VOLUME 17 | AUGUST, 1929 | NUMBER 8

# PROCEEDINGS

*of*

# The Institute of Radio Engineers

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# Institute of Radio Engineers

*Forthcoming Meetings*

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

CHICAGO SECTION
Chicago, Ill., September 20, 1929

CLEVELAND SECTION
Cleveland, Ohio, September 18, 1929

DETROIT, SECTION
Detroit, Mich., September 19, 1929

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

NEW YORK MEETING
New York, N. Y., September 4, 1929

PITTSBURGH SECTION
Pittsburgh, Penna., September 17, 1929

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

TORONTO SECTION
Toronto, Canada, September 16, 1929

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

PROCEEDINGS OF

# The Institute of Radio Engineers

Volume 17 August, 1929 Number 8



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PART II

*Technical Papers*

# The Institute of Radio Engineers

## GENERAL INFORMATION

The PROCEEDINGS of the Institute is published monthly and contains papers and discussions thereon submitted for publication or for presentation before meetings of the Institute or its Sections. Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscription rates to the PROCEEDINGS for the current year are received rom non-members at the rate of $1.00 per copy or $10.00 per year. To foreign countries the rates are $1.10 per copy or $11.00 per year.

Back issues are available in unbound form for the years 1918, 1920, 1921, 1922, 1923, and 1926 at $9.00 per volume (six issues) or $1.50 per single issue. Single copies for the year 1928 are available at $1.00 per issue. For the years 1913, 1914, 1915, 1916, 1917, 1918, 1924, and 1925 miscellaneous copies (incomplete unbound volumes) can be purchased for $1.50 each; for 1927 at $1.00 each. The Secretary of the Institute should be addressed for a list of these.

Discount of twenty-five per cent on all unbound volumes or copies is allowed to members of the Institute, libraries, booksellers, and subscription agencies.

Bound volumes are available as follows: for the years 1918, 1920, 1921, 1922, 1923, 1925, and 1926 to members of the Institute, libraries, booksellers, and subscription agencies at $8.75 per volume in blue buckram binding and $10.25 in morocco leather binding; to all others the prices are $11.00 and $12.50, respectively. For the year 1928 the bound volume prices are: to members of the Institute, libraries, booksellers, and subscription agencies, $9.50 in blue buckram binding and $11.00 in morocco leather binding; to all others, $12 00 and $13.50, respectively. Foreign postage on all bound volumes is one dollar, and on single copies is ten cents.

Year Books for 1926, 1927, and 1928, containing general information, the Constitution and By-Laws, catalog of membership etc., are priced at seventy-five cents per copy per year.

Contributors to the PROCEEDINGS are referred to the following page for suggestions as to approved methods of preparing manuscripts for publication in the PROCEEDINGS.

Advertising rates to the PROCEEDINGS will be supplied by the Institute's Advertising Department, Room 802, 33 West 39th Street, New York, N. Y.

Changes of address to affect a particular issue must be received at the Institute office not later than the 15th of the month preceding date of issue. That is, a change in mailing address to be effective with the October issue of the PROCEEDINGS must be received by not later than September 15th. Members of the Institute are requested to advise the Secretary of any change in their business connection or title irrespective of change in their mailing address, for the purpose of keeping the Year Book membership catalog up to date.

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All correspondence should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York, N. Y., U. S. A.

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# SUGGESTIONS FOR CONTRIBUTORS TO THE PROCEEDINGS

## Preparation of Paper

Form—Manuscripts may be submitted by member and non-member contributors from any country. To be acceptable for publication manuscripts should be in English, in final form for publication, and accompanied by a summary of from 100 to 300 words. Papers should be typed double space with consecutive numbering of pages. Footnote references should be consecutively numbered and should appear at the foot of their respective pages. Each reference should contain author's name, title of article, name of journal, volume, page, month, and year. Generally, the sequence of presentation should be as follows: statement of problem; review of the subject in which the scope, object, and conclusions of previous investigations in the same field are covered; main body describing the apparatus, experiments, theoretical work, and results used in reaching the conclusions and their relation to present theory and practice; bibliography. The above pertains to the usual type of paper. To whatever type a contribution may belong, a close conformity to the spirit of these suggestions is recommended.

Illustrations—Use only jet black ink on white paper or tracing cloth. Cross-section paper used for graphs should not have more than four lines per inch. If finer ruled paper is used, the major division lines should be drawn in with black ink, omitting the finer divisions. In the latter case, only blue-lined paper can be accepted. Photographs must be very distinct, and must be printed on glossy white paper. Blueprinted illustrations of any kind cannot be used. All lettering should be $^3/_{16}$ in. high for an 8 x 10 in. figure. Legends for figures should be tabulated on a separate sheet, not lettered on the illustrations.

Mathematics—Fractions should be indicated by a slanting line. Use standard symbols. Decimals not preceded by whole numbers should be preceded by zero, as 0.016. Equations may be written in ink with subscript numbers, radicals, etc., in the desired proportion.

Abbreviations—Write a.c. and d.c., kc, $\mu$f, $\mu\mu$f, emf, mh, $\mu$h, henries, abscissas, antennas. Refer to figures as Fig. 1, Figs. 3 and 4, and to equations as (5). Number equations on the right in parentheses.

Summary—The summary should contain a statement of major conclusions reached, since summaries in many cases constitute the only source of information used in compiling scientific reference indexes. Abstracts printed in other journals, especially foreign, in most cases consist of summaries from published papers. The summary should explain as adequately as possible the major conclusions to a non-specialist in the subject. The summary should contain from 100 to 300 words, depending on the length of the paper.

## Publication of Paper

Disposition—All manuscripts should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York City. They will be examined by the Committee on Meetings and Papers and by the Editor. Authors are advised as promptly as possible of the action taken, usually within one month.

Proofs—Galley proof is sent to the author. Only necessary corrections in typography should be made. *No new material is to be added.* Corrected proofs should be returned *promptly* to the Institute of Radio Engineers, 33 West 39th Street, New York City.

Reprints—With the galley proof a reprint order form is sent to the author. Orders for reprints must be forwarded promptly as type is not held after publication.

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C. M. Jansky, Jr.
Member of the Board of Direction, 1929

C. M. Jansky, Jr., was born at Delton, Michigan. In 1917 he was graduated from the University of Wisconsin and in 1919 received the Master's degree in Physics from the same institution. Since January 1, 1920, he has been in charge of instruction in radio engineering at the University of Minnesota and of the operation of the University's broadcasting station. He was a member of the four National Radiotelegraph Conferences. He is associate professor in radio engineering at the University of Minnesota and is practicing consulting radio engineering. Professor Jansky is on the Board of Direction of the American Radio Relay League. He has contributed several papers to the Proceedings of the Institute of Radio Engineers. In 1928 he was appointed to membership on the Institute's Committee on Standardization. Professor Jansky was elected Manager for a three-year term, beginning 1929. He was elected an Associate member of the Institute in 1918, was transferred to the Member grade in 1925, and the Fellow grade in 1928.

## 1928 Standardization Report

The 1928 Report of the Committee on Standardization, published in the 1929 Year Book, has been reprinted as a separate volume. Members of the Institute may obtain one copy gratis upon application to the Secretary. To non-members the price is one dollar.

## Change of Address or Business Title

Members of the Institute are again advised that the Institute office should be notified promptly of any change in mailing address or business title or occupation in order that the PROCEEDINGS may be forwarded promptly to the new address and the Year Book membership catalog kept up to date. The practice of sending forms with the annual ballot, upon which the membership indicates any change in business title, has been discontinued. Accordingly, unless the Institute office is advised otherwise, the 1930 Year Book listing of the catalog of membership will be identical with that of the 1929 book.

On page XXXV of the advertising section of this issue will be found a form which may be used for notifying the Institute office of any change in mailing address or business occupation or title.

## Nominations for 1930 Officers and Managers

The Committee on Nominations, Melville Eastham, chairman, is preparing recommendations for the September 4th meeting of the Board of Direction for nominations of officers and elective members of the Board of Direction for 1930.

As set forth in the Constitution, the membership is entitled to make nominations by petition. Such nominations are to be made by letter, addressed to the Board of Direction, 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 Board of Direction on or before October 15th and must be signed by at least thirty-five Fellows, Members or Associates.

There are to be elected a President, Vice President, and two members of the Board of Direction, the latter to serve for terms of three years.

## Civil Service Examinations

The U. S. Civil Service Commission announces open competition examinations for the positions of Senior Radio Engineer ($4,600 per year), Radio Engineer ($3,800 per year), Associate Radio Engineer ($3,200 per year), and Assistant Radio Engineer ($2,600 per year).

Competitors will not be required to report for examination at any place but will be rated on their education, training, experience and fitness, such ratings being based upon the competitors' sworn statements in their applications and upon corroborative evidence.

Members of the Institute interested in these positions should communicate with the U. S. Civil Service Commission, Washington, D. C., requesting application form #2600, mentioning announcement #166 and the position for which he desires to compete.

## Committe Work

### Committee on Bibliography

To investigate the feasibility of the Institute's sponsoring the publication of a complete bibliography on radio and the compilation and publication of a monthly abstract service, President Taylor has appointed the following Committee on Bibliography: B. E. Schackelford, chairman, M. C. Batsel, W. G. Cady, J. H. Dellinger, Melville Eastham, General G. W. Gibbs, C. B. Jolliffe, F. H. Kroger, R. H. Langley, R. H. Manson, Colonel J. O. Mauborgne, Donald McNicol, G. W. Pickard, Haraden Pratt, E. R. Shute, A. F. Van Dyck, H. M. Turner, L. P. Wheeler, H. A. Wheeler, W. C. White, L. E. Whittemore, and W. Wilson.

The Committee held its first meeting at 2 P.M. on June 26th in the office of the Institute in New York City. The following members were present: B. E. Shackelford, chairman, W. G. Cady, Melville Eastham, C. B. Jolliffe, Colonel Mauborgne, H. M. Turner, H. A. Wheeler, and W. C. White.

The Committee made considerable progress in its preliminary work, and will continue to hold meetings throughout the summer in order to submit its report to the Board of Direction early in the fall.

## Institute Meetings

### Cleveland Section

On June 11th the Cleveland section held a meeting in the Hotel Statler. This was the annual meeting and was preceded by a dinner. B. W. David, chairman, presided, and forty-seven members and guests attended.

Ralph Worden, radio editor, *Cleveland Plain Dealer*, gave a review of the Chicago Radio Show. A musical program was provided by WTAM Entertainers, which included the Metropolitan Trio.

### Los Angeles Section

The Los Angeles section held a meeting, May 28th, 1929. C. S. Breeding, assistant secretary, presided. There were thirty-six members and guests in attendance.

Two papers were presented, one by Professor Harry LaVerne Twining on, "New Developments in Radio Phenomena as Compared with the Einstein Theory" and the second paper by Elbert M. Fox on "Some Experiments on Wave Propagation at High Frequencies."

A general discussion followed the presentation of these papers.

### San Francisco Section

On May 21st the San Francisco section held a meeting in the Auditorium of the Pacific Gas and Electric Co., San Francisco, California. Donald K. Lippincott, chairman presided.

S.P.Grace, assistant vice-president of Bell Telephone Laboratories, presented a paper, "Speech Transmission."

A demonstration followed the presentation of the paper. One of the most important features of the demonstrations was the illustration of a method of delayed speech. Mr. Grace said "Hello" at the input end and as late as four and one half seconds later the apparatus said "Hello."

Methods of scrambled voice transmission were put on the loudspeaker to demonstrate the impossibility of understanding it and this was "unscrambled" for the audience.

The regular meeting of the San Francisco section for the month of June was held on the 19th at the Bellevue Hotel, following a dinner at which forty-six members and guests were present.

N. R. Morgan of Stanford University presented a paper on "Power Grid Leak Detection, C Bias Detection and Screen Grid Detectors."

Following the presentation of the paper L. F. Fuller, Donald Lippincott and a number of members and guests entered into its discussion.

Dr. Fuller presented an outline of his recent trip to the east during which he represented the local section at several Washington meetings.

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## Personal Mention

R. R. Brewin, of Atlanta, Ga., has been transferred from the engineering department of the Georgia Power Company to the department of radio coordination of the same organization.

George W. Brown, of Atlantic, Mass., is now Manager of the Radio Service Department of the Motor Supply Company of Boston.

E. Finley Carter has resigned from the General Electric Company at Schenectady, where he was in charge of special developments in the radio engineering department, to direct radio-frequency developments for the United Research Corporation located in Long Island City.

G. W. Clark, of Portland, Ore., is now receiving station engineer for the Mackay Radio and Telegraph Company at Honolulu.

William F. Devine, until recently connected in installation on sound projector systems for Electrical Research Products, Inc., of New York City, has moved to London, England, where he has joined the staff of the Western Electric Company, Ltd., as supervisor and inspector in sound projector systems.

Captain E. E. Eiler, for several years director of radio for the Republic of Haiti with headquarters at Port-au-Prince, has been transferred to Marine Barracks, Naval Air Station, Pensacola, Fla.

George L. Haller is now associated with E. A. Myers and Sons of Philadelphia as electrical engineer. Mr. Haller left the employ of the Westinghouse Elec. and Mfg. Company at East Pittsburgh where he was doing radio research work.

Norman R. Hood formerly associated with the Illinois Pipe Line Company at Casper, Wyo., is now radio operator with the Firestone Tire and Rubber Company at Akron, Ohio.

A. C. Matthews, until recently in the radio division of Stewart Warner Corporation at Chicago, has joined the staff of the United Research Corporation at Long Island City, New York, as radio engineer.

F. Cheney Beekley, for a number of years advertising manager and managing editor of *QST* at Hartford, Conn., has resigned to become associated with the Maxim Silencer Company of Hartford. As advertising manager of *QST* Mr. Beekley has been succeeded by G. Donald Meserve, formerly assistant advertising manager.

Harold L. Olesen has joined the engineering staff of the Jewell Electrical Instrument Company at Chicago. Mr. Olesen was formerly associated with the Fanstell Products Company of North Chicago.

Wallace E. Rushing, until recently operator with the Radiomarine Corporation of America, is now associated with broadcasting station WTIC of Hartford, Conn.

Hoyt S. Scott, for a number of years associated with the Willard Storage Battery Company of Cleveland as radio engineer, is now manager of Radio Engineering Service, Inc., of Cleveland.

F. H. Schnell has been given a year's leave of absence from the Burgess Battery Company of Madison, Wis., to engage in special work for Aero Products, Inc., in Chicago.

M. S. Thacker has joined Siemens Bros. and Company, Ltd. of Bristol, England in the outside contracts department upon leaving Merchants Venturer's College.

Russel S. Turner, recently a student of Dodge Institute at Stoughton, Wis., has joined the Radio Corporation of America at Chicago as radio inspector.

Loren H. Whan, Jr., formerly chief engineer of Miller Welles Company, Inc., of Chicago, is now engineer with the Minerva Radio Company of Chicago.

Harold C. Singleton has resigned from the General Electric Company at Schenectady to enter the employ of the Radio-Victor Corporation of America with headquarters at San Francisco.

John L. Barnes, upon completion of a five-year coordination communications course given at the Massachusetts Institute of Technology with the Bell System, has been appointed a Fellow in mathematics at the Princeton Graduate School.

R. F. Durant, A.F.C., formerly Radio Branch, Royal Air Force, has left to take up an appointment with Civil Aviation Radio, Air Ministry, London.

C. I. Soucy, until recently engaged in talking motion picture installation as inspection engineer, has assumed the new position of service superintendent with the Research Products, Engineering Department, of the Northern Electric Company, Ltd., of Canada.

