiers for 110 volt d.c. receivers. *Electronics*, vol. **4**, pp. 128–129; April, (1932).

An experimental study of output and distortion obtained using various tubes and combinations. Data are graphically presented.

R365.21 W. S. Parsons. Volume controls. *Radio Engineering*, vol. **12**, pp. 25–28; April, (1932).

A review of the development of volume control systems for radio receivers including design to meet present day requirements.

R365.21 J. R. Nelson. Circuits to obtain detection and delayed automatic voltage control. *Radio Engineering*, vol. **12**, pp. 13–14; April, (1932).

Circuit arrangements for obtaining better automatic voltage control action than with a single receiving tube.

R365.21 ×R143 H. Y. Levy. The theory and construction of volume controls, line filters and matching transformers. *Radio Craft*, vol. **3**, pp. 660–661; May, (1932).

After giving the purpose of "pads" the decibel is discussed.

R381 K. F. Rodgers. Smaller and better condensers. *Bell Laboratory Record*, vol. **10**, pp. 275–278; April, (1932).

A brief survey of the method of making paper condensers.

R381 I. G. Maloff. Mica condensers in high-frequency circuits. Proc. I.R.E., vol. **20**, pp. 647–656; April, (1932).

The functions of the mica condenser in high-frequency circuits are pointed out. The following calculations are discussed: (1) requirements for tank condenser bank; (2) rating of a given condenser; (3) choice of a proper bank of condensers for a tank circuit with 100 per cent modulation.

R387 E. V. Sundt. Saving instrument losses by proper fuse protection. *Radio Engineering*, vol. **12**, p. 20; April, (1932).

Oscillograms of burn-out time of several small current meters and filaments are compared with oscillograms of burn-out time of small fuses. It is found that a fuse whose current rating is many times that of a galvanometer will blow in time to save the instrument.

R400. Radio Communication Systems

R423.5 O. Pfetscher and R. Beck. Über Tragungsversuche mit der 1.3 m Wellen. (Radio transmission experiments on a 1.3 meter wave length.) *Phys. Zeit.* vol. **33**, pp. 242–244; March 15, (1932).

With a power radiation of one watt, satisfactory telephonic communication was established ona 1.3 meter wave length over a distance of 55 km. The object of these experiments was to establish the feasibility of a series of such stations for long-distance communication just as a series of repeaters are used in long-distance communication over wire lines.

R430 Paul O. Farnham. Automatic suppression of intercarrier noise in radio receivers. *Radio Engineering*, vol. **12**, pp. 21–23; April, (1932).

The problem of suppressing the undesirable noise output in sensitive radio receivers employing gain control and methods of solution are discussed.

R430 L. F. Curtis. Electrical interference in motor car receivers. Proc. I.R.E., vol. **20**, pp. 674–688; April, (1932).

In the high tension and low tension ignition circuits of present-day motor cars there are three sources of high-frequency transients in time and space. In the lighting generator there is another. These radiations and their reduction to acceptable levels to avoid pick-up by the supply and antenna leads to the receiver and the best form of antenna are discussed.

R500. Applications of Radio

R583 C. O. Brown. Multi-channel television. *Jour. I.E.E.* (London), vol. **70**, pp. 340–349; March, (1932).

An experimental television system is described. A satisfactory picture 24 inches by 16 inches, scanned 12½ times per second was obtained. The best operating conditions for the Kerr cells of the receiver are investigated, and the effects of geometric nonlinear, and frequency distortion are examined.

R590 W. Willms. Ein Schallübertragungsanlage grossen Frequenz-Umfanges. (A sound amplifying and reproducing system with a wide frequency range.) *Elek. Nach. technik*, vol. **9**, pp. 68–70; February, (1932).

The system described by the author consists of a condenser-microphone, a frequency compensated, two-leg amplifier, and two loud speakers. The frequency characteristic of the complete system is practically a straight line from 30 to 10,000 cycles per second.

R590 A. N. Curtiss and I. Wolff. Acoustical and electrical power requirements for electric carillons. Proc. I.R.E., vol. **20**, pp. 626–646; April, (1932).

The importance is shown of making noise level measurements in order to determine the acoustical or electrical power necessary to blanket any given area with satisfactory music. Measurements were made on the bells of the Valley Forge carillon, over a wide area using a sound meter and a local variable noise making machine. These data gave the necessary relations between noise level and satisfactory music and were used to calculate the acoustical and electrical power requirements.

R800. Nonradio Subjects

537.1 J. L. Barnes and C. T. Prendergast. On the time admittances of transmission networks. *Jour. Math. and Phys.* vol. **11**, pp. 27–72; March, (1932).

A method for determining the driving-point time admittances of transmission networks is developed. The method employs network transformations. The driving-point time admittances of six types of wave-filter sections, and the transfer time admittances of six corrective networks are obtained. An extensive bibliography is included.

537.7 F. M. Colebrook. A note on the frequency analysis of the heterodyne envelope. *Wireless Engineer and Experimental Wireless* (London), vol. **9**, pp. 195–201; April, (1932).

An analysis based on the evaluation of the Fourier coefficient integrals by expansion in terms of the Legendre coefficients is given.

537.7 ×R146 M. G. Nicholson and W. M. Perkins. A simple harmonic analyzer. Proc. I.R.E., vol. **20**, pp. 734–739; April, (1932).

Some of the difficulties experienced with extensively used methods of harmonic analysis are listed, and a harmonic analyzer more or less free of these defects is described. This analyzer in principle is a dynamometer type meter on which the fundamental and harmonic components of the current are read separately. A theoretical discussion of the method and its limitations is included.

621.374.31 C. F. Wainland. A thyratron voltage regulator. *Electronics*, vol. **4**, p. 132–133; April, (1932).

A bridge having carbon and Mazda lamps in its arms is used to excite a thyratron tube when voltage changes occur in output of a generator. The output of the thyratron controls the field current in the generator. Voltage changes were reduced to 0.1 to 0.2 per cent.