*Proceedings of the Institute of Radio Engineers*
*Volume 17, Number 8* *August, 1929*

# GEOGRAPHICAL LOCATION OF MEMBERS ELECTED JULY 3, 1929

### For Election to the Associate Grade

| | | |
|---|---|---|
| California | Bolinas | Baker, Thomas S. |
| | Bolinas, Radio Corporation of America | Clark, Robert W. |
| | Bolinas | Riddle, Elmer R. |
| | Hollywood, 1719 N. Gardner St. | Blackburn, John F. |
| | Huntington Park, 6608½ Rugby St. | Hudson, T. L. W. |
| | Jackson, 115 Court St. | Snyder, W. Gilman, Jr. |
| | Los Angeles, 425 S. Bonnie Brae | Dixon, A. L. |
| | Los Angeles, 451 North Hill St. | Haas, Clarence H. |
| | Los Angeles, 5533 Hollywood Blvd. | Wright, James L., Jr |
| | Menlo Park, Box 163 | Seal, H. Rober t |
| | Palo Alto, Federal Telegraph Co. | Beatty, W. E. |
| | Palo Alto, 515 Oberlin Ave. | Lawrence, Robert B. |
| | Palo Alto, Federal Telegraph Co. | Suydam, C. H. |
| | Rosemead, 1223 S. Earl St. | Turner, W. E. H. |
| | Sean Pedro, USS *New Mexico* | Ruble, W. J. |
| Colorado | Dnver, 2041 S. Josephine | Scheneman, Henry W. |
| Delaware | Wilmington, 418 S. Grant Ave. | Smyth, Earle |
| Dist. of Columbia | Washington, 621 G Street, S. W. | Appich, Wm. H. |
| | Washington, 3541 Holmead Pl., N. W. | Bradford, Henry K. |
| | Washington, 4637 Brewer Pl., N. W. | Burke, James W. |
| | Washington, Bureau of Standards | Mellwraith, Charles G. |
| | Washington, 1123 East Capitol St. | Simon, Isaac B. |
| | Washington, 1814 Jackson St. | Stevens, Waldo W. |
| Georgia | Columbus, Box 69 | Kirkland, A. H. |
| | Columbus, Sta WRBL | Shaffer, C. Robert |
| | Fort Benning, Headquarters Battery | Tate, Robert L. |
| Illinois | Chicago, 6429 S. May St. | Ellis, Robert M. |
| | Chicago, 1900 Mohawk St. | Fritzel, Joseph |
| | Chicago, 7614 Essex Ave. | Levy, Samuel L. |
| | Evanston, 139 Custer Ave. | Stein, Harold A. |
| Indiana | Anderson, 1219 Home Ave. | Miller, Louis |
| | Ashley | Urey, Geoge M. |
| | Sweetser | Myers, Delbert |
| | Vernon, Box 24 | Dausch, Elmer F. |
| Louisiana | New Orleans, 3111 Louisiana Ave. P'kway | Chateau, Arthur |
| | New Orleans, 512 St. Peter | Elkins, W. P. |
| | New Orleans, 1716 Painter St. | Peters, C. W. |
| Massachusetts | Cambridge, 7 Kirkland St. | Batchelder, L. |
| | Lexington, 16 Cliff Ave. | Chute, Dudley H. |
| | Lowell, 722 E. Merrimack St. | Cohurn, E. D. |
| | New Bedford, 373 Pleasant St. | Meredith, W. B |
| | Roxbury, 25 Fernboro St. | Katz, Louis S. |
| | Springfield, 28 Saratoga St. | Davis, William G. |
| Michigan | Detroit, 9125 Avis Ave. | Anderson, Donald T. |
| | Detroit, 8881 Lauder Ave. | Jackson, Paul |
| | Detroit, 2923 Kirby W. | Kirby, Otto I. |
| | Detroit, 5842 Vernor Hgy West | Pennebaker, R. T |
| | Lansing, 325 Smith Ave. | Wells, Lawrence V. |
| | Muskegon, 329 Merrill Ave. | Owens, Robert F. |
| | Sault Ste Marie, SS *M. A. Bradley* | George, Edward M. |
| Missouri | Kansas City, 3315 Holmes St. | Coates, B. Franklin |
| | Springfield, 906 East Grand | Moss, Terry L. |
| | St. Louis, 3328 Louisiana Ave. | Althoff, Frederick E. |
| | St. Louis, 5468 N. Kingshighway Blvd. | Cook, Jesse A. |
| | St. Louis, 3631 Bamberger Ave. | Proehl, Robert O. |
| Montana | Butte, 1120 West Gold St. | Walker, Raymond E. |
| New Jersey | Bloomfield, 18 Austin Place | Weaver, Karl S. |
| | Boonton, 302 Dawson Ave. | Cordell, Peter C. |
| | Collingswood, 106 Fern Ave. | Richards, Horace J. |
| | Deal, Box 122 | Kerwien, Arthur E., Jr. |
| | Irvington, 41-42 St. | Coman, George E. |
| | Long Branch, 58 Washington St. | Emerson, Kenneth H. |
| | Merchantville, 606 W. Maple Ave. | Closson, Luke E. |
| | Newark, 820 Mt. Prospect Ave. | Canfield, Wilson R. |
| | Newmark, 180 Runyon St. | Dauber, Arthur O. F. |
| | Roselle, 133 Vine St. | Bosler, Gustave A. |
| | Trenton, Glen Cairn Arms Apts. | Miles, Lester F. |
| New York | Brooklyn, 225—68th St. | Marra, Anthony |
| | Brooklyn, 6 Bay 23rd St. | Rosin, Arthur |
| | Brooklyn, 90 N. 9th St. | Stromeyer, Charles F. |
| | Brooklyn, 60 Clinton Ave. | Wood, Wilbert C. |
| | Buffalo, 158 Linden Ave. | Karslake, James S. |
| | Buffalo, 298 Hoyt St. | Parker, Arthur B. |
| | Elmira, 314 Sly St. | Taylor, Dale L. |
| | Lockport, 115 Main St. | Connette, T. W. |
| | New York, Lexington Ave. & 43rd St. | Alverson, George S. |

| | | |
|---|---|---|
| | New York, 333—8th St. | Brady, Leslie R. |
| | New York, 91st St. & Broadway | Cassell, Joseph L. |
| | New York, 414 W. 120th St. | Charton, Paul W. |
| | New York, 333 W. 52nd St. | Dean, C. E. |
| | New York, Sub Treasury Building | Jensen, George L. |
| | New York, 207 East 19th St. | Pavlow, Nicholas |
| | New York, 370 Seventh Ave. | Randolph, L. F. |
| | New York, 24 W. 59th St. | Theremin, Leon |
| | New York, 45 Grove St. | Victoria, Joseph L. |
| | New York, RCA Photophone, Inc., 438 W. 37 St. | Wisegarver, Orton H. |
| | Poughkeepsie, 42 Cannon St. | Boyle, Frank A. |
| | Riverhead, L. I., Radio Corp. of America | Michael, David F. |
| | Rochester, 64 Grafton St. | Esten, Perry W. |
| | Rochester, 17 Avenue D | Sylvester, Arthur |
| | Scotia, 223 James St. | Bergeron, Rosarie |
| | Scotia, 102 James St. | Steiner, Harry C. |
| | Schenectady, 1132 Baker Ave. | Acheson, Marcus A. |
| | Schenectady, 1307 Parkwood Blvd. | Eveleth, Lawrence N. |
| | Schenectady, General Electric Co. | Hansen, John C. |
| | Schenectady, General Electric Co. | Larson, Robert W. |
| | Schenectady, 111 Park Place | Maser, Harold T. |
| | Schenectady, 1061 Glenwood Blvd. | More, Clifton C. |
| | Schenectady, General Electric Co. | Newton, Raymond A. |
| | Schenectady, Y. M. C. A. | Westendorp, W. F. |
| | Valley Stream, 83 South Drive | Klesse, William |
| Ohio | Canton, 1030 Clarendon, S. W. | Ellis, Walter R. |
| | Cleveland, 4350 Pearl Rd. | Daymude, John F. |
| | Cleveland, 1369 W. 112th St. | Okeson, Hugh B. |
| | Columbus, 1130 Westwood Ave. | Ryder, Jack D. |
| | Cuyahoga Falls, 576 N. 4th | Reeder, Nelson R. |
| | Dayton, 53 Stratford Ave. | Cotter, Edwin M. |
| | Dayton, 121 Frank St. | Smith, Howard L. |
| | Dover, 313 Factory St. | Weber, H. S. |
| | East Sparta | Walker, Nolan S. |
| | Hudson, Box 124 | Lowrer, R. W. |
| | Mt. Healthy, R. 11 | Lockwood, Edward C. |
| | Wooster, 446 N. Buckeye St. | Taggart, Samuel E. |
| Oklahoma | Oklahoma City, 124 W. 6th St. | Kramer, V. J. |
| | Oklahoma City, 1926 West 22nd St. | Moore, Paul J. |
| | Oklahoma City, 10 East 8th St. | Prell, George Ray |
| Pennsylvania | Allentown, 725 New St. | Sauerwine, Charles A. |
| | Carrolltown | Brophy, Francis J., Jr. |
| | Harrisburg, 218 Chestnut St. | Hall, Thomas, Jr. |
| | Penbrook, 2845 Canby St. | Amsden, Frank P. |
| | Philadelphia, C & Ontario Sts. | Snyder, Christopher L. |
| | Pottstown, 130 Walnut St. | Betz, C. Leonard |
| | Scranton, 413 South Main Ave. | Bean, Clemens C. |
| Texas | Dallas, 4537 Elk Drive | Sides, J. L. |
| | Houston, 5 N. Milam St. | Harrison, U. M. |
| Washington | Seattle, 4225 Tenth, N. E. | Durkee, K. M. |
| | Seattle, 5212 18th Ave. N. E. | Maynard, J. E. |
| | Seattle, 735 N. 67th St. | Rotta, Allen E. |
| Wisconsin | Milwaukee, 1707 Wisconsin Ave. | Hilton, Waldo R. |
| Canada | Saint John, N. B. 16 Wall St. | Megarity, E. A. |
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| | Kent, 23 Fairfield Rd., Bromley | Allen, Leslie |
| | Kent, Powder Mill Lane, Dartford | Mullholland, William |
| | Leigh-on-Sea, 1337 London Rd. | Uphill, Sydney G. |
| | London, 23 Elmwood Gdns. | Biltcliffe, Thomas |
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| Japan | Tokyo, 2 Mita Shikokumachi Shiba | Hijikata, S. |
| Mexico | Charcas, S. L. P., Jardin Hidalgo No. 10 | Torres, Willehado |
| New Zealand | Auckland, Dallinghoe Crescent, Milford | Pinder, A. |

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| | | |
|---|---|---|
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| California | Los Angeles, 1234 E. 74th St. | Heather, Harold |
| | Pasadena, 1091 Wesley Ave. | Poorman, Edwin H. |
| Connecticut | Bridgeport, 119 James St. | Cousins, Maurice N. |
| Georgia | Atlanta, 1599 Langston St. | Jones, Albert L. |
| Illinois | East Peoria, 130 East Washington St. | Hoffman, John L. |
| Massachusetts | Adams, 171 Summer St. | Barschdorf, Harry O. |
| Michigan | Detroit, 10800 Devine St. | Steinhauser, C. J. |
| Nebraska | Omaha, 4328 Erskine St. | Stratman, Fred W. |
| New Jersey | Bloomfield, 26 Fairview Pl. | Otterbein, Milton H. |
| New York | Huntington, L. I., 15 Wall St. | Flessel, Frank B., Jr. |
| | Rochester, 96 Martin St. | Driscoll, George |
| Ohio | Columbus, 341 West 9th Ave. | Goddard, John B. |
| England | Yorks, 10 Northolme Villas, Hessle | Hewetson, Geoffrey B. |

## APPLICATIONS FOR MEMBERSHIP

Applications for election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to election of any of these applicants should communicate with the Secretary on or before August 30th. These applicants will be considered by the Board of Direction at its September 4th meeting.

### For Election to the Associate Grade

| | | |
|---|---|---|
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| | Napa, 2143 Main St. | Rawson, Clifford L. |
| | Mayfield, 1627 College Ave. (Box 503) | Redeker, Harry E. |
| Connecticut | Stamford, 757 Main St. | Sullivan, Robert J. |
| Indiana | Angola, 407 West South St. | Huntley, Kenneth L. |
| Illinois | Chicago, 3451 Beach Ave. | Blom, Roy |
| | Chicago, 6533 Woodlawn Ave. | Carothers, R. F. |
| | Chicago, Bremer Tully Mfg. Co., 656 W. Washington Blvd. | Glassman, George |
| | Chicago, c/o Triangle Elec. Co., 600 W. Adams St. | Nelson, R. G. |
| | Chicago, 4253 W. Winchester Ave. | Rech, Charles B. |
| | Chicago, 4540 Clifton Ave. | Ross, Frank C. |
| | Chicago, 1464 Larrabee St. | Sieben, Clarence M. |
| | Decatur, 1352 Riverview Ave. | Boggs, R. A. |
| | Evanston, 936 Hinman Ave. | Clarke, R. E. |
| | Fort Sheridan, Hq. Co. 12th Brigade | Hoover, Richard T. |
| | Lombard, 7 East St. Charles Road | Pukalski, Donald |
| | Oak Park, 610 North Grove Ave. | Willing, Wm. P. |
| | Peoria, c/o Nailon Corp., 108–110 Liberty St. | Snyder, Roy A. |
| | Quincy, 1124–6 Ave. N. | Daly, F. Grey |
| | Rankin, Box 195 | Denton, Frank O. |
| | Winnetka, 934 Westmoor Rd. | Manly, Harold P. |
| Louisiana | New Orleans, 2807 Jefferson Ave. | Breedlove, Frederick Wallace |
| Maryland | Baltimore, 1413 John St. | Dudley, Charles B., Jr. |
| | Mt. Rainier, 352 Harris St. | Flather, Bryan S. |
| Massachusetts | Cambridge, 70 Lake View Ave. | Spike, J. Edward, Jr. |
| | East Holliston, Washington St. | Peters, John L. |
| | East Springfield, 95 Ardmore St. | Russ, George H. |
| | Lawrence, 223 Hampshire St. | Theberge, Albert R. |
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| | Detroit, 5432 Livernois Ave. | Goldman, Sherman |
| | Jackson, 1024 Lansing Ave. | Williams, Billy G. |
| | Rives Junction | Ostrander, R. M. |
| Missouri | Kansas City, 4030 Bellefountain | Screechfield, R. M. |
| | Kansas City, 3654 Campbell St. | Vasen, Gustave |
| | Nevada, Ellis Music Co. | Kluth, Wm. J., Jr. |
| | St. Louis, 3330 Abner Place | Bush, Walter S. |
| | St. Louis, 4417 Clayton Ave. | Koehler, Elmer F. |
| | St. Louis, 5179 Easton Ave. | Suggs, Thomas B. |
| | Waldron | Barker, L. T. |
| New Jersey | Merchantville, 1442 Lexington Ave. | Frenz, H. J. |
| | Newark, 113 Huntington Terrace | Reiner, Leonard |
| | Newark, 165 Mt. Pleasant Ave. | Warren, Chester L. |
| | Ridgewood, 21 Phelps Road | Bondy, Hugo Alois, Jr. |
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| | Cleveland, National Carbon Co., Inc., Edgewater Works | Baeckler, Walter |
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| | Tulsa, 2808 E. 7th St. | Bowen, Leonard R. |
| | Tulsa, 114 East 24th St. | Morrison, John P., Jr. |
| Oregon | Salem, Willamette University | Leamer, Frank D. |
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| | | |
|---|---|---|
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| | London EC1, Radio Section, Engineer in Chief's Office, G. P. O. | Warren, A. C. |
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| | | |
|---|---|---|
| Georgia | Atlanta, 75–12th St., N. E. | Holliday, F. S. |
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# Part II

# TECHNICAL PAPERS

*Proceedings of the Institute of Radio Engineers*
*Volume 17, Number 8* *August, 1929*

# THE MUTUAL IMPEDANCE BETWEEN ADJACENT ANTENNAS*

By

CARL R. ENGLUND AND ARTHUR B. CRAWFORD
(Bell Telephone Laboratories, Inc., New York City)

***Summary***—*The simple theory for the computation of reflecting or multibranch antenna systems is sketched. If the points at which observations of electrical quantities are to be made are definitely specified, a knowledge of the self and mutual impedances (properly defined) between antennas is sufficient to make the computations determinate. Of the circuit constants, the most useful and accessible is the antenna current ratio*

$$K_{12} = \frac{I_2}{I_1} = K_0 e^{i(\phi-(2\pi d/\lambda))}$$

*and in the work here reported* $\phi$ *has been measured in the range 0.33λ to 1λ. Experiment has shown that in this range* $\phi$ *is that theoretically calculable for a Hertzian doublet. Actually this range is equivalent to λ/3 to ∞. The discussion of experimental procedure is purposely thorough.*

## INTRODUCTION

IN this paper a start is made at putting the mutual antenna relation in circuit theory form by the aid of experimental procedure. The discussion is limited to parallel rectilinear antennas in free space, the centers of which are in a common plane, and it is postulated that all current or impedance measurements are to be made by opening this central point.

## THEORY

The usual method of treating "concealed" circuits, of which this is an application, may be developed as follows. Given two accessible terminal pairs (as in Fig. 1), we define the positive current direction for each terminal pair in an arbitrary manner, for example as shown, then apply an emf at (1) and measure the resultant current at (1) and the voltage at (2), the secondary terminal being open. We have then by direct measurement,

$$Z_1 = \frac{E_1}{I_1}, \quad Z_{12} = \frac{E_2}{I_1}, \quad I_2 = 0 \tag{1}$$

* Dewey decimal classification: R320. Original manuscript received by the Institute, March 13, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

Next we reverse the terminals and repeat. We have then

$$Z_2 = \frac{E_2}{I_2}, \quad Z_{21} = \frac{E_1}{I_2}, \quad I_1 = 0 \tag{2}$$

and with these four quantities we uniquely define the network for all currents and voltages.

Thus when for open secondary circuit we write $E_1 = Z_1 I_1$, the closure of the secondary results in a secondary current $I_2$ which, in turn, introduces in the primary circuit a voltage of $Z_{21} I_2$ so that the new primary


Fig. 1

current is given by $E_1 + Z_{21} I_2 = Z_1 I_1$. At the same time the voltage induced in the secondary circuit by the primary current is all absorbed by the secondary impedance drop or $Z_{12} I_1 = Z_2 I_2$. Rewriting these expressions in symmetrical form gives

$$\left.\begin{aligned} E_1 &= Z_1 I_1 - Z_{21} I_2 \\ 0 &= -Z_{12} I_1 + Z_2 I_2 \end{aligned}\right\} \tag{3}$$

from which we obtain, by solution and definition,

$$\left.\begin{aligned} I_1 &= \frac{E_1}{S_1} = E_1 \frac{Z_2}{Z_1 Z_2 - Z_{12} Z_{21}} \\ I_2 &= \frac{E_1}{S_{12}} = E_1 \frac{Z_{12}}{Z_1 Z_2 - Z_{12} Z_{21}} \\ \frac{I_2}{I_1} &= K_{12} = \frac{Z_{12}}{Z_2} = \frac{S_1}{S_{12}} \end{aligned}\right\} \tag{4}$$

If we transfer these operations to the secondary side, we have a second set of similar expressions

$$\left.\begin{aligned} I_2 &= \frac{E_2}{S_2}, \quad \frac{I_1}{I_2} = K_{21} = \frac{Z_{21}}{Z_1} = \frac{S_2}{S_{21}} \\ I_1 &= \frac{E_2}{S_{21}} \end{aligned}\right\} \tag{5}$$

The most readily measured quantities are the self impedance ones $Z_1$, $Z_2$, $S_1$, and $S_2$, but they are not sufficient for a determinate theory. We must also measure a pair of mutual impedances ($Z_{12}$, $Z_{21}$) or a pair of transfer impedances ($S_{12}$, $S_{21}$). For ordinary wire circuits it is readily demonstrable that

$$\left.\begin{aligned} Z_{21} &= Z_{12} \\ S_{21} &= S_{12} \end{aligned}\right\} \tag{6}$$

and it has recently been shown[1] that the same is true, with reservations unimportant here, for the antennas of radio technique.

In the radio applications of the above we are chiefly interested in the values of the currents flowing in the several antennas, in particular in the ratios $I_1/I_0$, $I_2/I_0$, $\cdots$, etc., where we relate phase and amplitude of any current to one fiducial current of the system, and it is the chief purpose here to discuss the determination of the current ratio for a single pair of mutually influencing antennas.

Assume, therefore, two mutually influencing antennas, in the center of one of which an emf is introduced. Equations (3), (4), and (5) apply directly and we have

$$S_1 = \frac{Z_1 Z_2 - Z_{12} Z_{21}}{Z_2} = Z_1(1 - K_{12} K_{21})$$

whence

$$K_{12} K_{21} = \frac{Z_1 - S_1}{Z_1}$$

or since

$$K_{21} = K_{12} \cdot \frac{Z_2}{Z_1}, \quad K_{12} = \sqrt{\frac{Z_1 - S_1}{Z_2}}. \tag{7}$$

Of these four quantities a measurement of three will be necessary to determine the fourth except in the case of identical antennas. Then $Z_1 = Z_2$, by symmetry, and $K_{12} = \sqrt{1 - S_1/Z_1}$ so that the determination of $K_{12}$ can be made directly by a pair of a.c. bridge measurements[2] on one antenna, the second being alternately present and absent.

Obviously the ratio

$$\left|\frac{I_2}{I}\right| = |K_{12}| \tag{8}$$

[1] Carson, John R., *Bell Sys. Tech. Jour.*, **3**, 393; 1924, and Proc. I. R. E., **17**, 952; June, 1929.

[2] Another special case is mentioned by Breit, Sci. Paper No. 430, Bur. of Stand. 1922, and by Wilmotte *Jour.* I.E.E. 66, 961; 1928.
Here $K_{12} = 1/K_{21}$ or $K_{12}^2 = S_1/S_2 \cdot S_{21}/S_{12}$ or $K_{12} = \sqrt{S_1/S_2}$.

is immediately determinable by means of a pair of ammeters but arg $I_2/I_1$ is not so obtainable. Any method of simultaneously conveying, by metallic conductors, currents from the two antennas to a common point for phase comparisons is open to the objection that the physical connections introduce errors unknown or difficult of control, and the conductors can act as antennas themselves. A straightforward radiation comparison is immune to these errors, but lacks the independent phase and amplitude control of the wire method.


Fig. 2

We may consider the following radiation experiment. An antenna (1) is driven by a generator and has a reflector or parasitic antenna (2) in its immediate neighborhood. The spacing between, and orientation of the line joining them are variable and the field is observed at substantially radiation distance by a third antenna (0) supplied with current indicating apparatus. The geometry will be as in Fig. 2 where

$$r_1 \gg d$$

$$r_2 \gg d .$$

Now with $r_1$ and $r_2$ large compared with the wavelength used,[3] the radiated electric field will have the same space variation with $r$ as for a simple Hertzian doublet, and will be strictly proportional to the currents as measured in the radiating antenna centers. Moreover, the resulting receiver antenna current will be proportional to the resultant electric field at its location, the reaction of the receiver current upon the driving antenna being negligible. Accordingly, we may write for the receiver antenna current, if we drop the factor $e^{i\omega t}$,

$$I = C\left[\frac{h_1 I_1}{\lambda r_1} e^{-i(2\pi r_1/\lambda)} + \frac{h_2 I_2}{\lambda r_2} e^{-i(2\pi r_2/\lambda)}\right]$$

where $C$ is the complex constant of proportionality, $I_1$ and $I_2$ the current amplitudes, and $h_1$ and $h_2$ the effective antenna heights. Putting in the current ratio gives,

$$I = \frac{C I_1}{\lambda}\left[\frac{h_1}{r_1} e^{-i(2\pi r_1/\lambda)} + K_{12}(h_2/r_2) e^{-i(2\pi r_2/\lambda)}\right] \tag{9}$$

[3] A distance of 5 wavelengths to the nearest antenna is ample to meet this condition; the spacing $d$ can hardly exceed 2 wavelengths and leave a workable antenna reaction.

In radiation theory it is a… …ate" all phenomena to a common source; we th…

… (10)

where $K_0 = |K_{12}|$ and the …

$$I = \frac{CI_1 h_1}{\lambda r_1} e^{-i(2\pi r_1/\lambda} \cdots {}^{-r_1)-\phi]} \Big] \qquad (11)$$



Of this we can observe di… …gives

$$|I| = I_0 = \frac{|C| I_1 h_1}{\lambda r_1}$$

$$\sqrt{1 + \left\{ K_0 \frac{h_2}{h_1} \cdots \right.} \cdots -r_1) - \phi \Big] \qquad (12)$$

This expression is difficult … …solute magnitude, directly. However, since it is possible to determine $K_0$ rather simply, and the configuration may be changed arbitrarily, the remaining unknown $\phi$ is determinable in several manners.

With both $K_0$ and $\phi$ depending on $d$ an advantageous manner of altering the configuration is to hold $d$ constant and vary $\theta$. We have then

$$r_2^2 = r_1^2 + d^2 - 2r_1 d \cos\theta \qquad (13)$$

and the current expression becomes

$$I_0 = \frac{|C| I_1}{\lambda} \cdot \left\{\frac{h_1}{r_1}\right\} \sqrt{1 + \frac{K_0^2 \left\{\frac{h_2}{h_1}\right\}^2}{1 + \left\{\frac{d}{r_1}\right\}^2 - \frac{2d}{r_1}\cos\theta} + \frac{2K_0 \frac{h_2}{h_1}}{\sqrt{1 + \left\{\frac{d}{r_1}\right\}^2 - \frac{2d}{r_1}\cos\theta}} \times}$$

$$\cos\left[\frac{2\pi r_1}{\lambda}\left\{\frac{d}{r_1} - 1 + \sqrt{1 + \left(\frac{d}{r_1}\right)^2 - \frac{2d}{r_1}\cos\theta}\right\} - \phi\right] \qquad (14)$$

and when $r_1 \gg d$

$$I_0 = \frac{|C| I_1}{\lambda} \frac{h_1}{r_1} \sqrt{1 + \left(\frac{K_0 h_2}{h_1}\right)^2 + 2K_0 \frac{h_2}{h_1} \cos\left[\frac{2\pi d}{\lambda}(1 - \cos\theta) - \phi\right]} \qquad (15)$$

As a function of $\theta$ it is evident by inspection that the maxima of this expression occur when the cosine term is a maximum; this maximum may be an absolute or a relative maximum. An absolute maximum occurs when

$$\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi=2n\pi \tag{16}$$

with $n=0, 1, 2, \cdots$, etc., and the cosine term becomes unity. A relative maximum occurs when the cosine term approaches unity but does not reach it before receding again. Only absolute maxima yield determinations of $\phi$; relative maxima occur only at $\theta=\pi$, and are geometrical rather than electrical in character. No maximum obtained at $\theta=\pi$ is therefore usable. Furthermore a minimum value of $d$ exists below which absolute maxima are unobtainable and the evaluation of $\phi$ impossible by this method. The greater $\phi$ is, the greater is this minimum distance.

Absolute minima occur equally with the corresponding maxima, the condition for their existence being $2\pi d(1-\cos\theta)/\lambda-\phi=(2n+1)\pi$ with $n$ taking the same values as before.

It is not difficult, practically, to satisfy the condition $r_1 \gg d$ but the experimental procedure itself is not without difficulty. Thus at the very short wavelengths ($\lambda<6$ meters) where the manipulation itself is practicable the power leads and apparatus carry very disturbing currents which may introduce serious errors in the phase angle as determined. A rough criterion of safety in this respect is to demonstrate that the polar characteristic of the transmitter electric field is a circle. The work reported by Tatarinoff[4] (the only similar work so far noticed) was performed indoors and is therefore open to question. Only a small amount of experimentation is necessary to demonstrate the sensitivity of such experiments to neighboring conductor systems.

Another, and general, question concerns the antennas themselves. If a pair of rectilinear rods of equal length are operated at their natural period a very definite specification of such antennas is possible. This is not a workable case in general, however, it being usually necessary to shorten the antenna so as to allow the insertion of coupling inductances. The radiation resistance is thus lowered and the antenna resonance sharpened so that deliberate tuning is required, and the experimental observations must be carried out with the antenna properly tuned. There is no evident reason, however, why a $K_0$ and $\phi$ thus determined cannot be applied to a pair of half wavelength rods without serious correction.

[4] "Zur konstruction der Radio Spiegel," *Jahr. d.D.T.u.T.*, 28, 117; 1926.

A modification of (7) gives another method of varying the configuration. This is to choose some workable pair of $\theta$ and $d$ values and then alternately place and remove the reflector antenna. Minus the reflector antenna we have $I_{0m}=\{|C|/\lambda\}\cdot\{h_1/r_1\}\cdot I_{1m}$ and with the reflector antenna we have (15), so that by division,

$$\left\{\frac{I_{1m}I_0}{I_1I_{0m}}\right\}^2=1+\left\{K_0\frac{h_2}{h_1}\right\}^2+2K_0\frac{h_2}{h_1}\cos\left[\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi\right]$$

or when the antennas are alike in effective height

$$\left\{\frac{{}_{1m}I_0}{I_1I_{0m}}\right\}^2=1+K_0^2+2K_0\cos\left[\frac{2\pi d}{\lambda}(1-\cos\theta)-\phi\right]$$

and

$$\phi=\frac{2\pi d}{\lambda}(1-\cos\theta)-\cos^{-1}\left[\frac{\left\{\frac{I_{1m}I_0}{I_1I_{0m}}\right\}^2-1-K_0^2}{2K_0}\right] \tag{17}$$

with only known quantities on the right-hand side. This method should be especially suitable at small values of $d$. The indicated current ratios require merely two separate deflections on a "square law" meter; the ratio $K_0=|I_2/I_1|$ on the other hand is that of two different meters and will have to be evaluated in absolute measure. This is the chief experimental difficulty at short wavelengths. Notice that if we make $r_1=r_2$ we may use (12) directly and need not locate the receiver at a great distance. The equation for $\phi$ will be (17) with $\cos\theta=0$.

Equation (15) will give radial maxima, as $d$ is varied, which are simpler to observe experimentally than the angular ones with $\theta$, already mentioned, since they are more sharply defined thus. But the reduction of the results is more difficult since both $K_0$ and $\phi$ are functions of $d$, and although $K_0(d)$ can be separately measured this is not sufficient additional information. Obviously the radial maxima as functions of $\theta$ will be a slightly different set of curves from the angular maxima as functions of $d$, the latter lying outside of and enclosing the former. This is readily seen to be the case, for as we move the reflector antenna radially towards the transmitter antenna from a point on the angular maxima curve, the dephasing action, due to wrong location, is, for a certain decrease in $d$, compensated for by a corresponding increase in reflector current, and the maximum will lie where the dephasing effect and current rise just cancel. This will be most noticeable for small values of $d$; for large values the two types of maxima (or minima) move towards coincidence. If the transmitter antenna itself determines the generator frequency, a radial motion of the reflector antenna will noticeably affect the generator frequency. However, the sharpness of a radial maximum is such that serious error is not introduced in this manner.

Another procedure for obtaining angular maxima is to move the reflector antenna from the transmitter to the receiver antenna, and while this is advantageous in the fact that receiver apparatus is much


Fig. 3

more compact and simple than transmitter apparatus, the theory becomes more complicated. In the transmitter-reflector case the distant antenna action was negligible while in the receiver reflector case the distant antenna action is the driving field itself. We now have the geometry of Fig. 3 and the equations

$$\left.\begin{aligned} Z_{01}I_0 &= Z_1I_1 - Z_{21}I_2 \\ Z_{02}I_0 &= -Z_{12}I_1 + Z_2I_2 \end{aligned}\right\} \tag{18}$$

from which we have

$$I_1 = I_0 \frac{Z_{01}Z_2 + Z_{02}Z_{21}}{Z_1Z_2 - Z_{12}Z_{21}}.$$

Substituting the current ratio values of (4) and (5) turns this into

$$I_1 = I_0K_{01} \frac{1 + \dfrac{Z_1}{Z_2} \cdot \dfrac{Z_{02}}{Z_{01}} K_{21}}{1 - K_{12}K_{21}}. \tag{19}$$

When $r_1$ and $r_2$ are relatively large we may fall back on the Hertzian doublet expression for the driving field at the receiver antennas and have

$$Z_{02} = C_2 \frac{-i60\pi h_0}{\lambda r_2} e^{-i(2\pi r_2/\lambda)} \tag{20}$$

where $C_2$ is the effective height of the antenna, defined as the voltage appearing in antenna center divided by the field producing it. A similar expression holds for $Z_{01}$, and forming the ratio of these two gives

$$\frac{Z_{02}}{Z_{01}} = \frac{C_2}{C_1} \cdot \frac{r_1}{r_2} \cdot e^{-i(2\pi/\lambda)(r_2 - r_1)}$$

and the current expression becomes

$$I_1 = I_0 K_{01} \frac{1 + \dfrac{Z_1}{Z_2} \cdot \dfrac{C_2}{C_1} \cdot \dfrac{r_1}{r_2} e^{-i(2\pi/\lambda)(r_2 - r_1)} K_{21}}{1 - K_{12} K_{21}}. \tag{21}$$

Comparing this with (11) we see that instead of the sum of two vectors we have the quotient of two such sums and the unraveling, for radial maxima, of experimental observations to give $K_0$ and $\phi$ is doubtless more difficult. On the other hand angular maxima involve only the numerator, and (15) can be applied almost unchanged.

Experimentally there is still a difference, however, since with the reflector adjacent to the generator the receiver antenna system is immaterial and the deflecting meter can be carried to any favorable situation by means of a pair of wires and read with ease, while for the reflector adjacent to the receiving antenna no such procedure is permissible and the meter must be read at a distance by a telescope. But it should be easier to make the two antennas identical in the latter case. Then since

$$\begin{cases} K_{12} = K_{21} = K_0 e^{i(\phi - 2\pi d/\lambda)} \\ Z_1 = Z_2 \\ C_1 = C_2 \end{cases}$$

we have

$$I_1 = I_0 K_{01} \frac{1 + \dfrac{r_1}{r_2} K_0 e^{-i[(2\pi/\lambda)(r_2 + d - r_1) - \phi]}}{1 - K_0^2 e^{-2i(2\pi d/\lambda - \phi)}} \tag{22}$$

and

$$\left|\frac{I_1}{I_0}\right| = |K_{01}| \sqrt{\frac{1 + \left\{\dfrac{r_1}{r_2} K_0\right\}^2 + 2\dfrac{r_1}{r_2} K_0 \cos\left[\dfrac{2\pi}{\lambda}(r_2 + d - r_1) - \phi\right]}{1 + K_0^4 - 2K_0^2 \cos 2\left(\dfrac{2\pi d}{\lambda} - \phi\right)}}. \tag{23}$$

The procedure involved in (17) is less readily usable for receiver-reflector experiment, owing to the power required for direct meter operation.

Since $\phi$ can be calculated for a Hertzian doublet and since the Hertzian doublet has played an important role in radio theory, it is of interest to compare this calculated value with the experimental values for finite antennas. The "median plane" electric field of a Hertzian doublet is given by

$$E^* = -\frac{30hI_0}{d}\left(\frac{i\omega}{c}+\frac{1}{d}+\frac{c}{i\omega d^2}\right)e^{i\omega(t-d/c)} \tag{24}$$

when the doublet current is assumed as $I = I_0 e^{i\omega t}$. This expression is most conveniently written as

$$E = \frac{60\pi h}{d\lambda} I_0 K e^{i\omega(t-d/c)+i\psi} \tag{25}$$

where

$$K = \sqrt{1-\left(\frac{\lambda}{2\pi d}\right)^2+\left(\frac{\lambda}{2\pi d}\right)^4} \quad \text{and} \quad \psi = \tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)+\pi$$

$\psi$ being the angle of lead of $E$ over $I$. The values of $K$ and $\psi$ as functions of $d/\lambda$ are attached in the curves of Figs. 4 and 5. The application

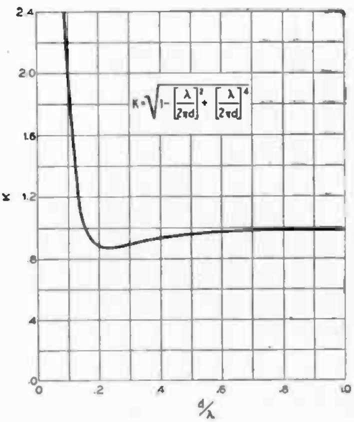


Fig. 4

of (12) gives for the equiphase lines, where a reflector antenna with cophased current would affect a distant receiver in phase with the transmitter current

* The units used are amperes, volts per cm, and centimeters, to conform with the rest of the paper. $c = 3 \times 10^{10}$ cm = vel. of light.

$$\frac{2\pi}{\lambda}(r_2+d-r_1)-\tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)=(2n+1)\pi$$

and when the receiver moves to infinity

$$\frac{2\pi d}{\lambda}(1-\cos\theta)-\tan^{-1}\left(\frac{2\pi d}{\lambda}-\frac{\lambda}{2\pi d}\right)=(2n+1)\pi.$$

The antiphased lines occur for even multiples of $\pi$, Fig. 6 gives the first two cophased and the first antiphased lines.