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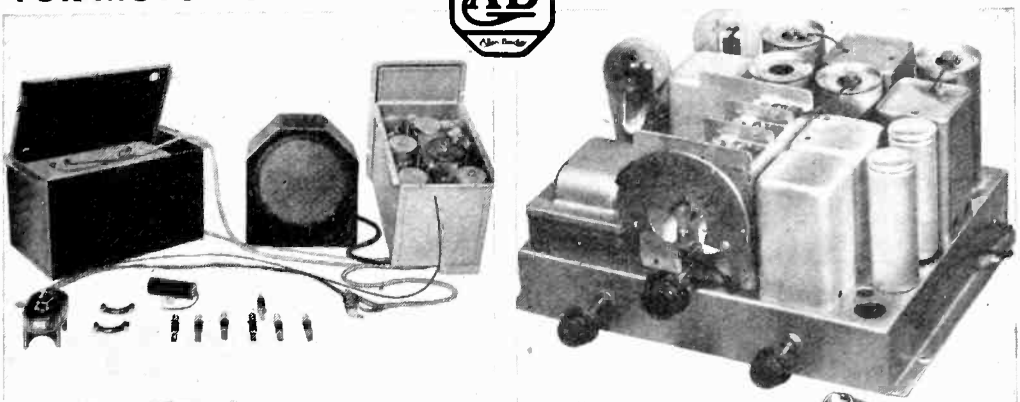

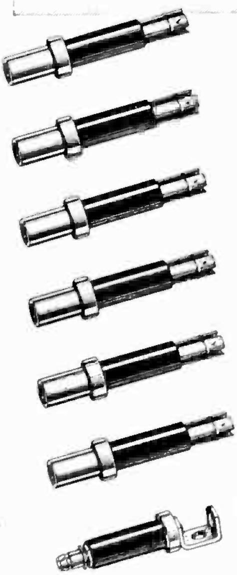

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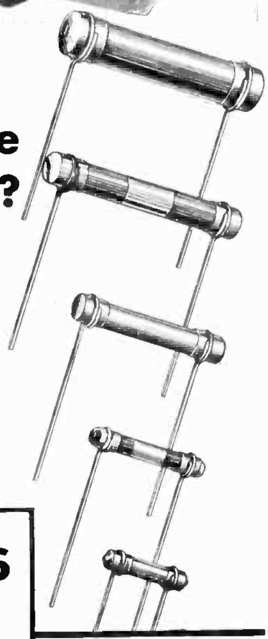

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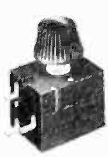

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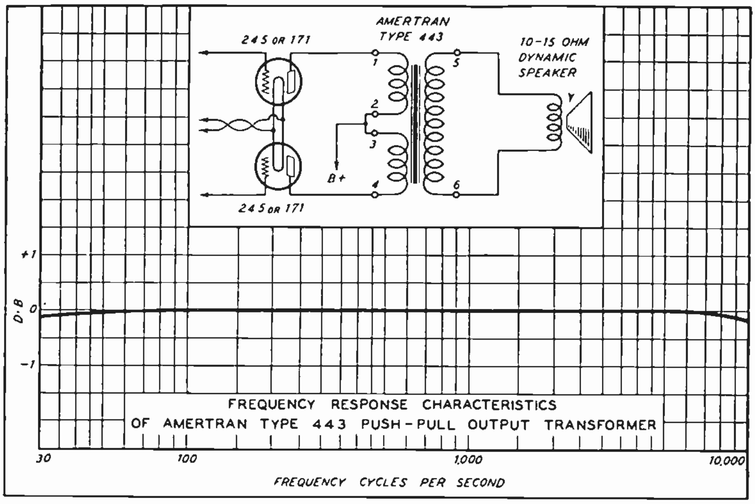

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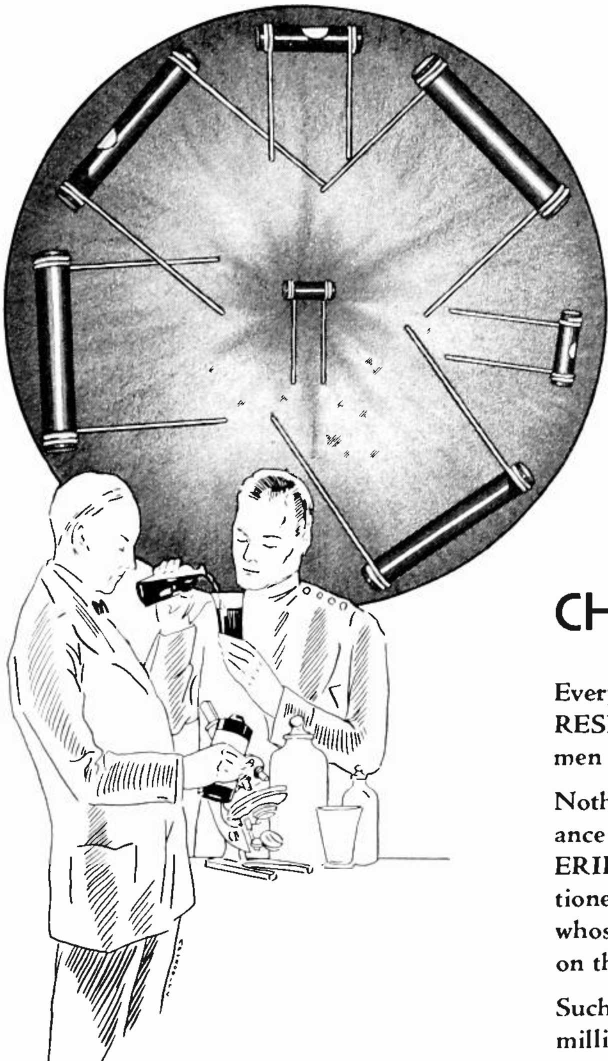