## Experimental

An experimental study of the maxima and minima of (15) and (23) has proved to be more difficult than was anticipated. All moving conductors, animate or inanimate, such as pedestrians and automobiles,

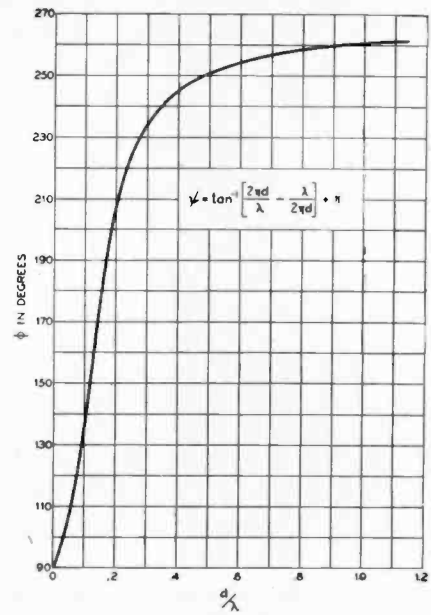


Fig. 5

definitely prevent readings when within some 50 meters (app. 12 wavelengths) of the generator-receiver system. The system actually functions as an automatic detective apparatus, the meter oscillations betraying at once any human movement within the 50-meter range. This movement passes through a cycle every time the pedestrian has altered, by a whole wavelength, the generator-pedestrian-receiver ether path. In the same manner activity by the operator masks the true maxima and minima settings, and it is necessary for the operator to remain immobile at a distance.

As stated earlier the effect of immobile neighboring conductors is to produce a serious error in the measured value of $\phi$. For suppose, in Fig. 2, a conductor located between antennas (1) and (0) and so disposed as to carry a current when the generator antenna (1) is excited. The field from this current superposes at (0) on the field from (1), and in general the vector sum will have a different phase from that of the component arriving from (1). But the component arriving from (1) is the one with which the phase of the (2) field component is to be com-

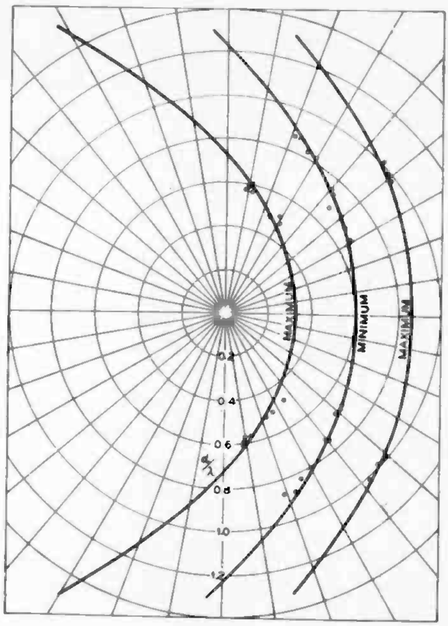


Fig. 6

pared, and if the immobile conductor carries considerable current or is near to (0) a bad error will be introduced. Since the main exciting field arises from the generator antenna current, which always considerably exceeds the reflector current, this error is likely to be very nearly a constant one.

For angular maxima determinations the most serious source of error arises in the mistuning of the reflector antenna, a fact early discovered experimentally. In order to make experiment definite it is necessary to fix on a standard relation between the ether electric field and the reflector antenna current produced by it. This relation is preferably that of cophasing. The reactance of the reflector is then zero and the current and field phases are identical. Various methods of setting a correct tune were tried. If the reflector is tuned, when near a maximizing position, by observing the receiver meter, the angle $\theta$ then varied to improve the maximum, the antenna retuned, $\theta$ readjusted and so on, the correct tune should be obtained in the limit. Possibly owing to the unavoidable effect of the operator on the tuning of the antenna the method proved unsatisfactory. On the other hand, the same process applied to radial maxima determinations proved satisfactory.

The next method tried was that of observing the receiver current as the reflector condenser was varied over its scale. If $\theta$ is off on one

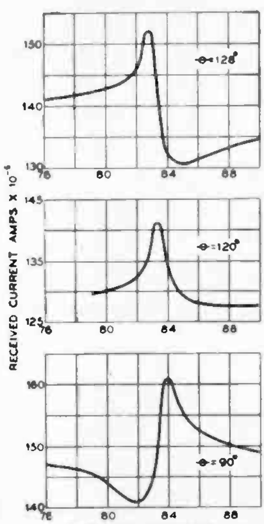


Fig. 7

side of the proper value the resulting resonance curve is characteristically unsymmetrical; if $\theta$ is off on the other side the same resonance, but with a mirror inversion, results; with $\theta$ correct the resonance curve becomes symmetrical. These curves, one of which is given in Fig. 7, checked properly with the theory. However, the accuracy of tune was again insufficient.

Another method of obtaining a reflector tune is by observing its effect on the generator tune, itself due to the transmitter antenna constants. A very sensitive one, too sensitive in this case, is to note the generator frequency variation as an audible beat with a second oscillator. Theoretically, positions can be found where the reflector at exact resonance (reflector reactance zero) can introduce only resistance into the generator circuit,[5] and if the resultant coupling is not too great this introduced resistance will only slightly affect the generator frequency. Under these circumstances the beat note will be identical with that when the reflector antenna is removed to infinity. This method was quite unworkable here, the frequency change being some 70 kc. However, the wavemeter used[6] was very sharply selective and would indicate a frequency change of 1 part in 2000 without trouble and seemed available. The results were again not encouraging and this method was abandoned.

A meter in the center of the reflector antenna will indicate resonance but not without a certain error. Thus if we write for the reflector current

$$I=\frac{E}{R+iX}, \quad I_0=\frac{E}{R}$$

we have

$$\frac{|I|}{I_0}=\frac{R}{\sqrt{R^2+X^2}}=1-K$$

where $K$ is the fractional drop in the current off tune. Further, arg $\{I/E\}=-\delta=-\tan^{-1}X/R$ and from this we obtain the table

| $K$ | $\delta$ |
|---|---|
| 0.005 | 5.74 deg. |
| 0.01 | 8.11 " |
| 0.015 | 9.94 " |
| 0.02 | 11.48 " |
| 0.03 | 14.07 " |
| 0.04 | 15.78 " |
| 0.05 | 18.18 " |

and for a given value of $K$, detectable in the reflector meter reading, the phase angle variation over which the observations may lie is twice the corresponding $\delta$. Tuning at a distance of 1.5 meters and reading a sluggish meter is unlikely to give values of $2\delta$ less than app. 12 deg. This error must be countered by averaging numerous observations.

It is, of course, not necessary to have driving field and reflector current in phase provided we know their phase difference. Thus we may tune for 0.7 of the resonance current, on either side, where resistance equals reactance and $\delta=45$ deg. Two advantages seem present, viz.: the steeply rising resonance curve makes an accurate setting possible, and, by tuning on the lagging side, some of the lead of $\phi$ may be cancelled allowing measurements on a smaller value of the radius $d$. The feasibility of this method is yet to be tried.

[5] For two Hertzian doublets the first two positions are $d=0$, $d=0.713\lambda$.
[6] Described in *Bell System Tech. Jour.*, 7, 417; 1928.

Lastly, the setting of $\theta$ is not an accurate process. The change in receiver current per degree of rotation of receiver antenna is almost unobservable, and when masked by vibrations produced by ever present winds is a difficult measurement. Again an average of a number of readings becomes necessary.

For radial maxima the procedure of plotting current vs. distance curves is easily accurate enough for radii in back of the operating antenna. Radii approaching right angles do not have as sharp maxima

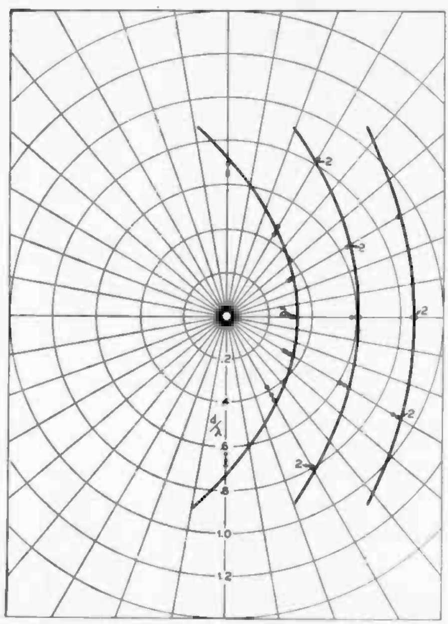

Fig. 8

however. As mentioned earlier either method is good for large values of $d/\lambda$, only the angular maxima are accurate for the smaller $d/\lambda$ values.

The experimental arrangement, pictured in Figs. 11 and 12, consisted of a generator and a receiver each mounted on tripods so as to bring the centers of the (always vertical) antennas 2.5 meters above ground. The generator used a UX852 tube,[7] had a frequency range of 4 to 8 meters, and was battery driven, the power wires being led out horizontally for a distance of 7 meters before dropping to the battery

[7] Substantially the same generator as shown in *Bell System Tech. Jour.*, 7, 408; 1928.

cabinet. Two filters separated this power cable into three parts. The plate power averaged 540 volts×0.05 ampere.

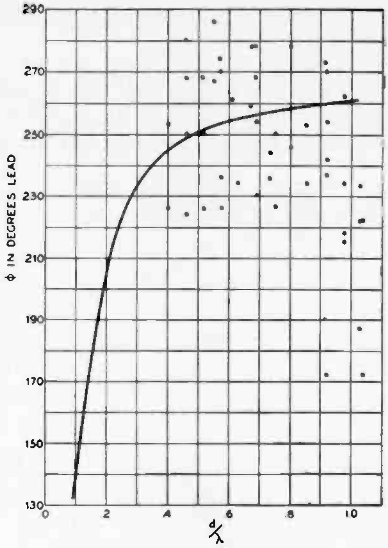


Fig. 9

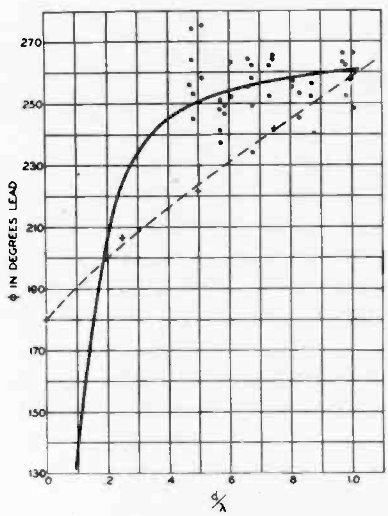


Fig. 10

The receiver was a simple "push pull" vacuum-tube voltmeter using two 215A "peanut" tubes with a microammeter in their common plate lead and was stationed at approximately 31 meters from the generator. The reflector antenna was mounted either on a radial carriage and track or on a rotating arm, both operated at a distance by means of a cord and pulley system. All three antennas were as nearly identical as possible, and were each tuned by means of a small three turn, 4.7 cm diameter, copper tube inductance unit with cutdown Remler condenser connected across it, this antiresonant circuit being mounted in the center of the antenna. The overall antenna length was 106.6 cm or approximately 52 per cent of the corresponding half wavelength resonator. The wavelength used varied slightly from day to day, averaging 4.34 meters.

The first results obtained were radial (receiver) maxima, and were found by plotting radial distance versus receiver current curves and locating the maxima and minima graphically. The operator sitting at a distance of seven meters read the receiver current by means of a field

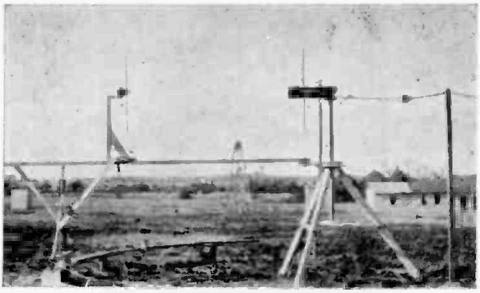

Fig. 11

glass. These maxima and minima are plotted in Fig. 8, the circles being observed values and the full curves the theoretical Hertzian doublet co- and antiphase lines of Fig. 6. The fit is within experimental error; moreover, the first observational maxima values lie, correctly, between the first cophase line and the generator point.

The next results were obtained by means of angular maxima about the generator, the receiver current being carried back to the operator by leads lying on the ground. Meanwhile experiments leading to the determination of a definite tune were carried out. The results are plotted in Fig. 9, the circles being observations, and the continuous curve the theoretical Hertzian doublet phase angle. The scattering is marked, since all results are included irrespective of method of tune. In Fig. 10 the tuning has been done as carefully as possible by means of a reflector antenna ammeter[8] and the scattering much reduced. As mentioned earlier, it is to be expected that the dispersion will cover a 12 deg. band.

The observations of Fig. 10 are plotted on Fig. 6, and the fit of experiment with theory is again close. Since the theoretical Hertzian doublet expressions will be unquestionably valid at great distances we may conclude that from infinity to 0.33 wavelength spacing between antennas which are substantially half the resonant linear conductor length, the phase angle between driving and reflector antenna currents is that calculable from the theory of the Hertzian doublet. Unfortunately, the onset of winter prevented measurements of $\phi$ at spacings

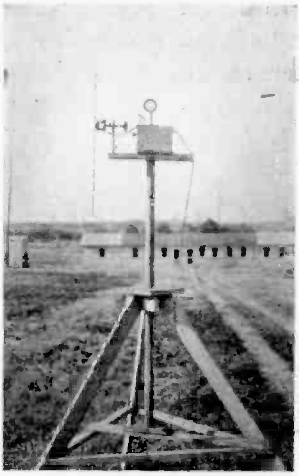

Fig. 12

less than 1/3 wavelength. As shown by Figs. 6 and 8 this is very nearly the optimum spacing between a driver and reflector antenna for maximum effect when both antennas are of equal length, and not 1/4 wavelength as has often been assumed. If Tatarinoff's $\pi/2$ value of $\phi$ for great distances is a lag, then his published curve will be the dotted one on Fig. 10. His angular maximum observation at 1/4 wavelength spacing (Fig. 10) is hard to explain.

The dependence of these results on the wavelength has not been determined. Theoretically no such dependence is to be expected for

[8] A 600-ohm carbon filament thermocouple was tapped across 1/6 of a turn of the tuning coil, and the thermocouple current read by means of a Weston Model 301 microammeter symmetrically mounted with respect to the antenna halves.

systems the scale of which is proportional to the wavelength. The effect of the ground is also unknown, but it is not believed that it was dominant. The polar diagram of the generator without reflector was taken at a rather close range, and when the fixed radius brought the measuring antenna near to the direct-current power down leads a bad hump was noticed. By roughly determining the ratio of driving antenna current to down lead current it was found by computations that the probable error introduced, at the spacings actually used, was less than the errors of tuning and setting of $\theta$. The angular range of the reflector antenna arm was 180 deg., and over this range the reflector antenna meter showed no change. The use of an anti-resonant central antenna tune should not introduce error as compared with the preferable series tune, the latter not so readily tapped for meter operation.

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# THE PROPAGATION OF LOW POWER SHORT WAVES IN THE 1000-KILOMETER RANGE*

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***Summary***—*A description is given of a series of experiments carried out between two ground stations, and between an airplane and a ground station, to determine whether it is possible to obtain with relatively low power reliable short-wave communication over distances of 500 km, or more. Continuous-wave transmitters supplying a constant power of two watts were employed throughout the experiments. Results at fixed distances are recorded and discussed, particularly with regard to fading in summer and winter. An airplane installation, operating into a fixed dipole antenna is described, and the results of a large number of observations at ground receiving stations, of the signals received from the airplane in flight are presented.*

In earlier communications,[1] the Division for Radio and Electrical Engineering of the German Experimental Institute for Aeronautics has already pointed out the advantages offered by the use of short waves for radio communication in aerial transportation, as compared with long waves which have been used exclusively up to the present. The first experiments showed immediately that the long ranges which could be covered by equipment of relatively small dimensions and weight constituted some of these advantages.

It is true that there were available a large number of investigations[2] regarding the propagation of short waves over very long distances. However, the distances to be considered in connection with present air traffic are those up to about 500 km and in exceptional cases up to 1000 km, which must be covered continuously by the radio equipment on board the aircraft. Systematic investigations of the wavelengths suitable for this purpose, and of the power of the transmitting stations required, have not been published hitherto.

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[1] H. Fassbender, K. Krüger and H. Plendl, *Naturwissenschaften*, **15**, 357, 1927. H. Plendl, *Zeits. f. tech. Physik*, **11**, 456, 1927. H. Fassbender, *Luftfahrtforschung*, **1**, 121, 1928. K. Krüger, H. Plendl, *Jahrb. d. drahtl. Tel.*, **31**, 169, 1928. Experiments with short waves during the trip of the airship *Graf Zeppelin* to America, *E. T. Z.*, **50**, 16, 1929.

[2] References to existing literature to be found in: A. Sacklowsky, *E. N. T.*, **4**, 62, 1927. R. Mesny, *Les Ondes Electriques Courtes*, Paris, 1927. R. Mesny, *L'Onde Electrique*, 76, 129, 1928. L. W. Austin, Proc. I. R. E., **16**, 348; March, 1928.

The Radio Division, under the supervision of Prof. Dr. H. Fassbender, therefore took upon itself the task of investigating these problems. Most important was the question whether it would be possible to cover the entire range of distances continuously with a single wavelength, or with a band of wavelengths of a certain width, without communication being impaired to any appreciable extent by the phenomenon of weakening zones.

Another problem was the determination of the influence of the power, and of the time of the day and the season, on the propagation of these waves.

## Equipment

Table I lists the equipment used in the present experiments.

The Lorenz set, mentioned under No. 1 of the table, generates its high-frequency energy in a single quartz-controlled stage. The low limit of its wavelength is therefore about 40 m, as quartz crystals which are reliable in operation can be manufactured, with the means available at the present time, only for wavelengths down to this value. Signals are sent by the interruption of the anode voltage, so that the

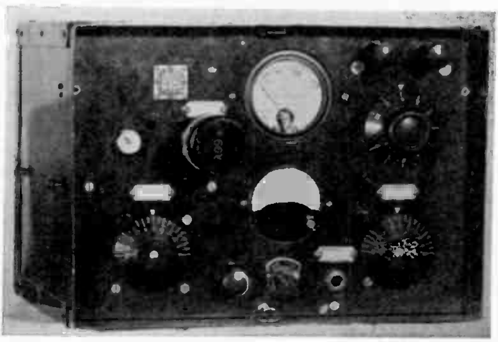

Fig. 1—Short-wave Transmitter for Airplanes. Design DVL—Telefunken (improved type).

oscillation of the quartz must start anew each time the key is pressed down. This system of signalling has two drawbacks: The impulse at starting under certain conditions will excite one of the secondary waves of the quartz which often appear in crystals of small size, instead of the primary wave; this causes a sudden change in the tone in the receiver, or even inaudibility. Furthermore, the slight change in frequency which may easily occur at the beginning of the oscillation is made evident at the receiving end in a disturbing manner as a change in tone, especially at high speed.

TABLE I

List of Equipment Used

| No. | Designation of equipment | Manufacturer | Type of wiring | Range of wavelengths in meters | Antenna power of transmitter in watts | Weight without batteries in kg | Figure No. |
|---|---|---|---|---|---|---|---|
| 1 | One-knapsack set SERKT 127 Transmitter: | C. Lorenz A.-G. | quartz-controlled, one stage without intermediary circuit | 40–60 | 2 | | |
| | Receiver: | | audion, 2 low-frequency stages | 30–60 | — | 5.7 | |
| 2 | Short-wave transmitter for airplanes (first experimental type) | Telefunken G.m.b.H. in cooperation with Radio Division of DVL | (a) quartz-controlled, one stage with intermediary circuit | 40–80 | 2 | 2.2 | |
| | | | (b) quartz-controlled, two stages with duplication of frequency | 20–40 | 2 | 4.5 | |
| 3 | Short-wave transmitter for airplanes (improved type) | " | quartz-controlled, two stages with duplication of frequency | 30–70 | 2 | 4.0 | 1 and 2 |
| 4 | Laboratory transmitter | Radio Division of DVL | quartz-controlled, double duplication of frequency Amplification of capacity | 10–60* | 10 or 60 | 14.4 | |
| 5 | Short-wave receiver for large stations, Gr. 98 special | Telefunken G.m.b.H. | push-pull audion, 3 low-frequency stages | 11–80* | — | 14.3 | |
| 6 | Short-wave receiver for airplanes | " | audion, 3 low-frequency stages | 30–70 | — | 5.0 | 3 |
| 7 | Short-wave receiver for large stations, E.R.K.327 | C. Lorenz A.G. | audion, 2 low-frequency stages | 12–100* | — | 12.1 | |
| 8 | Rectifier measuring apparatus | Radio Division of DVL | grid rectification with measuring instrument in anode circuit | — | — | 2.2 | |

* with interchangeable coils

In order to eliminate these drawbacks, the 2-watt short-wave transmitter for airplanes, mentioned under No. 2 in Table I, was first developed. This set consists of two stages, according to wiring scheme *b* (Table I). The first stage is controlled by a quartz crystal and has a wavelength range from 40 to 80 m. In the second stage, the quartz frequency is doubled, the low limit of the wavelength being consequently reduced to 20 m. In this set signalling is done in the anode voltage (about 200 volt) of the frequency-doubling stage, the quartz-controlled stage being constantly in the condition of oscillation. The superposed tone produced in the receiver by such a transmitting set is perfectly pure and has a constant frequency; therefore it is easily distinguished from the disturbing noises and is very suitable for high speed telegraphing. This advantage would also be obtained if, in the keyed second stage, a power amplification of the quartz frequency were provided,

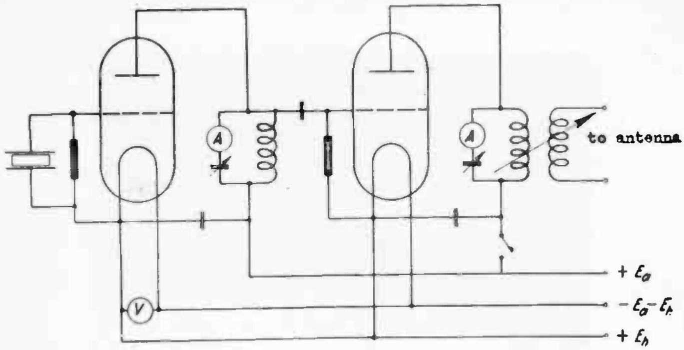


Fig. 2—Basic Wiring Diagram of Short-wave Transmitter for Airplanes, Quartz-Controlled Type with Duplication of Frequency. Design DVL—Telefunken.

instead of the doubling of the frequency. In this case, however, because of the amplifier circuits tuned to the quartz wave, the coupling would be too large between the antenna and the quartz stage that continues to oscillate during the intervals of the transmission, that is, when the key is released. When such a transmitter is being operated, the superposed tone in the receiver during the intervals consequently would not disappear, but only decrease in intensity. This, however, would impair the legibility of the signals.

The quartz-controlled first stage can also be used independently, but in this case the drawbacks referred to in the beginning of this article make themselves felt. The higher cost entailed in the elimination of these drawbacks by the addition of a doubling stage is in general well spent, for operation sets. Therefore, the quartz control and the doubling of the frequency were combined in a single cabinet, in the improved type of short-wave transmitter for airplanes (No. 3 in Table I). The range of wavelengths of the doubling stage is from 30 to 70 m. Fig. 1 shows a view of this apparatus and Fig. 2 the basic wiring diagram of the latter.

The reception in the airplane is made relatively difficult by the disturbances caused by the running motor, such as the noise of motor and propeller, vibrations and ignition sparks. A good short-wave receiver for airplanes must therefore have special requirements. With a minimum weight and space, it must give very strong amplification in order to be able to exceed in intensity the disturbing noises reaching the ear from the outside. Furthermore, it must be soundly built and protected against acoustic influences, in order to prevent the ever present mechanical and acoustic vibrations from exerting a disturbing influence on reception. Especially as regards the inevitable noise of

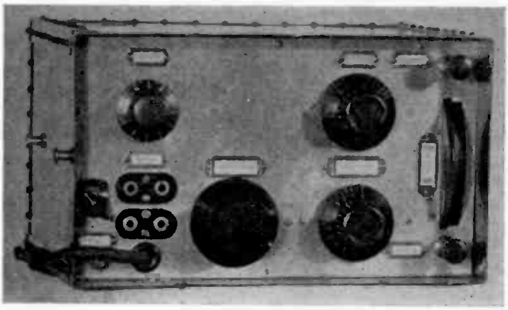

Fig. 3—Short-wave Receiver for Airplanes. Design DVL—Telefunken.

the ignition, it is important to obtain a pure constant tone in reception, which can be well distinguished from its background. If this condition be fulfilled, reception in a flying plane is still possible even when the intensity of the signals occasionally drops somewhat below the relatively high level of the disturbances.

For the major part of the reception observations made in the airplane, the receiver mentioned under No. 5 was used. The latter is a special form of the "Telefunken" receiver for large stations; it is different from the latter insofar as it was provided with a third low-frequency amplification stage, instead of the heterodyne, and instead of a copper cabinet, with a lighter one of aluminum. This receiver generally gave satisfactory results, but it did not produce a pure superposed tone due to the vibrations of the airplane. Passing through certain intermediate types, the development led to the short-wave receiver for airplanes mentioned in Table I under No. 6 and shown in Fig. 3. This receiver, while possessing the same sensitivity, represents a great improvement in weight and space; also, it is considerably less sensitive to vibrations.

The investigations discussed in the next chapter not only served the purpose of collecting data by observation concerning the phenomena of propagation but also that of developing and testing the apparatus described above.

## PROCEDURE OF THE EXPERIMENTS AND RESULTS

In order to solve the problem stated above, it was necessary to sub-divide the experiments in the following manner.

For *constant distance*, the intensity of the signals in relation to the time of day was observed with different wavelengths as the parameter. Moreover, different airplane antennas were compared in this respect. The transmitter power was 2 watts in most cases.

The influence of *varying distance* on the intensity of the signals was investigated with different wavelengths as the parameter. In general, these observations were made exclusively in broad daylight throughout the whole distance. They were spread out over a whole year. The antennas used in these experiments were always horizontal dipoles.

### (*a*). *Experiments with Constant Distance*

These experiments were made for the major part by two ground stations, one being situated in Berlin-Adlershof, the other one in Munich. The distance between these two stations was 500 km. Adlershof was generally the transmitting station, while the reception was observed in Munich. In order to keep the transmitting station in Adlershof continuously informed about the results of the reception, there had been installed in Munich, beside the receiver, a small 2-watt transmitting set which could, upon request, pass on the information at once. For the purpose of comparing airplane antennas, local flights over one of the two stations were made, while the other station observed the reception; in this way, the distance between transmitter and receiver remained practically constant.

The transmitters used during these experiments were installed in Adlershof in the main building of the Radio Division, whose equipment has been described in previous publications.[3] Insofar as Adlershof had to deal with observations of the reception, these were made in a small isolated reception building, in order to prevent disturbances. This small building was connected with the main building by means of

[3] See footnote 1 and also H. Fassbender, *Jahrb. d. drahtl. Tel.*, 30, 173, 1927.

a double conductor, so that the transmitters could also be operated from this observing station.

In Munich, the apparatus was also located in a special small building.[4] The antenna was here, in the same way as in Adlershof, a horizontal dipole with a length of about twice 8 m, and with bifilar conduction of energy.

The experiments between the two ground stations were primarily for the purpose of collecting data on the behavior of different wavelengths during different hours of the day. It was desired to ascertain if and by what means suitable communication during the daytime could be established over a distance of 500 km, with outputs of from

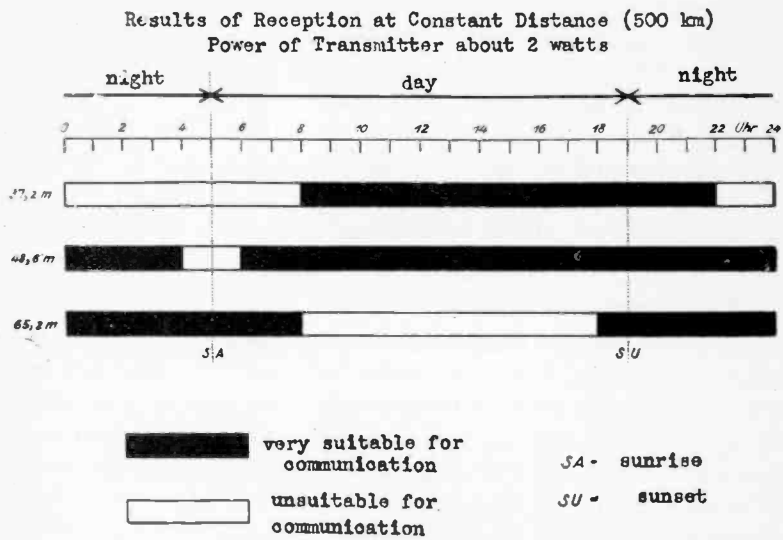


Fig. 4—Graphic Presentation of the Results Obtained with Reception at Constant Distance.

1 to 10 watts. The wavelengths used varied between 30 m and 65 m, the transmitters functioning exclusively with undamped telegraphy.

Fig. 4 shows part of the results of these experiments for the three wavelengths principally used, namely, 37.2 m, 48.6 m, and 65.2 m. The black portions of the bars indicate the hours during which it was possible to use these wavelengths for communication, whereas during the hours indicated by white portions of the bars, no communication, or only a very faint one, was obtained. The data represented here

[4] This small building was located on the premises of the "Electrotechnische Versuchswerkstätte G.m.b.H." (Workshops for electrical experiments) which also supplied the equipment required, such as anode storage batteries, heating batteries, etc.

relate to the middle of April. They vary with the season, in connection with the change in the length of the day. The figure merely represents a diagrammatic condensation of a large number of experiments and does not claim to show quantitative values.

It is interesting to note that the limits of the fading and the reappearance of the short waves, as shown in the figure, are relatively very distinct.[5] The transition from a large volume of sound to near inaudibility generally takes place in a few minutes. At this time reception suddenly wavers greatly, that is, the frequency of fading increases many times, while the amplitude of the signal intensity decreases rapidly. In this critical period, the intensity of the reception fluctuates in the course of a few seconds, and sometimes in the course of fractions of seconds, in the ratio 1: 1000 and more.

Brief variations in the intensity also occur frequently at other hours, especially around noontime, but to a considerably lower degree, about 1:10 and more rarely 1:100 read on the measuring instrument. Because of the logarithmic sensitivity of the ear, variations in intensity in the ratio 1:10 have but little influence on the audibility. At other times, especially during the evening and night hours, the intensity of reception varied only within narrow limits, about 1:1.5 and in several cases even a perfect constancy of the signal intensity for several hours was observed on the rectifier measuring instrument.

An essential impairment of the reception by atmospheric disturbances could hardly be found during any of the observations, provided there were no indications of a thunderstorm in the immediate vicinity of the observing station. The intensity of the signals amounting to from 2 to 8 ma, and even to a maximum of 30 ma, was in general considerably above the level of atmospheric disturbances, the latter being seldom higher than 0.05 ma. On the other hand, temporary disturbances of local origin (commutator sparks, ignition sparks, etc.) were annoying, but could be eliminated to a large extent through proper selection of the location of the observing station.

A picture of the wave propagation phenomena can be obtained in the following manner.

The failures in reception occurring in some places during the night and in the early morning hours, for shorter waves (37.2 and 48.6 m in Fig. 4) are evidently caused by a shift in the minimum distance required for the return of the space wave to the surface of the earth, that is, by a displacement of the "skip distance" away from the sender, during the night. This phenomenon may be imagined as being caused by the fact that during the night the space wave due to the less in-

[5] See also R. A. Heising, PROC. I. R. E., 16, 75; January, 1928.

tensive ionization of the lower layers, is refracted at a greater altitude than during the daytime. The diagram in Fig. 5[6] visualizes this phenomenon. The lower boundary of the Heaviside layer during the night gradually shifts upward from I to III, so that the innermost wave belonging to the skip distance shifts from *A* to *C*. At a certain moment, this limiting wave passes the location *B* of the receiver, the result being a rapid decrease in the intensity of the tone. In the morning, the process is reversed, the result being a correspondingly rapid increase in the intensity of the tone received at *B*. Therefore, it is not necessary to assume that the sudden variation in the intensity of the sound during fading and the reappearance of the wave is caused by a correspondingly rapid variation in the altitude of the Heaviside layer.

Contrary to the waves with a short length so far considered, for which the reception is suspended during the night or in the early morning hours, the moments when the somewhat longer waves fail (for example those of 65 m in Fig. 4) occur around noon. The transition

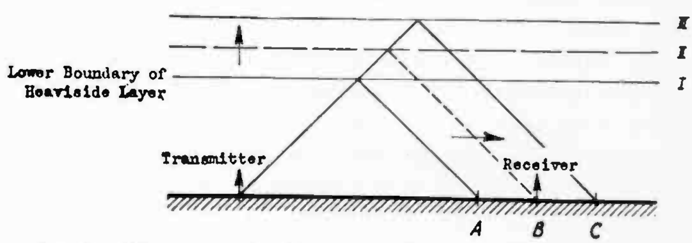


Fig. 5—Diagram of the Boundary Wave of the Fading Zone.

differs here from that occurring in the case of shorter waves, in that it is gradual. This difference must be ascribed to the fact that with increasing wavelength, the guided wave becomes active at points farther and farther away, while the innermost limit of the space waves shifts toward the sender, so that space wave and guided wave overlap. Therefore, fading zones, which were the cause of the sudden variation in tone intensity, as shown above, do not occur here any longer.

A similar result as obtained by the experiments described above between the two ground stations was also obtained by numerous local flights above Berlin-Adlershof and above Königsberg in East Prussia, these flights being made during different times of the day and also during the night. In this case, the transmission occurred with different waves from the airplane while the latter was in the air, and the reception was observed in Munich, the distance being about 500 and 1000

[6] For the sake of simplicity, simple reflection of the waves has been shown in the figure. Furthermore, it has been assumed, also in order to simplify the matter, that the critical angle does not vary perceptibly with the time of the day.

km, respectively. It was proved by these experiments that the results obtained with experiments between the ground stations also applied to a great extent to communication between an airplane and the ground. Furthermore during the numerous ascents and landings there was no perceptible difference in reception where the plane transmitted from the ground or from the air. Also, there was not found to exist any essential difference caused by the altitude[7] at which the airplane was flying during its transmission.

Furthermore, during these local flights, comparisons were made between different kinds of transmission antennas. The dipole always used in other cases was compared with a one-wire trailing antenna which was excited in one quarter or three quarters of a wavelength respectively. It was shown that the tightly strung dipole was essentially superior as to constancy of frequency, that is purity of superposed tone in the receiver, to the trailing antenna whose position is never

Fig. 6—Airplane with Dipole for Short Waves.

entirely stable. With regard to the intensity of tone, the three-quarter wavelength trailing antenna was slightly superior to the dipole, while the one-quarter wavelength trailing antenna was considerably inferior.