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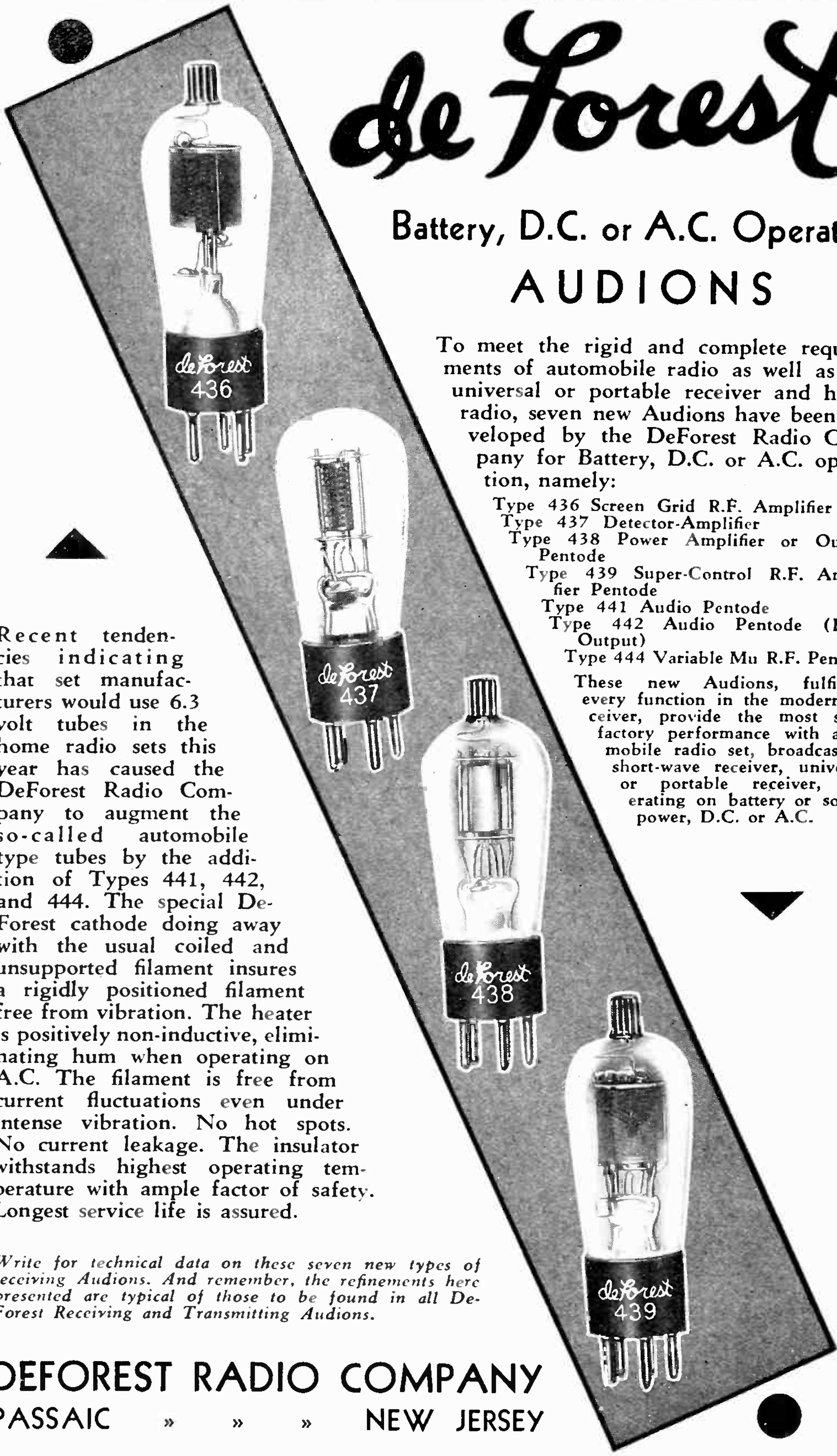

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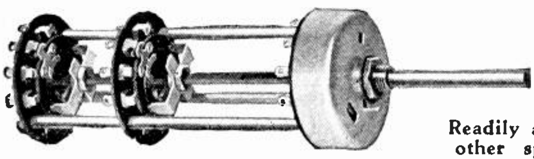

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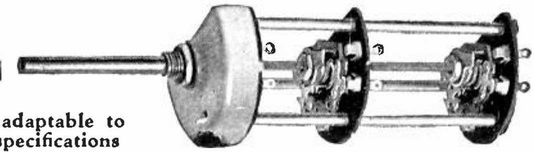

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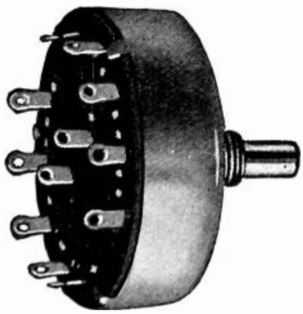

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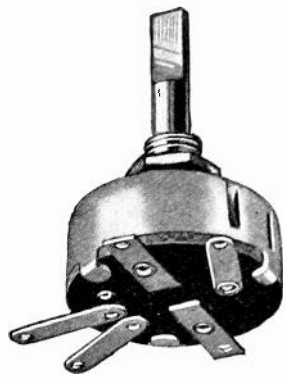

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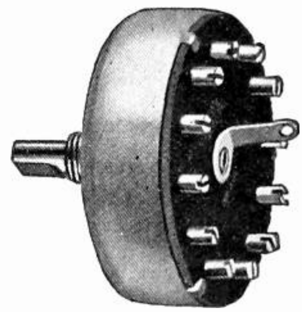

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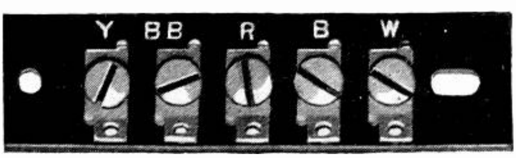

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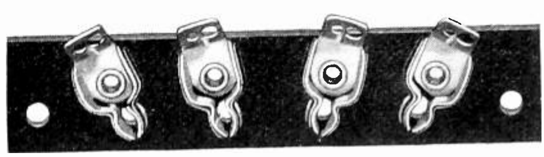

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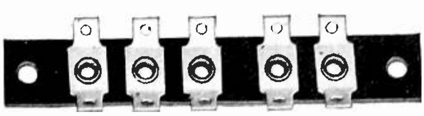

Terminal Strip
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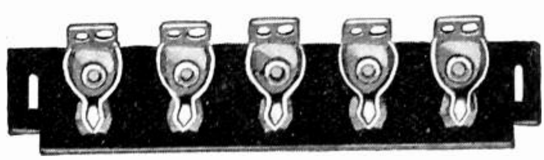

Terminal Strip
5 Clips, No. A6310AA, 4 Clips No. A6320AA

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Characteristics of the
Wunderlich Tube

by

Frederick E. Terman, Sc.D.
Professor of Communication Engineering
Stanford University

"The Wunderlich tube can be thought of as a triode to which there has been added a second grid that is wound between the meshes of the usual grid. This tube has been developed for grid leak power detection purposes, and gives full wave grid rectification in a balanced circuit in which negligible radio frequency current flows in the plate circuit."