(*b*) *Experiments with Varying Distance*

Whereas the previous chapter dealt mainly with investigation on the propagation of short waves as a function of the time of day, the experiments described below had for their purpose the determination of the influence of the distance between transmitter and receiver on the intensity of the tone in the receiver. Metal airplanes of the Junkers F-13 type were available for this purpose,[8] equipped with dipole

[7] A similar result was also found for long waves (900 m), see F. Eisner, H. Fassbender and G. Kurlbaum, *Jahrbuch der drahtlosen Telegraphie*, 1909, 31, 1928. It is true that this condition changes when there are mountain ranges within the distance over which transmission takes place, whose shadow may exert a considerable influence on the long-wave communication. With short-wave communication, however, interposed mountain ranges cannot cause any disturbance, as the space wave which is the most active one bridges these mountains independent of the altitude at which the airplane is flying.

[8] Experimental flights were also made in a Dornier-Wal airplane whose wings were covered with fabric.

antennas and corresponding interior equipment. The outside view of an airplane of this kind is shown in Fig. 6, while a view of the interior with the newly developed short-wave transmission and receiving apparatus for airplanes is shown in Fig. 7.

Numerous overland flights in different directions were made with these airplanes within the German frontiers and transmission from the airplane occurred mainly with undamped waves and a power of 2 watts. The observation of the reception was always taken care of in Adlershof, and often at the same time in Munich. As Adlershof was the starting and finishing point for all flights, the longest distance within Germany was limited to about 600 km when the reception was observed in Berlin. In order to be able to extend the experiments to

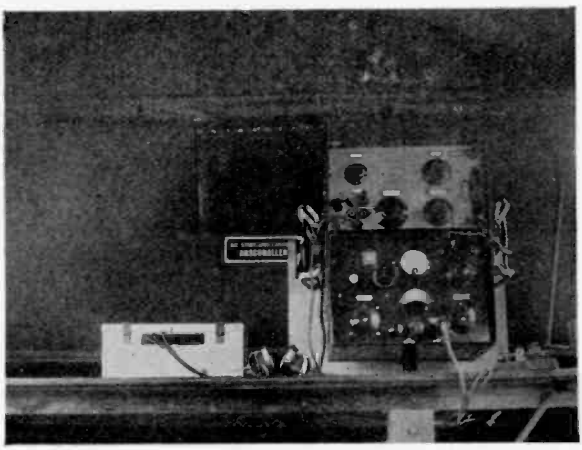

Fig. 7—Short-Wave Equipment in Airplane.

longer distances, without having the planes go outside the frontiers of Germany, several flights were made to Königsberg and Tilsit, in which cases the reception could be observed in Munich for a maximum distance of more than 1000 km. In addition to the 2-watt transmitter, a receiver was always taken on the flights, this receiver serving both for checking the transmission and for communicating with the two observing stations. During each of these overland flights, the transmitter on the airplane was kept in continuous operation. The key was operated automatically by means of a signal transmitter driven by clockwork. In addition to this, reports were transmitted on the position of the airplane and on the weather.

Fig. 8 shows the results of the observations in relation to distance, the receiver always being placed at a distance *O*, while the airplane

TABLE II

List of Overland Flights

| Serial No. | Date | Time of Day | λ Meters | Distance Covered by Flight | Observing Station |
|---|---|---|---|---|---|
| 1 | June 2, 1928 | 12:00–13:30 | 27.6 | Königsberg—Danzig | München |
| | June 6, 1928 | 11:15–17:45 | 27.6 | Danzig—Adlershof | " |
| 2 | June 2, 1928 | 12:00–13:30 | 27.6 | Königsberg—Danzig | Adlershof |
| | June 6, 1928 | 11:15–17:45 | 27.6 | Danzig—Königsberg | " |
| 3 | April 25, 1928 | 9:00–14:30 | 32.6 | Adlershof—München | Adlershof |
| 4 | April 25, 1928 | 9:00–14:30 | 32.6 | " " | München |
| 5 | April 27, 1928 | 9:00–14:45 | 32.6 | München—Adlershof | " |
| 6 | April 27, 1928 | 9:00–14:45 | 32.6 | " " | Adlershof |
| 7 | June 1, 1928 | 10:15–18:30 | 32.6 | Adlershof—Königsberg | " |
| 8 | June 1, 1928 | 10:15–18:30 | 32.6 | " " | München |
| 9 | March 19, 1928 | 9:00–15:00 | 37.2 | Adlershof—Königsberg | Adlershof |
| 10 | March 19, 1928 | 9:00–15:00 | 32.6 | " " | München |
| 11 | March 23, 1928 | 9:15–21:45 | 32.6 | Königsberg—Tempelhof | " |
| 12 | March 23, 1928 | 9:15–21:45 | 32.6 | " " | Adlershof |
| 13 | July 11, 1928 | 9:30–17:30 | 32.6 | Adlershof—Friedrichshafen | " |
| 14 | July 13, 1928 | 9:30–12:30 | 32.6 | Fürth—Adlershof | " |
| 15 | September 28, 1927 | 13:15–16:45 | 40.0 | Norderney—Adlershof | Adlershof |
| 16 | February 18, 1928 | 11:15–12:30 | 40.0 | Hamburg—Adlershof | " |
| 17 | February 27, 1928 | 13:00–17:00 | 40.0 | Adlershof—Danzig | " |
| | February 28, 1928 | 10:15–13:15 | 40.0 | Danzig—Tilsit | " |
| 18 | February 27, 1928 | 13:00–17:00 | 40.0 | Adlershof—Danzig | München |
| | February 28, 1928 | 10:15–13:15 | 40.0 | Danzig—Tilsit | " |
| 19 | March 6, 1928 | 10:00–15:00 | 40.0 | Adlershof—München | Adlershof |
| 20 | March 6, 1928 | 10:00–15:00 | 40.0 | Adlershof—München | München |
| 21 | March 8, 1928 | 12:00–15:45 | 40.0 | München—Schkeuditz | " |
| 22 | March 8, 1928 | 12:00–15:45 | 40.0 | " " | Adlershof |
| | March 9, 1928 | 9:30–11:00 | 40.0 | Schkeuditz—Adlershof | " |
| 23 | July 26, 1928 | 9:30–17:15 | 40.0 | Adlershof—Köln | " |
| 24 | June 27, 1928 | 9:45–13:15 | 40.0 | Köln—Adlershof | " |
| 25 | July 18, 1928 | 8:30–12:30 | 41.6 | Adlershof—München | Adlershof |
| 26 | July 19, 1928 | 10:00–14:30 | 41.6 | München—Adlershof | " |
| 27 | July 31, 1928 | 9:30–16:00 | 41.6 | Adlershof—Köln | " |
| 28 | August 1, 1928 | 10:00–13:45 | 41.6 | Köln—Adlershof | " |
| 29 | August 24, 1927 | 13:30–14:45 | 46.3 | Adlershof—Leipzig | Adlershof |
| 30 | August 24, 1927 | 14:45–15:45 | 46.3 | Leipzig—Adlershof | " |
| 31 | August 29, 1927, | 10:00–12:30 | 46.3 | Adlershof—Hannover | " |
| 32 | August 29, 1927 | 15:15–17:00 | 46.3 | Hannover—Adlershof | " |
| 33 | August 31, 1927 | 9:30–14:15 | 46.3 | Adlershof—Köln | " |
| 34 | September 1, 1927 | 11:30–18:15 | 46.3 | Köln—Adlershof | " |
| 35 | September 7, 1927 | 11:00–15:30 | 46.3 | Adlershof—München | " |
| 36 | September 9, 1927 | 13:45–18:30 | 46.3 | München—Adlershof | " |
| 37 | October 13, 1927 | 10:45–17:15 | 46.3 | Essen—Adlershof | Airplane between Stolp and Adlershof |
| 38 | October 13, 1927 | 10:45–17:15 | 46.3 | " " | |
| 39 | February 16, 1928 | 10:15–13:30 | 46.3 | Adlershof—Hamburg | |
| 40 | October 7, 1927 | 11:00–13:30 | 49.8 | Adlershof—Hannover | Adlershof |
| 41 | October 7, 1927 | 15:45–17:45 | 49.8 | Hannover—Adlershof | " |
| 42 | October 12, 1927 | 12:00–17:30 | 49.8 | Adlershof—Essen | Airplane between Stolp and Königsberg |
| 43 | October 12, 1927 | 12:00–17:30 | 49.8 | " " | |
| 44 | August 3, 1928 | 10:15–14:30 | 49.8 | Adlershof—Königsberg | Adlershof |
| 45 | August 4, 1928 | 7:00–11:15 | 49.8 | Königsberg—Adlershof | " |
| 46 | August 6, 1928 | 11:00–17:00 | 49.8 | Adlershof—Friedrichshafen | " |
| 47 | September 5, 1928 | 10:00–16:00 | 49.8 | Friedrichshafen—Adlershof | " |
| 48 | October 2, 1928 | 9:15–17:30 | 49.8 | Adlershof—Fehmarn | " |
| 49 | October 3, 1928 | 10:00–15:15 | 49.8 | Fehmarn—Adlershof | " |
| 50 | August 8, 1928 | 9:15–15:00 | 52.7 | Friedrichshafen—Adlershof | Adlershof |
| 51 | September 4, 1928 | 7:15–13:45 | 52.7 | Adlershof—Friedrichshafen | " |
| 52 | March 1, 1928 | 10:15–15:00 | 55.2 | Königsberg—Adlershof | München |
| 53 | March 1, 1928 | 10:15–15:00 | 55.2 | Königsberg—Adlershof | Adlershof |

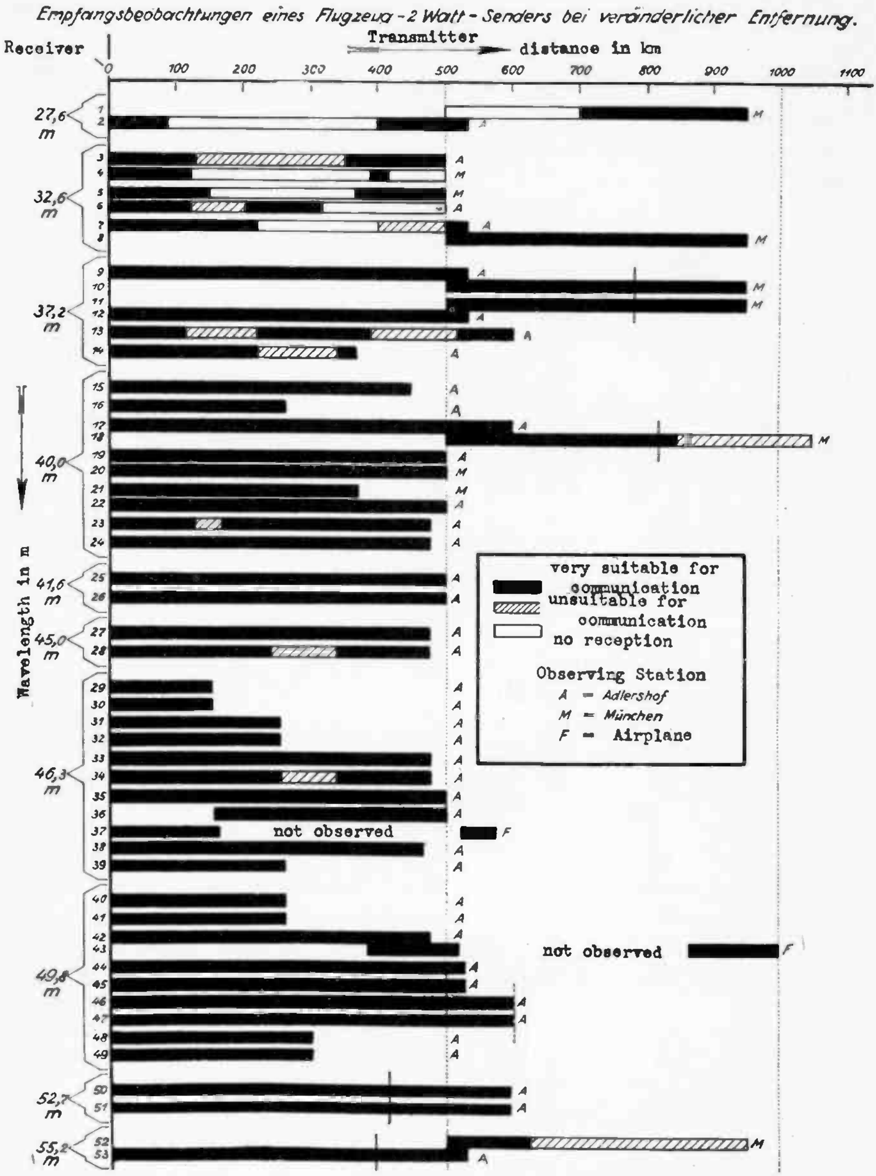


Fig. 8—Results of Reception of Signals from a 2-watt Transmitter in Airplane, for Varying Distance.

transmitter must be considered as moving in the direction of the abscissa. Each observation of an overland flight corresponds to a horizontal bar, the bars indicated by $A$ having been plotted in Adlershof, those indicated by $M$ in Munich. The bars are numbered continuously and arranged according to the wavelength. The black portions in the diagrams correspond to reception very suitable for communication; the cross-hatched portions indicate wavering uncertain reception and the white portions represent the range of distances where reception fails. Further data concerning the individual flights, such as date, time of the day, and course, are given in Table II.

A review of the diagrams shown in Fig. 8 shows clearly the essential difference between the shorter and the longer waves within the range of 27 to 55 m. The shorter waves, below about 38 m, show distinct fading zones, whereas they come over in a satisfactory manner over longer distances. For wavelengths between about 40 m and 46 m, the fading zones occur only exceptionally, so that the chance of good communication increases for the shorter distances. For longer waves, with a length of 50 m and over, no fading zones are perceptible any longer. This wave band (around 50 m) therefore proved to be suitable for constant communication over a range of distances up to about 600 km.

This favorable result obtained with the 50-m band was confirmed by a number of overland flights not mentioned in Fig. 8, during which the signal intensity of a transmitter located on the ground was observed by means of a receiver on the airplane. This transmitter operated, in the majority of the cases, with undamped waves of 48.5 m, or with waves having a length close to this, and with an antenna power of about 60 watts. Four of these flights extended over a distance of 600 km, and an equal number over a distance of 300 to 450 km. In these cases, a satisfactory signal intensity, without fading zones, could be observed with receivers of sufficient sensitivity (audion and 3 A.F.)

According to Fig. 8, the fading zones for the waves of 27 m and 32 m occur between about 100 and 400 km. The two boundaries of these zones have an entirely different behavior. Whereas for the inner boundary the reception grows weaker in a gradual manner, there occurs in the case of the outer boundary an abrupt change in the tone intensity corresponding to the sudden action of the space wave. There is not always a complete extinction of the reception in the fading zone; rather it happens that the transmitter, even with such a low power as 2 watts, remains faintly audible all the time. In principle, it is impossible to indicate definite boundaries for these zones, as shown by the example of observation No. 6 in Fig. 8. In fact, in the middle of the range which had appeared to be, in all other observations of this wave band, a pronounced fading zone, there was obtained good communication over a long distance (about 120 km).

It must be assumed that the zones of strong weakening or entire lack of reception observed for a transmitting power of 2 watts would no longer have any disturbing effect if the power were sufficiently increased, in the ratio of about 1:1000 to 1:10000; this assumption is based on experience previously gathered[4] with high powers (8 kw). The experiments made at the time with high powers showed that even with considerably shorter wavelengths (15, 18, and 28 m), there cannot be found any absolutely dead zones, this being in contrast with the results obtained by Reinartz, Taylor-Hulburt, and Heising.[9] The only result was that zones of strong weakening of the reception intensity were observed, this being in accordance with the investigations of T. L. Eckersley,[10] published at about the same time, which, in addition to similar results obtained by observations, contain a theoretical explanation of these phenomena.

For the wave with the next greater length of 37 m, the results of the observations were very inconsistent. Whereas in the cases 9 and 12 the reception was always free from weakening, cases 13 and 14 showed spots where the reception was uncertain. The discrepancy may have been caused by the difference in seasons, as the former observations were made at the end of March, the latter in the beginning of July.

In the adjacent wave band of 40 to 46 m, about twenty observed flights gave weakening zones in only three cases, the longest distance being 90 km. In this connection, it must be observed that both at the transmitting and the receiving end, exclusive use was made of horizontal dipoles. More recent experiments, however, seem to indicate that the weakening zones mentioned above would not be so pronounced if vertical antennas or a combination of different kinds of antennas were used at the receiving end.

With the exception of these three cases where weakening zones were observed, these waves and especially the 50-m wave continuously gave a large volume of tone at the reception end resulting generally in a pure loud speaker reception. It was always possible to obtain distinct

[9] Reinartz, *QST*, **9**, 9, 1925. A. H. Taylor, Proc. I. R. E., **13**, 677; December, 1925. A. H. Taylor and E. O. Hulburt, *QST*, **1**, 13, 1925. A. H. Taylor and E. O. Hulburt, *Phys. Rev.*, **27**, 189, 1926. E. O. Hulburt, *Jnl.* Franklin Institute, **201**, 597, 1926. R. A. Heising, J. C. Schelleng, and G. C. Southworth, Proc. I. R. E., **14**, 613; October, 1926.

[10] T. L. Eckersley, *Jour.* I. E. E., **65**, 600–644, 1927; compare also A. H. Taylor, Proc. I. R. E., **15**, 707; August, 1927.

and easily measurable deflections of the rectifier measuring instrument after the two low-frequency amplifying stages of the receiver.

The average course of events with regard to the signal intensity observed was about as follows. When the airplane, equipped with the transmitter, moved away from the observing station, the signal intensity decreased in the first 20 km from about 15 ma to 5 ma; thereafter it remained at this amount during the entire remaining part of the flight up to a certain critical distance. With the tubes used in the measuring apparatus, this deflection corresponded to a great volume in the loud speaker reception, without being impaired by the outside disturbances. When this distance was exceeded, the signal intensity decreased rapidly, but it always remained sufficient for reception by means of a head set. This critical distance has been indicated in Fig. 8 by a vertical line. It was found to lie, for the 37 and the 40-m waves, at about 800 km; for the 53 and 55-m waves, at about 400 km; and for the 50-m wave, at about 600 km. The critical distance therefore increases with decreasing wavelength. The width of these critical zones was about 10 to 20 km and was covered by the airplane in a few minutes. Both the sudden decrease in signal intensity with increasing distance, and the equally sudden increase in signal intensity with decreasing distance, were repeatedly observed. In the case of observations 10 and 11 in Fig. 8, for example, the same critical distance (780 km) for the wave with a length of 37.2 m was observed both during the outward flight and the return flight.

The fading phenomena observed during transmission from the airplane in flight were of the same order of magnitude as those observed for a constant distance, under normal circumstances. Within the critical distance, for which the signal intensity was high and practically constant, it was never found that the communication was impaired by possibly existing fading phenomena. Only in the case where this distance was exceeded, the effect of fading occasionally caused a disturbance during a short period of time. The critical distance therefore constitutes the maximum range for communication by means of the wave under consideration, for which continuous good reception is certain ("maximum distance for good communication").

The observations made in the manner described above appeared to be independent of the altitude of the flight. The signal intensity remained unchanged whether the airplane transmitted during the flight or, over the same distance, from the ground. In several cases reception was still possible when the airplane, at a distance of 500 km from the observing station, was located, together with its transmission apparatus, in a closed shed reinforced with steel.

In addition to the experiments described above, during which the transmitter was located in the airplane, there was also made a series of observations on reception on the airplane. These experiments were intended primarily for the development of a short-wave receiver for airplanes, and also for determining the power of a transmitter located on the ground in order to communicate with airplanes. The wave band of from 46 to 50 m, which had been proven to be suitable in the above investigations, was mainly used in this connection. The experience was collected during ten long distance overland flights, the longest distances lying between 300 and 600 km.

When the airplane is on the ground, with its motor stopped, the results of the observations mentioned above also apply, without further complication, to the reception inside the cabin. When the motor is running, however, we have to deal with the disturbances already mentioned, which impair the clarity and relative signal intensity of the reception. Because of these disturbances, the 2-watt transmitter usually will no longer be sufficient in this case: at any rate, the transmitters on the ground which are intended for communication with airplanes will be given much higher powers. However, it has been possible repeatedly to get continuous reception in the airplane, with satisfactory signal intensity, up to a distance of 450 km, by means of the receiver described under No. 5 in Table I, a transmitter with a power of 2 watts on the ground, and undamped telegraphy. In the other cases, the transmission from the ground station occurred with about 60 watts, the reception giving good signal intensity up to a flight distance of 600 km.

The results thus far obtained with observations of the reception on board the airplane in flight show that the favorable results with waves around 50 m in length, obtained in the experiments discussed above, also apply to this case. These observations have not yet been concluded, however. They rather require further clarification of the question of the power of the transmitter on the ground, sufficient to insure dependable communication.

An important point to be considered during the further investigations is the elimination of the fading phenomena. This elimination has for its purpose the improvement of short-wave communication by the establishment of an even signal intensity which remains constant during a long period of time. The solution of this problem must be sought primarily in the selection of the proper kind of antennas to be used in the ground station.

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# FURTHER NOTE ON THE IONIZATION IN THE UPPER ATMOSPHERE*

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A RECENT paper[1] by the present writer has brought from other workers in the field a considerable amount of discussion through the medium of personal letters. The author believes that the objections which were in this way raised have been shown not to be valid and that his correspondents now agree in this statement. However, it may be well to put on record certain considerations the omission of which for the sake of brevity caused difficulty.

It was proved that the apparent height found by the "fringe" method employed by Appleton and Barnett, Bown, Martin, and Potter, and by Heising is the same as the apparent height found by the method of Breit and Tuve[2]. In the course of this proof, the following expression for group time was used.

$$T_g = \frac{d}{df}(fT_p), \tag{1}$$

in which $f$ is the frequency and $T_p$ the phase time. This expression was used instead of the usual one involving phase and group velocities in order to avoid the difficulty brought about by the fact that different frequency components follow different paths. No difficulty is encountered in homogeneous media. Letting $S$ be the distance and $U$ and $V$ the group and phase velocities we have:

$$T_g = \frac{S}{U} = S\frac{d}{df}\left(\frac{f}{V}\right) = \frac{d}{df}\left(\frac{fs}{V}\right) = \frac{d}{df}(fT_p)$$

* Dewey decimal classification: R113.4. Original manuscript received by the Institute, May 18, 1929.

[1] J. C. Schelleng, "Note on the Determination of the Ionization in the Upper Atmosphere," Proc. 16, 1471; November, 1928.

[2] Since the writing of the paper under discussion, attention has been called to the fact that E. V. Appleton at the Brussels meeting of the U. R. S. I. presented a proof of the equivalence of these methods based on the method of rays and Fermat's principle. The proof given by the writer does not involve the method of rays and Fermat's principle is not needed. Appleton's paper was given on September 13, 1928.

In these methods, the apparent height is *defined* as the altitude of the isoceles triangle whose base is the line between stations and whose sides are of a length such that if the atmospheric wave is assumed to travel along them the observed "fringes" and the observed group delay will be the same as that observed. An essential part of this definition is the assumption that the path is independent of frequency, i.e., $dD/df = o$, where $D$ is the difference between the length of the paths of the atmospheric and ground waves. It is well-known that the path is really dependent on frequency, but this is no objection as long as we are defining an *apparent* height.

Now without further analysis it is obvious that even in the case of non-homogeneous media, in which therefore the rays of different frequencies which make up a pulse follow different paths, this expression is still true. The group arrives at the receiver when certain phase relations are established between the components. It is true that $T_p$ is a function of the method of wave propagation involved, but having given $T_p$ we need not know the mechanism of propagation. The expression given above still applies.

Perhaps, however, a more formal proof will be preferred by some. Let two sinusoidal waves pass from point $A$ to point $B$ by any path and by virtue of any mechanism whatever.

Letting $n=2\pi f$, we may represent the first wave at point $A$ as $\sin n_1 t$ and the second as $\sin(n_2 t-\phi)$. The difference of phase is therefore

$$[(n_1-n_2)t+\phi] \tag{2}$$

At the same time $t$, the phase at $B$ is less depending upon the time of phase propagation, or the time required for a crest to travel from $A$ to $B$. The two waves at $B$ and at time $t$ are therefore $\sin n_1(t-T_{p_1})$ and $\sin[n_2(t-T_{p_2})-\phi]$. The difference of phase at $B$ is therefore

$$[n_1(t-T_{p1})-n_2(t-T_{p2})+\phi]. \tag{3}$$

Now the time required for the group to travel from $A$ to $B$ is $T_g$. It is a time such that the phase differences at $B$ at time $(t+T_g)$, are the same as they were at $A$ at time $t$. This is true because these phase differences determine how the waves interfere to produce the envelope of the group. Substituting $(t+T_g)$ for $t$ in (3) and equating to 2, we have $[(n_1-n_2)t+\phi]=n_1(t+T_g-T_{p_1})-n_2(t+T_g-T_{p_2})+\phi$. As a result we obtain

$$T_g=\frac{n_1T_{p_1}-n_2T_{p2}}{n_1-n_2}. \tag{4}$$

This expression may be used for the case of any two frequencies. In the case of narrow clusters such as those with which we are usually concerned, it is more convenient to use differential notation

$$T_g=\frac{d(nT_p)}{dn}=\frac{d(fT_p)}{df}. \tag{5}$$

This is seen to be identical with (1). It will therefore be seen by reference to the original paper that the fringe experiment and the group experiment give identical results, the identity being proved regardless of what the mechanism will eventually prove to be. The proof is more general than one based on ray theory, and attention is particularly called to the fact that Fermat's principle of least time is not needed to prove the equivalence of the two methods.

With reference to the third method of determining the "height" of the layer, i. e., the triangulation method, Breit and Tuve showed that neglecting dissipation and the effect of the earth's magnetic field, it gives the same result as the echo experiment. However, they assumed that the group time is given by the expression $\int ds/U$, $U$ being the usual function of the ionic concentration at points on the ray path of one of the frequencies of the cluster. This expression is correct, but it probably is not obvious in view of the fact that the ray paths of the component frequencies of the cluster differ from each other.

In special cases of ionic distribution we may calculate the group time by use of (1). The procedure is to calculate the phase time by standard methods, remembering that in transmission between two points the initial earth angle is a function of frequency while the distance is not. About a year ago the writer carried out this procedure in the case of a linear increase in ionic concentration with height. The result was that the method of Breit and Tuve was checked. It was then realized that the explanation is to be found in the well known fact that the ray path in general is one of least time.[3] While the different rays of the cluster follow slightly different paths, an error of only a second order is incurred by assuming that ray $(f+\Delta f)$ actually follows the path of ray $f$.

The error is of a second rather than of a first order because while a slight upward shift of the path would result in a first order increase in the distance to be travelled, it would also be accompanied by a first order increase in average phase velocity due to the greater ionization. The phase time is therefore not changed. This balance of course applies only to the vicinity of the actual ray path. Since by least time considerations we see that no error in $T_p$ or in $f\ T_p$ is introduced by considering that the components travel over the same path, we need not consider $ds$ to be a functionof frequency. We may therefore write:

$$T_g=\frac{d}{df}(fT_p)=\frac{d}{df}\left(f\int_A^B\frac{ds}{V}\right)=\frac{d}{df}\int_A^B\frac{f}{V}ds$$

$$=\int_A^B\frac{d}{df}\left(\frac{f}{V}\right)ds=\int_A^B\frac{ds}{U}$$

Therefore the group time is the same as though the rays travelled over the same path, and the method of Breit and Tuve is correct.

[3] E. V. Appleton independently arrives at this conclusion in the U. R. S. I. paper. The present proof is essentially the same, but emphasis is here placed on the physical aspects of matter.

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# AN ELECTROMAGNETIC MONOCHORD FOR THE MEASUREMENT OF AUDIO FREQUENCIES*

By
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***Summary***—*The desirable properties for an instrument for measuring frequencies over the audible range are briefly mentioned and a suggested electrically excited monochord is considered. In practice certain difficulties are found and lead to a proposal for employing the harmonic modes of vibration of the stretched wire. The theory of this is given, as well as the relation between the frequency response and the position of a movable bridge. The constructional details and the method of calibration from a single tuning fork are described in turn. Miscellaneous considerations concerning the practical operation conclude the paper.*

## 1. Frequency Measuring Methods

In a laboratory in which telephony research is undertaken it is essential that there should be some method of rapidly measuring the frequency of any current produced, and of setting a source of current to a given frequency.

An instrument for this purpose should have a range from 32 up to 5,000 cycles at least.

One method is to use an electrically excited tuning fork and obtain harmonics from this. But the labor and patience required to count up to, say, the thirtieth harmonic without error (only 480 cycles in the case of a 16-cycle fork) is such that the method can usually be used only as a check, and one has to rely otherwise on the calibration of the oscillator in use, which is not always too certain.

Another alternative is a large number of separate forks to cover the range. This is very expensive, and does not cover the gamut of frequencies continuously.

The author was faced with this problem and noting a brief reference[1] to the electromagnetic monochord decided to investigate its possibilities.

This monochord was a stretched steel wire carrying the current to be measured. The wire passed between the poles of a magnet, and by electromagnetic action is thrown into vibration when its natural frequency corresponds to the frequency of the current flowing through it. A bridge sliding along the wire adjusts the length in use, and therefore the natural frequency. From known data the position of the bridge corresponding to any frequency is found.

* Dewey decimal classification: R210. Original manuscript received by the Institute, January 10, 1929.

[1] P. K. Turner, *Jour.* I. E. E. (Wireless Sec.) 2, No. 6, p. 205.

The writer, however, experienced considerable difficulty in practice. It was not easy to set the bridge accurately enough, at the higher frequencies especially; and at this part of the range the wire in use became so short that it refused to respond to the electrical excitation. Also the exciting system given did not work, and better results were obtained with an old Brown loud speaker magnet arranged to pull direct on to the wire.

The trial of thinner gauges of steel wire, down to the sizes employed for banjos, was unsuccessful on raising the natural frequency of the wire (in order to lengthen the upper frequency lengths, compared with their diameter, to get a better response) as the tensile strength decreased far more rapidly, with decrease of diameter, than the frequency went up.

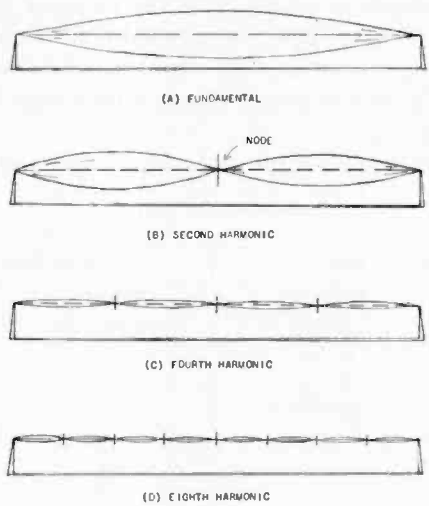


Fig. 1

It was then decided to try to do without the bridge and to work on a system of harmonics as follows.

## 2. Harmonic Monochord Theory

Consider a stretched wire provided with an arrangement to vibrate it at any frequency $f$ upwards from its own natural period $f_1$. Now when $f = f_1$, i.e., when the exciting frequency is the same as the natural frequency, the wire will vibrate as a whole as in Fig. 1 (a). The nodes, or positions of no vibration, are at the ends of the wire, and the anti-node, or position of maximum amplitude of vibration, is at the center of the wire as shown.

Now let $f=2f_1$, i.e., the second harmonic of the wire is excited. For convenience the fundamental will be considered as the first harmonic, as this agrees with the frequency ratios. Now we have one node in the center of the wire. Fig. 1(b).

Similarly (Figs. 1(c) and 1(d)) we may show that if $n$ is the number of nodes in the wire then it is vibrating to a frequency $(n+1)$ times its fundamental $f_1$.

Further, if we know any harmonic frequency of the wire and the number of its nodes, we can find any other response frequency from the relation

$$f=f_1(n+1) \tag{1}$$

where $f$ is the harmonic frequency.

By this means we may find the frequency of each harmonic response of the monochord as we raise the exciting frequency from $f_1$ upwards. The nodes are easily counted by running a finger nail or a piece of metal up the wire, and counting the times the harmonic becomes audible (as the indicator passes a node and does not interfere with the vibration).

A specimen calibration table is shown for the monochord about to

CALIBRATION TABLE

| 1/16 in. diam., 5 ft. wire | | 1/32 in. diam., 16 in. wire | |
|---|---|---|---|
| Harmonic | Frequency | Harmonic | Frequency |
| Fundamental | 32.625 | Fundamental | 261 |
| 2 | 65.25 | 2 | 522 |
| 3 | 97.875 | 3 | 783 |
| 4 | 130.5 | 4 | 1044 |
| 5 | 163.125 | 6 | 1566 |
| 6 | 195.750 | 7 | 1827 |
| 8 | 261 | 8 | 2088 |
| | | 9 | 2349 |
| | | 10 | 2610 |
| | | 11 | 2871 |
| | | 12 | 3132 |
| | | 13 | 3393 |
| | | 15 | 3915 |
| | | 18 | 4698 |

be described. The harmonic points given were found sufficient for all ordinary purposes.

### 3. The Use of the Bridge

In general a series of points obtained from one standard tuning fork in this manner is sufficient, but there is also the method of obtaining a measurement of any frequency within the range by feeding it to the exciting magnet and sliding the bridge until resonance is found. The frequency range, however, is not so high as in the case of the harmonic method, for reasons already stated, though a special design of exciting magnets and the like would probably help here. The author has not had need to investigate this further up to the time of writing.

If $l_1$ is the length of the wire from end to end, and $l_{11}$ is the electrically excited length stopped off by the bridge, then it can be easily seen that the relationship between the natural frequency $f$ of the short length $l_{11}$ and that of $l_1$ is

$$f/f_1 = l_1/l_{11} \tag{2}$$

By direct measurement $f$ can always be determined; or a graduated scale may be fitted, though the writer has not found this latter worth while, as the harmonic points are generally amply sufficient, and a scale near enough to the wire for accuracy tends to foul the other parts.

The resonance is very sharp and, though the author has no exact data at hand, he believes that the accuracy of the harmonic method is at least comparable with other substandards. The advantage of the ease of checking and setting the frequency adjustments is obvious.

If the bridge is employed, however, the precision of adjustment depends on the mechanical design, and may not be high enough for certain work.

## 4. Constructional Details of Monochord Base

It is essential that the body of the monochord should be extremely massive as the strain imposed is immense. The author has not tried metal, but can recommend a 2×2 in. section length of wood, with two 4×1 in. boards bolted flat on top and bottom. 3/8-in. steel bolts are good. The wood should be teak, or of a similar hard nature, though actually quite excellent results were obtained with oak boards and a deal center.

For the ends of the wire, piano pins (easily obtained from any piano shop) were employed. They were screwed tightly into 1/4-in. holes in blocks of hard wood at each end of the base. Slight counter-sinking of the top of the holes and the use of French chalk will facilitate the operation. A piano tuner's key will turn these pins and so adjust the tension of the wire.

Instead of the pins a very stout worm drive mechanism would undoubtedly give finer adjustment.