"When compared with the triode type of grid leak power detector, the Wunderlich power detector has about the same efficiency, introduces less distortion because the balanced input circuit prevents simultaneous grid and plate rectification, and develops approximately twice as much output voltage."

"When compared with the plate rectifier commonly employed in broadcast receivers, the Wunderlich detector has the advantage of a somewhat greater rectification efficiency, particularly when the signal voltage is in the order of several volts."

"The Wunderlich tube has ample power capacity to excite the power amplifier of any broadcast receiver now on the market, and also supplies a voltage which can be used directly for automatic volume control purposes."

Excerpt from technical paper by Prof. F. E. Terman. Complete paper will be sent upon request.

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The **BLUE TUBE** *with the* **RED BASE**

manufactured by

ARCTURUS RADIO TUBE CO., NEWARK, N. J.

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There is often a wide gap between the paper specifications and the actual production of radio parts. . . . It is the function of the Scovill Manufacturing Company to bridge that gap . . . to cooperate closely with the radio manufacturer in turning his paper plans into practical finished products.

Scovill is particularly well fitted to take over the manufacturer's problems. For this organization has a background of accumulated experience dating to the beginning of the radio industry . . . the equipment necessary for *quantity* production . . . the skill and precision methods required for *quality* production.

The efficiency and economy which Scovill brings to the manufacture of metal parts have enabled many radio manufacturers to simplify their plants, lower costs, and raise the standards of their products. Scovill's facilities are available to you . . . for the manufacture of any part from a simple machine screw to a complete radio condenser.

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CARDWELL variable condensers and CARDWELL-designed and built-to-order apparatus have, for considerably more than a decade, enjoyed a reputation for outstanding excellence won by conscientious adherence to an ideal of fair dealing and a determination to sponsor only *quality* products.

Look around. Somewhere, in the majority of the really fine radio installations and equipments in the country, governmental, broadcast, commercial or amateur, will be found some product of CARDWELL manufacture.

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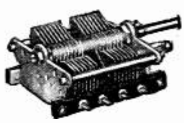

May we send our literature?

CARDWELL CONDENSERS AND MANUFACTURING SERVICE

The Allen D. Cardwell Mfg. Corpn.
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AT THE TOP OF THE HILL

A LONE figure in overalls surveys the fields of his labor. Freshly planted rows point their even lines around a gently rising hill. Seemingly the world and its people are far away. But this man is not alone!

His home is at the top of the distant hill. And in his home is a telephone. Eighty-five million miles of wire lead to it. His call is a command to one or more of several hundred thousand employees. Day or night he may call, through the Bell System, any one of nearly twenty million other telephones in this country and an additional twelve million abroad.

And yet, like you, he pays but a small sum for a service that is frequently priceless in value. The presence of the telephone, ready for instant use, costs only a few cents a day. With your telephone, you are never alone. It is an investment in companionship, convenience, and security. Through it you can project your personality to the faraway places of the earth, or bring familiar voices to the friendliness of your fireside.

Undoubtedly a great factor in the continued progress and improvement of telephone service is the intangible but real spirit of service that has become a tradition in the telephone business. This spirit expresses itself daily and in any emergency. And behind the army engaged in giving service is the pioneering help of a regiment of five thousand scientists and technical men, engaged in the sole task of working for improvement. This group devotes itself exclusively to seeking ways and means of making your telephone service constantly better and better.

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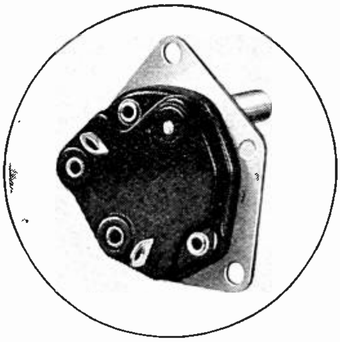
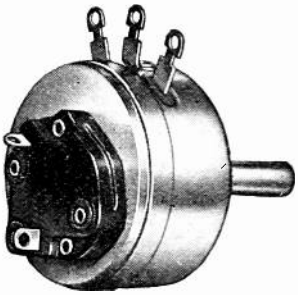
—the new, long-lived, low-contact resistance snap switch with positive kick-off



No. 11 Switch, for panel mounting



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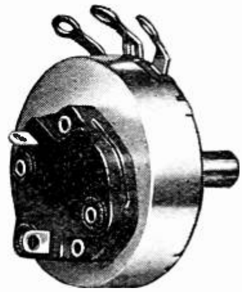
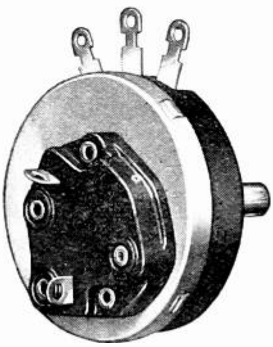


No. 70 Series, with switch



No. 80 Series Single Unit, with switch

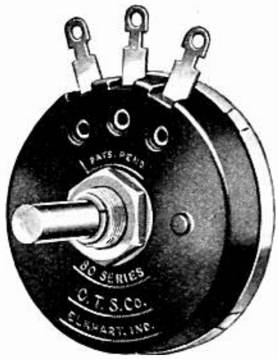
OF primary interest to set manufacturers is the announcement of our new snap switch. This is now available in two forms, No. 11, a separate S. P. S. T. switch for panel mounting, or Type "T," in combination with our complete line of positive-wiping-contact volume controls.

In either type this new switch has an extremely low and a remarkably uniform contact resistance. It possesses exceptionally long life, as proved by our extensive breakdown tests. Because of its positive kick-off the opening or closing of the circuit is doubly assured.

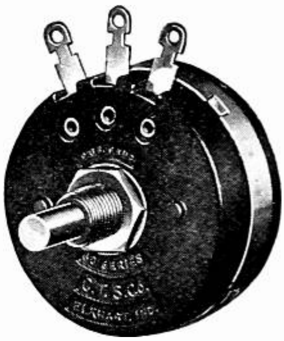
The operating torque of No. 11 is the lowest of any commercial switch now offered the set manufacturer. In addition to its low torque this new switch operates with the smallest knob movement of any switch on the market, making available the maximum length of resistance element for controlling volume or tone.

Other features of this switch that you will be quick to appreciate are its "cold" cam which is double bearing and cannot bind or wabble in operation; the wide separation of all live parts from the cam; electrostatic shield, that effectively prevents hum pick up by the volume control from live parts of the switch; heavy silver-plated terminals, insuring low contact resistance and ease of soldering; and approval by Underwriters' Laboratories for 3 A, 125 v., 1.5 A, 250 v., ac. or dc. We can supply these switches with or without leads.

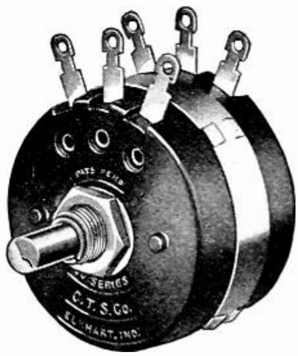
We invite inquiries from interested manufacturers regarding this new switch, either for panel mounting or in association with our complete line of wire-wound or carbon element volume and tone controls. Write us fully regarding your needs and allow us to submit samples made to your specifications.



No. 80 Series Single Unit, without switch



No. 80 Series, Type H, with switch



No. 2-80 Series Tandem Unit, without switch

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Incorporated

33 West 39th Street, New York, N. Y.

APPLICATION FOR ASSOCIATE MEMBERSHIP

(Application forms for other grades of membership are obtainable from the Institute)

To the Board of Direction

Gentlemen:

I hereby make application for Associate membership in the Institute 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)

References:

(Signature of references not required here)

Mr. .... Mr. ....

Address .... Address ....

City and State .... 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.

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............

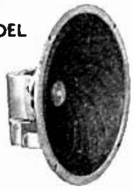
Grade .... Advised of Election.......... This Record Filed..........

Magnavox DYNAMIC • SPEAKERS •

Model 154

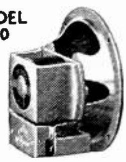
8 inch Dynamic Speaker

MODEL 152

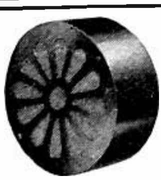


10¼ inch Dynamic Speaker

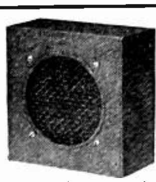
MODEL 150



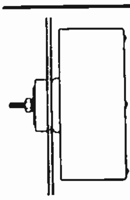
6½ inch Dynamic Speaker



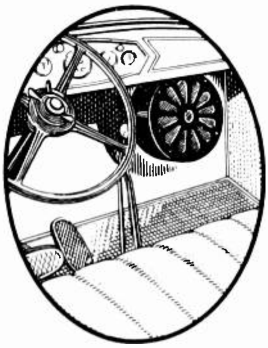
Model 154—8" Auto Speaker



Model 150--6½" Auto Speaker



SINGLE STUD MOUNTING



AUTO SPEAKERS

MAGNAVOX engineering has mastered the tone problem - - the most difficult in auto radio - - and has added new features assuring ease and simplicity of installation.

MAGNAVOX-QUALITY speakers will help you assure trouble-free performance and long life under the difficult conditions which your automobile radios must face. The tone is rich, full and true. Single stud mounting simplifies application. Available in two sizes, Models 150 and 154, in round or square baffle cases.

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Magnavox Model 530 Dynamic Speaker is the superlatively fine speaker in the line - - designed for the maximum of performance in Class B radio sets. All the experience gained in Magnavox' 21 years of leadership in acoustics goes to make this truly an achievement in radio speaker design. Manufacturers who are building their future upon performance rather than upon price, choose Magnavox inevitably.

● PERMANENT MAGNET SPEAKERS

At the right are presented two new Magnavox developments - - Model 254 and Model 252 Permanent Magnet Dynamic Speakers. They are primarily designed for battery operated home and automobile radio sets, Sound Installations in schools, hotels, auditoriums, etc.

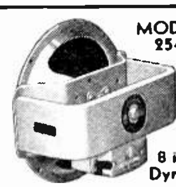
● MAGNAVOX ENGINEERING SERVICE

is available to recognized manufacturers upon request. There is no obligation. Write us.

MAGNAVOX MODEL 530

The Quality Speaker for Class B Radio Sets, Public Address, etc.

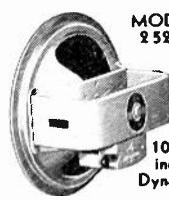
MODEL 254



8 inch Dynamic

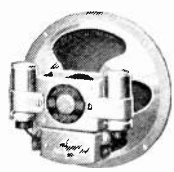
Permanent Magnet Speaker

MODEL 252



10¼ inch Dynamic

Permanent Magnet Speaker



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ESTABLISHED 1911

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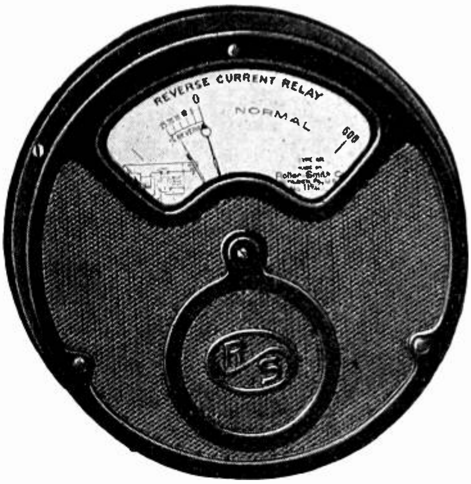
MAGNAVOX



ROLLER-SMITH Announces

A new line of contact making instruments of several types for many different applications in the radio and allied fields.

This new line of contact making instruments is described and illustrated in new Technical Data Sheet No. K-R1.

Other types of Roller-Smith contact making instruments are described and illustrated in Bulletin No. K-550.

Copies of the Technical Data Sheet and Bulletin referred to will be sent on request.

ROLLER-SMITH COMPANY
Electrical Measuring and Protective Apparatus

Main Office: 2134 Woolworth Bldg.,
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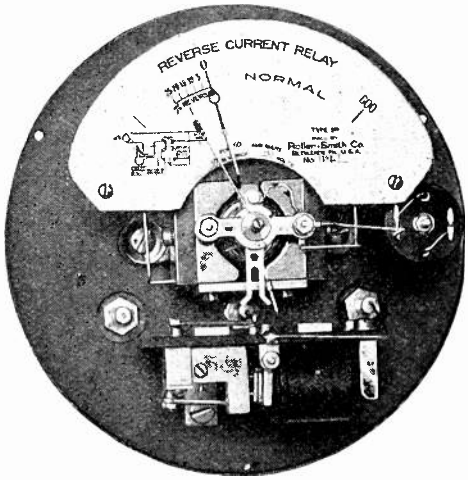
Offices in principal cities.



Cornell

TRADE MARK REG.

CUB CONDENSERS

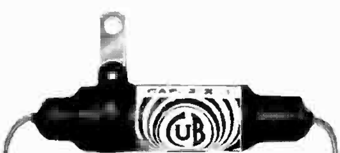
NOW USED BY

135 SET MANUFACTURERS

IN THE UNITED STATES AND CANADA

TYPE BB

This type is used for capacities between .02 to .5.



TYPE BC

This model has two capacities on the same unit. The lug is common for both capacities. Both sections must be the same voltage. This is a most economical unit.

To have won such universal approval, Cub Condensers had to have outstanding merit. Since their introduction by us three years ago, they have met the most rigid tests and withstood the most rugged usage.

The new models shown here are wound non-inductively on a wooden mandrel to which both the contacts and self supporting soft copper tinned mounting wires are attached. They are enclosed in thoroughly impregnated moisture proof casings.

WRITE FOR NEW CATALOG A

This new catalog describes our complete line of Paper Dielectric Capacitors for radio, television and ignition, and Resistors for radio and television. Write for a copy today.

CORNELL ELECTRIC MFG. CO., Inc.

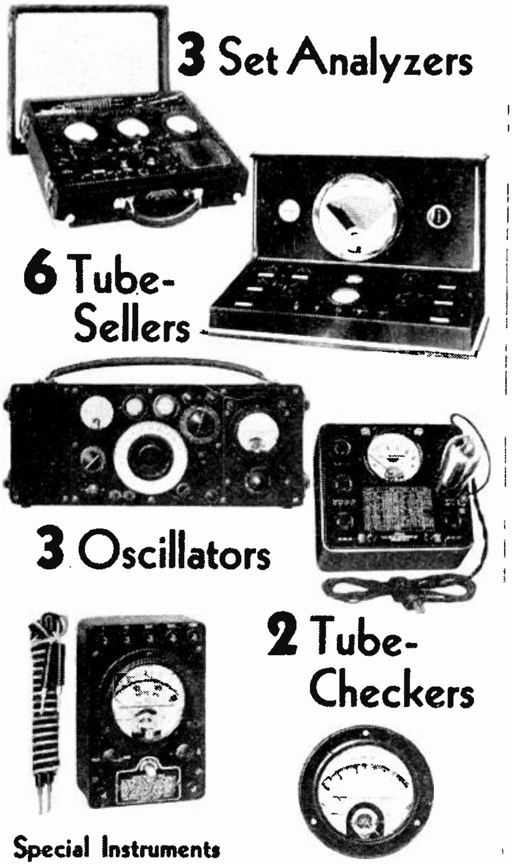
Manufacturers of

CORNELL "CUB" CONDENSERS

Filter and By-Pass Condensers, Interference Filters and All Types of Paper Dielectric Capacitors and Resistors

LONG ISLAND CITY, NEW YORK

High Grade Radio Instruments for every purpose and every purse



New service instruments, developed through the combined efforts of Weston and Jewell engineers, will be announced at the R. M. A. Trade Show in June.

These new instruments, added to the combined Weston and Jewell Lines of radio testing equipment, provide a selection that meets every service requirement and every purse.

The 1932 Weston-Jewell Radio Catalog—a veritable encyclopedia of high grade service equipment—describes every instrument in this incomparable line. An extensive selection of Set Analyzers, Tube-Sellers, Tube-Checkers, Ohmmeters, Voltmeters, Output Meters, Panel Meters, and accessories enables you to choose equipment that exactly fits your needs.

Every radio engineer and radio service manager should be informed about this incomparable line of radio instruments. Mail the coupon for the most comprehensive radio instrument catalog ever printed!

WESTON JEWELL

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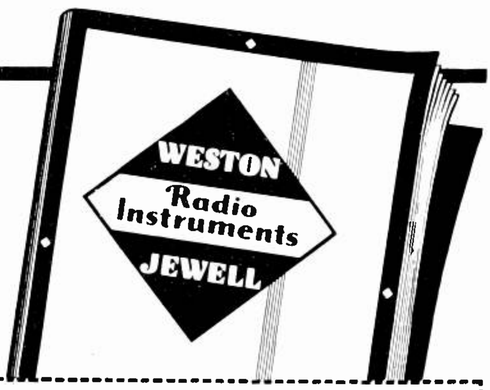

Weston Electrical Instrument Corp.,
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Please mail complete catalog covering Weston and Jewell Radio Instruments.

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CHANGE IN MAILING ADDRESS OR BUSINESS TITLE

Members of the Institute are asked to use this form for notifying the Institute office of a change in their mailing address or the listing of their company affiliation or title in the Year Book.

The Secretary,
THE INSTITUTE OF RADIO ENGINEERS,
33 West 39th Street,
New York, N.Y.

Dear Sir:

Effective .... please note change in my address
(date)

for mail as follows:

FROM

....
(Name)

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(Street Address)

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(City and State)

TO NEW ADDRESS

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(Street Address)

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(City and State)

Please note following change in my Year Book listing.

....
(Title)

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(Company Name)

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(Company Address)

EMPLOYMENT PAGE

Advertisements on this page are available to members of the Institute of Radio Engineers and to manufacturing concerns who wish to secure trained men for positions. All material for publication on this page is subject to editing from the Institute office and must be sent in by the 15th of the month previous to the month of publication. (April 15th for May PROCEEDINGS IRE, etc.) Employment blanks and rates will be supplied by the Institute office. Address requests for such forms to the Institute of Radio Engineers, 33 West 39th Street, New York City, N.Y.

MANUFACTURERS and others seeking radio engineers are invited to address replies to these advertisements at the Box Number indicated, care the Institute of Radio Engineers. All replies will be forwarded direct to the advertiser.

ENGINEER AND CHEMIST with three years experience on application of vacuum tubes to chemical problems, fourteen months as chemist and engineer in charge of development and manufacture of tubes for prominent manufacturer, and three years as assistant professor of chemistry in well known university available for position after July 15, 1932. Wishes research or engineering work with company manufacturing tubes. College graduate with Masters and Doctors degrees. Age 30. Will travel within U. S. or Canada. Box 125.

RADIO ENGINEER with one year's experience working on vacuum tubes and photo-electric cells. Desires position as research or development worker on vacuum tubes or radio circuits. Seven years' college and post graduate work with A.B. in 1929. All college work has been in the field of physics. Age 25. Box 122.

EUROPEAN RADIO ENGINEER, one and one half years development of automatic receivers for high and low speed reception, and public address equipment and servicing, two years in charge of design and construction of amplifiers, five and one half years consulting engineer for European government. Familiar with European trade conditions and can speak several European languages. Desires position as European technical representative of American firm or as research worker. Age 31. Box 126.

SERVICEMAN with six years' experience in service work. Has specialized in short wave development and design during past two years. Desires any radio position where experience can be best utilized, especially development of high frequency receivers and television. High school graduate. Age 24. Married. Will travel. Box 124.

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Does the frequency of your monitor comply with the new regulations of being within the plus or minus 50 cycle limits? If not, we are at your service to adjust your monitor to within those limits. *Ship your monitor to us* for either adjustment or grinding a new crystal if necessary. Our charge for this service is right, and will require but *seven* to *ten* days to perform this work. *Ask any broadcast radio engineer* what *he* thinks of our service.

CRYSTALS CRYSTALS CRYSTALS

Prices for grinding POWER CRYSTALS in the various frequency bands are as follows:

Frequency Range	
100 to 1500 Kc	$40.00
1501 to 3000 Kc	$45.00
3001 to 4000 Kc	$50.00
4001 to 6000 Kc	$60.00

The above prices include holder of our Standard design, and the crystals will be ground to within .03% of your specified frequency. If crystal is wanted unmounted deduct $5.00 from the above prices. Delivery two days after receipt of your order. In ordering please specify type tube, plate voltage and operating temperature.

Special Prices Will Be Quoted in Quantities of Ten or More

POWER CRYSTALS FOR AMATEUR USE

The prices below are for grinding a crystal to a frequency selected by us unmounted, (if wanted mounted in our Standard Holder add $5.00 to the prices below) said crystal to be ground for POWER use and we will state the frequency accurate to better than a tenth of one per-cent. IMMEDIATE SHIPMENT CAN BE MADE.

1715 to 2000 Kc band	$12.00 each
3500 to 4000 Kc band	$15.00 each

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We have stock available to grind crystals as low as 13 Kilo-cycles. Prices quoted upon receipt of your specifications.

PIONEERS: POWER CRYSTALS SINCE 1925

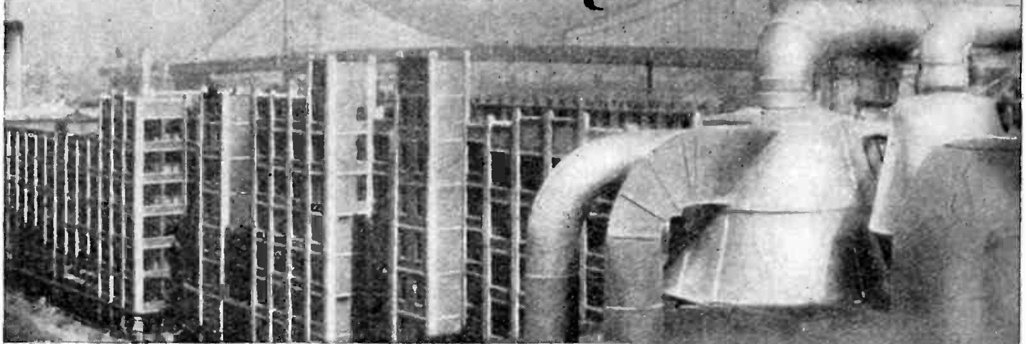
This record is proof to you that you will get the best there is in Piezo Electric Power Crystals. Get the best. It is more economical.

Scientific Radio Service

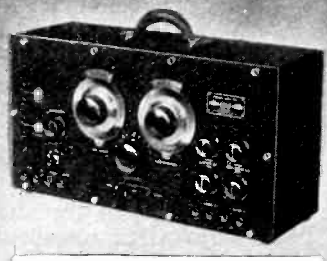
"THE CRYSTAL SPECIALISTS"

124 Jackson Ave., University Park Hyattsville, Maryland

FROM "RADIO HEADQUARTERS"



Two radically new laboratory instruments *for* Radio Engineers



The Signal Analyzer
TMV-48A

The Signal Analyzer Type TMV-48A

An instrument for accurately analyzing the components of a modulated signal. Provides means for separating and quickly measuring amplitude of carrier and side band components with due regard to phase. For use in determining amount of frequency modulation, percentage total modulation and percentage modulation present in each side band.

Price $375.00, *less tubes and batteries.*

The Standard
Microvolter
TMV-47A

The Standard Microvolter Type TMV-47A

An inexpensive instrument for rapidly checking and calibrating laboratory or factory Signal Generators, or receiver testing systems. Provides means for determining accurately minute values of radio frequency voltage.

Price $125.00, *less tubes and batteries.*

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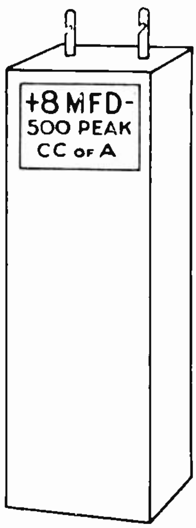

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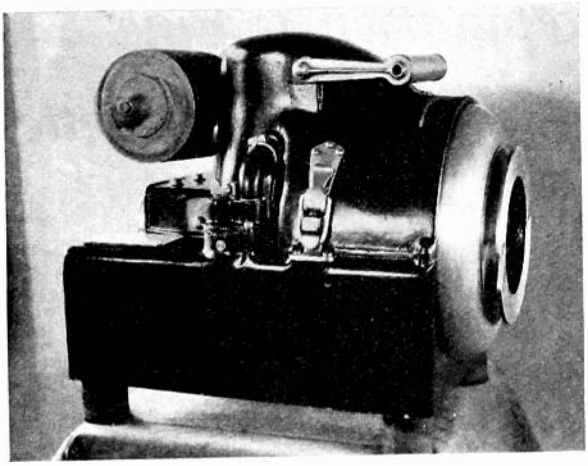

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¶There are no revolving windings, sliprings, commutators or brushes.

¶The output is *governed electrically* without moving parts.

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¶Our years of experience in the development of light weight equipment are at your disposal in the sensible solution of your problems calling for portable power for any use.

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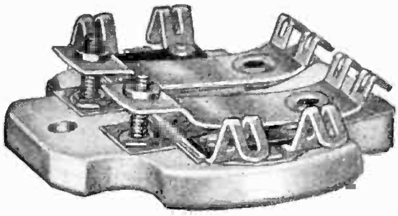

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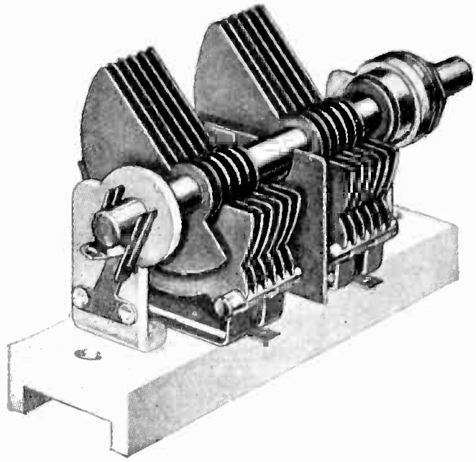

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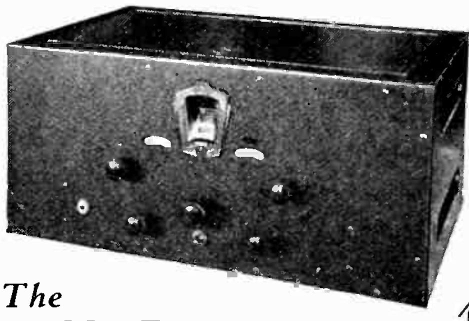

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Preprints Available

A LIMITED number of preprints of some of the papers presented at the technical sessions of the Twentieth Anniversary Convention of the Institute are available without cost to members of the Institute. They are as follows:

2. "Design of Resistors for Precise High-Frequency Measurements," by L. Behr and R. E. Tarpley.

3. "The Campbell-Shakelton Shielded Ratio Box," by L. Behr and A. J. Williams, Jr.

6. "Westinghouse Radio Station at Saxonburg, Pa.," by R. L. Davis and V. E. Trouant.

7. "Radio Dissemination of the National Standard of Frequency," (Abstract), by J. H. Dellinger and E. L. Hall.

8. "Radio Test Methods and Equipment," (Abstract), by W. F. Diehl.

9. "A New Circuit for the Production of Ultra-Short-Wave Oscillations," by H. N. Kozanowski.

10. "A New Water-Cooled Power Vacuum Tube," by I. E. Mouromtseff.

11. "The Precision Frequency Measuring System of RCA Communications, Inc.," by H. O. Peterson and A. M. Braaten.

12. "Kennelly-Heaviside Layer Studies Employing a Rapid Method of Virtual-Height Determination," by J. P. Schafer and W. M. Goodall.

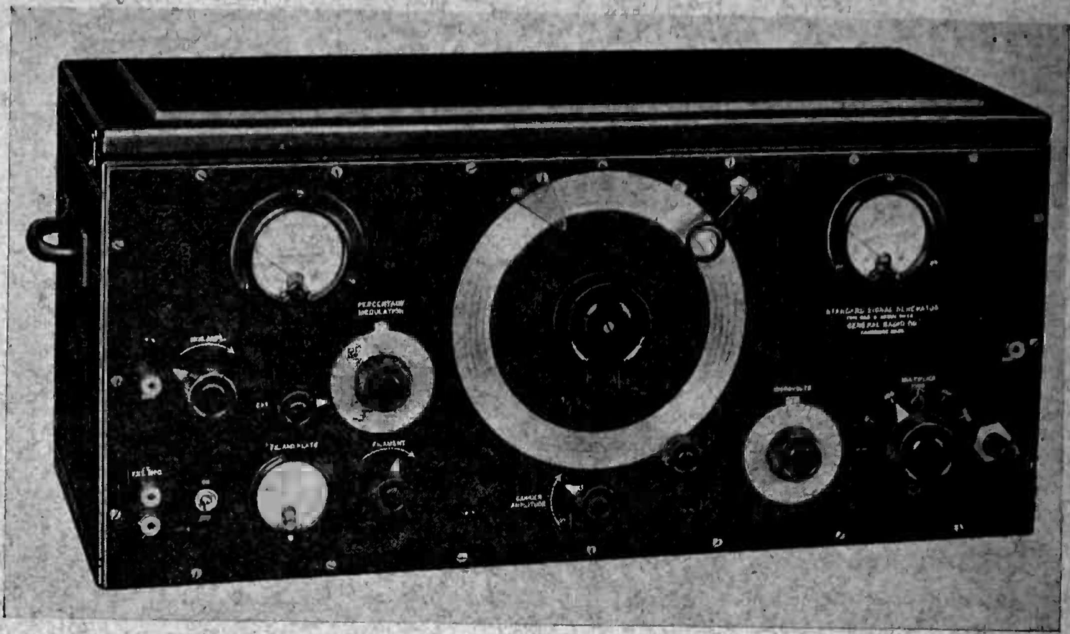
13. "Transmission Lines for Short-Wave Radio Systems," by E. J. Sterba and C. B. Feldman.

15. "Note on the Measurement of Resistance at High Frequency," by P. B. Taylor.

16. "Dynamic Symmetry in Radio Design," by Arthur Van Dyck.

17. "Two-Way Radiotelephone Circuits," by S. B. Wright and D. Mitchell.

Requests for copies of any of the above should be made to the Institute office, 33 West 39th Street, New York City.



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