The ends of the wires must not run direct to the fastening off pins, or buzzing and uncertain lengths of vibration will give trouble. It is most important to pass them through a clamp of two layers of ebonite fixed to the base with grooves to bite the wire tightly and positively in order to give an exact end to the vibrating chord.

Further details of the base may be gauged from Fig. 2.

### 5. Wires and Exciting Mechanism

A piano wire about 1/16 in. in diameter and about 5 ft. long will go down to 32 cycles nicely and right up to the harmonics. It is very tedious to count about a hundred odd nodes for each high note check; therefore the writer employs this wire for up to about 261 cycles (roughly the 8th harmonic) and a short length of about 16 in. with a fundamental of 261 cycles (middle *C* philharmonic) for up to about 5000 cycles. There seems no reason to doubt that the harmonic response goes still higher than this, but the author's oscillator does not work beyond this point, consequently no actual tests have been made. The short wire is about 1/32 in. in diameter.

These sizes are the result of much experiment and appear to be the best.

Unless the very lowest frequencies only are needed the wires must have a mechanical tensioning device. Weights of practicable

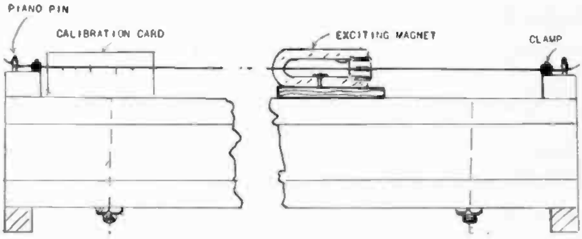


Fig. 2

size are useless for this purpose.

The amplitude of movement of the wires is very small—quite invisible—at the notes over, say 2000 cycles, and may reach as much as a half inch at 32 cycles. Hence the distance between the exciting magnet and the wire must be adjustable.

A convenient method is to mount the magnet on a heavy base at the side of the wire and move it to and from it, as required.

### 6. Calibration

This is easily performed by tuning the oscillator in use to any available electrically excited tuning fork, switching over to the monochord and adjusting the tension of the wire until the maximum response is attained. If the fork has a frequency which corresponds to a harmonic instead of the fundamental of the wire it is inadvisable to stop the latter with the bridge, as this will usually produce an error due to slightly inaccurate measurement. Instead, work to the harmonic directly by means of counting the nodes.

The position of the nodes and their frequencies may be marked on the monochord. It is only necessary to mark, say, the left-most, if this is the end of the wire used for high frequencies with the bridge. For the top notes a piece of card close behind the wire is necessary to avoid errors in reading due to the crowding of the nodes at this part of the frequency range.

In practice any setting may be found in a few seconds once the monochord is calibrated.

## 7. Miscellaneous

A middle *C* tuning fork (philharmonic 261 cycles) may be excited by mounting it with an old earphone magnet system. Care should be taken that the correct note response is employed, and not a harmonic, as the fundamental will not usually be by any means the loudest reponse of the fork when used in this way.

To render the harmonics easily found, particularly when first calibrating the monochord, plenty of power to the exciting magnet should be employed. If the a-c source is not powerful enough an extra valve amplifier should be interposed between it and the monochord. This method has the advantage also that no appreciable power need be taken from the source of current.

The author employs two LS5A valves (in push-pull to avoid saturation of the output transformer core) with 200 volts on the anodes. The monochord will work with much less than the full output of this combination.

The sharpness of the resonance of the wires is very great indeed, and failure to find harmonics is generally due to this cause. To avoid interference it is well to damp the unused portion of the wire when using the sliding bridge.

If difficulty is found in hearing the response of the wire, a telephone magnet system placed close up to it, as if to excite it, but with a pair of phones connected (if desired via an amplifier) to the coils of the magnet, will act as an excellent microphone. It will pick up only the movement of the steel wire it is close to, which may be an advantage in a busy laboratory.

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# AN EMPIRICAL EQUATION FOR DETERMINING THE $d^2i_g/de_g^2$ OF DETECTORS*

By
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***Summary***—*An empirical equation for the grid-current grid-voltage curve of the C-327 tube is developed. By obtaining the derivatives of this equation rather than determining them from the $i_g$-$e_g$ curve by graphical means the inaccuracy of the graphical methods is avoided. The equation holds accurately in the range of $e_g$ encountered in practice.*

In the March, 1929, issue of the Proceedings, an experimental method of determining the second derivative of the grid-current grid-voltage curve of electron tubes was presented by J. R. Nelson. The main advantage of the method lies in the fact that the great difficulty of evaluating the slopes at various points of the $di_g/de_g$ curve by graphical methods is avoided. However, the method requires a know-

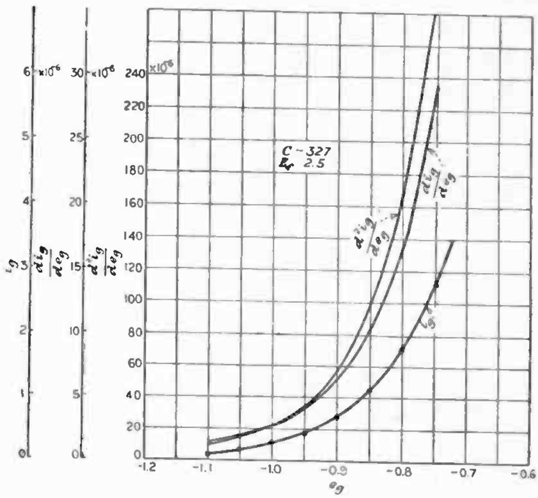

Fig. 1

ledge of the values of the first derivative, which are usually obtained from the grid-current grid-voltage curve by graphical means, and which are subject to the same inaccuracies which the method seeks to avoid in passing to the second derivative. It is clear, then, that

* Dewey decimal classification: R134. Original manuscript received by the Institute, March 25, 1929. Revised manuscript received May 28, 1929.

the method is of value only insofar as the values of $di_g/de_g$, or $r_g$, are accurately known.

It is much more accurate, and quite simple, to obtain an empirical equation for the $i_g$-$e_g$ curve; this can then be differentiated in order to obtain the first and second derivatives. In order to illustrate the method of obtaining the equation, an actual numerical case follows.

Fig. 1 shows the $i_g$-$e_g$ curve of a typical 327 tube. This has been replotted in Fig. 2 on logarithmic coordinates, and may be considered a straight line for small values of $i_g$. In this case the equation has the form

$$i_g = ae_g{}^m \tag{1}$$

However, it is seen that the difference between $i_g$ and the values given

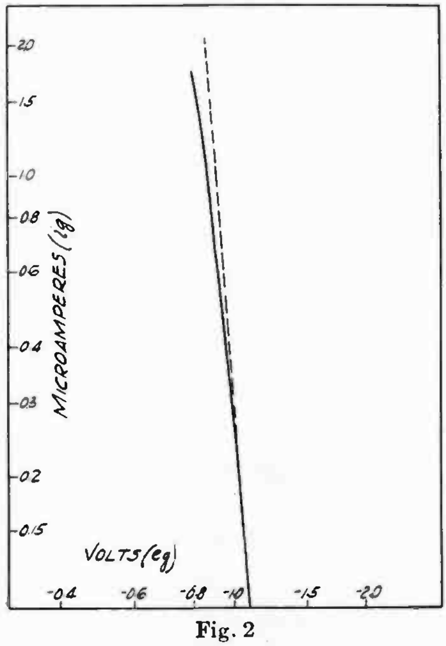


Fig. 2

by (1) becomes greater and greater with increasing $e_g$. Equation (1), therefore, must be corrected by a constant negative term $i_0$, viz.,

$$(i_g - i_0) = ae_g{}^m \tag{2}$$

Substituting into (2) the coordinates of three well-separated points of the $i_g - e_g$ curve there results

$$0.09 - i_0 = (1.10a)^m \tag{3}$$

$$0.46 - i_0 = (0.95a)^m \tag{4}$$

$$1.78 - i_0 = (0.80\text{a})^m \tag{5}$$

Subtracting (3) from (4):

$$0.37 = (0.95\text{a})^m - (1.10\text{a})^m$$

and factoring out the $(0.95\text{a})^m$th term

$$0.37 = (0.95\text{a})^m [1 - 1.158^m] \tag{6}$$

Performing a similar operation on (4) and (5):

$$\begin{aligned} 1.32 &= (0.80\text{a})^m - (0.95\text{a})^m \\ &= (0.95\text{a})^m [0.843^m - 1] \end{aligned} \tag{7}$$

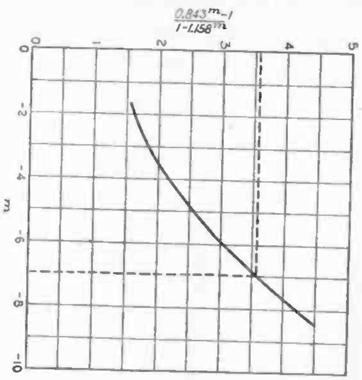


Fig. 3

The ratio of (7) to (6) gives:

$$3.57 = \frac{0.843^m - 1}{1 - 1.158^m} \tag{8}$$

The value of $m$ in (8) must be determined by trial. Various values are substituted for $m$ in the right-hand member of (8) and the values of the fraction so obtained are plotted in Fig. 3. The correct value of $m$ is then the abscissa of the point whose ordinate is the left-hand member of (8), or, $m = -7$.

The values of $a$ and $i_0$ are then obtained by simple substitution. The resulting equation is:

$$i_g = (0.40 e_g^{-7} - 0.114) \times 10^{-6} \tag{9}$$

Its first derivative is

$$di_g/de_g = -2.80 e_g^{-8} \times 10^{-6} \tag{10}$$

and its second derivative is

$$d^2i_g/de_g^2 = 22.40e_g^{-9} \times 10^{-6} \qquad (11)$$

Curves calculated from (9), (10), and (11) are shown in Fig. 1. The calculated values of $i_g$ are indicated by circles which fall directly upon the experimentally obtained $i_g$-$e_g$ curve, indicating the reliability of the equations.

In conclusion, it might be pointed out that whenever inflections are found in the curve, such as often occur at large values of $i_g$, equations so determined cannot be used. For the smaller values of $i_g$, however, in the range encountered in practice, these equations are quite accurate.

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# ENGINEERING ASPECTS OF THE WORK OF THE FEDERAL RADIO COMMISSION*

By
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THE administrative and legal aspects of the work of the Federal Radio Commission are complicated and interesting. Much of this complexity and interest can be traced to the peculiar engineering facts of radio transmission. If it were not for the limitations imposed by the nature of radio waves, the Commission would have a relatively easy task, or indeed the Commission might never have been created.

The numerous engineering problems which have to be dealt with in the course of the Commission's work arise mainly from two physical phenomena. These are: (a) radio waves spread out everywhere, stopping at no boundaries, and capable of great mutual interference, (b) the number of radio communication channels is definitely and severely limited. The implications of these basic facts are far-reaching. The first has led to international regulation, now embodied in the 1927 International Radio Convention.

**Limited Number of Communication Channels.** This, likewise, has international as well as national consequences. The right to operate radio transmitting stations has become so valuable that the demand for channels far exceeds the supply. The number of channels is being increased, from time to time, as radio technique develops, but at any given time there are only a limited number of communication channels. If stations are permitted to operate in excess of the capacity of these channels extensive interference develops and radio operation becomes unsatisfactory.

In the present state of radio technique the number of channels in the whole radio spectrum is as follows: in the low frequencies (15 to 550 kc), there are something less than 1000 channels; in the broadcast band of frequencies (550 to 1500 kc), there are 96 channels, of which 90 are available for the use of the United States; and in the high frequencies (from 1500 to 23,000 kc) there are about 1260 channels. These figures are on the basis of an approximate 0.2 per cent width of channels for frequencies above 1500 kc, a 10-kc width in the broadcast band, and

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a width grading from 0.2 per cent to 1.0 per cent below 550 kc. The factors determining these channel widths are discussed below.

Thus we have a total of about 2350 channels available for the radio traffic of the entire world. On some of these frequencies, particularly the very low and the very high, it is not feasible to have more than one station operating at any given time in the whole world. On many of the others a large number of stations can operate simultaneously. The facts regarding these frequencies are well enough established to permit us to calculate the number of stations which can be licensed without causing excessive interference.

The fact that the number of channels is limited and the number of stations assignable to any one channel is again limited, imposes upon the Government the necessity of choice among applicants for the radio channels. This is the underlying reason why a Federal Radio Commission came to be created. To provide for choice among those who aspire to construct and use radio stations, Congress created not only the Commission as its instrument to make the choice, but also a judicial principle to be the basis of choice, viz., the principle of "public interest, convenience, or necessity."

It was the congestion in the broadcast band which spurred Congress to this legislation. Only in that band of frequencies did the number of applicants for licenses exceed the supply of channels, in early 1927, when the law was passed. The condition extended, however, and the demand now exceeds the supply in the high-frequency band as well as as in the broadcast band. The Commission's task becomes progressively more difficult, and at the same time the stimulus to engineering progress increases.

The number of stations which can be in simultaneous operation without destructive interference depends on a number of factors. First of these is the width of channel occupied by the intelligence transmitted. That is to say, every message or signal actually preempts certain frequencies on either side of that of the radio wave which carries it. Speech or music thus takes up a wider channel than telegraphic dots and dashes. The channel widths required for the various classes of intelligence transmitted by radio are about as follows: for telegraphy, even at very high speed, a few tenths kc or less. For telephony, 10 kc. The same for photograph transmission at maximum commercial speeds. For television of fair quality, 100 kc.

The use of damped waves, produced by spark transmitters, involves even wider channels than any of the foregoing. In fact it is so nearly impossible to conduct radio communication on damped waves without interference that their use has become steadily more objectionable.

The International Radio Convention of 1927 forbids their use in new stations at frequencies below 375 kc after 1929, and forbids their use entirely (except for ships and aircraft stations, of less than 300 watts) after 1939. The Radio Commission, by its General Order No. 51, forbade their use entirely (except for ship stations) after January 1, 1929.

Another limitation on the number of communication channels available is the lack of perfect constancy of station frequencies. The channels must be wide enough so that frequency variations will not cause a transmitting station to invade the channel of another station. If a station frequency varied as much as 0.2 per cent, the present allowed width of high-frequency channels, this would put it exactly on the frequency of the station occupying the adjacent channel. An accuracy of frequency maintenance much better than 0.2 per cent is therefore necessary to permit the use of channels of this width.

The Commission is therefore requiring high-frequency stations (other than mobile and amateur), to maintain frequency with an accuracy of 0.05 per cent or better at all times; it also requires that transmitters be tuned with an accuracy of 0.025 per cent. This requires very careful design of transmitting apparatus. The use of piezo oscillators or some equivalent means of accurate maintenance is essential.

Another important factor limiting the number of stations that can be on the air simultaneously is the selectivity of receiving apparatus. This, taken together with geographical and frequency separation of transmitting stations, their power, and the location of the receiver with respect to interfering stations, largely determines the allowable channel width at the present time.

**High Frequencies.** For frequencies above 1500 kc, the known facts regarding these various factors determining channel width (intelligence band width, frequency variation, receiver selectivity, and related factors) indicate that a width of approximately 0.2 per cent is practicable at the present. As the design of receivers improves, giving greater selectivity, and as the constancy with which stations maintain their frequency improves, the channels may be narrowed. The channel width may perhaps soon be reduced to approximately 0.1 per cent, allowing twice as many stations to be licensed, in some parts of the spectrum. There are highly important political consequences of this purely engineering circumstance. Frequencies above 6000 kc are world-wide in their effects, and they are thus subject to division among the nations. The greater the number of available channels, the less is the likelihood of serious international conflict over their exploitation.

Even in the 1500–6000-kc band, transmissions are continental (although not world-wide), in their effects, and it has been necessary to secure agreement with Canada, Cuba, and other North American nations on their use. Those nations have agreed to use the same width of channel, frequency maintenance requirements, etc., as the United States. Of the 639 channels in this band each North American nation reserved a few for priority use by that nation. Most of them are used in common by all these nations, and agreement has been reached as to the parts of the spectrum in which to license various types of users, such as Government, ship, aircraft, visual broadcasting, experimental, etc., stations.

In January, the Commission had about 850 applications pending for frequencies in the 1500–6000-kc band. These were for all sorts of uses, e.g., ship telephone and telegraph, airplane telephone and telegraph, freight train communication, geophysical exploration, power line emergency service, television transmission, point-to-point commercial message service, broadcasting pickup, relay broadcasting, police signalling, general experimentation, etc. It was by no means possible to grant all these applications. Even though several stations at suitable distances may operate simultaneously on one channel, the total number was definitely limited. In this band, just as in the higher frequencies, the Commission was under the necessity of denying many applications, since their number exceeded the transmission opportunities on the channels available.

There are 624 channels available in the band of higher frequencies from 6000 to 23,000 kc, in which any signal may be heard all over the world. There are already some 1700 stations (other than amateur), in the world operating on these frequencies, an average of about 3 per channel. This frequency band is therefore already fully occupied. Whenever more than one station is operated on a channel there is a potential source of interference. Additions can be made only in special cases, by consideration of the areas affected, times of operation, differing capacities of the various frequencies at different parts of the diurnal period, and engineering expedients like directional reception transmission. The real nature of the congestion is apparent from the fact that the Commission has been forced to deny hundreds of applications for licenses in this frequency band.

The frequencies above 6000 kc are suitable for very long distance transmission and are, therefore, of great international importance. They have been appropriated as needed in the various countries without any agreed plan or basis of assignment. Congestion has now begun and an international agreement on their allocation will soon be imperative. This is expected to be one of the major subjects of discussion by the meeting of the International Technical Consulting Committee on Radio Communications, which is expected to meet at The Hague in September.

**Public Interest, Convenience, or Necessity.** The interpretation and application of this phrase is a novel development in jurisprudence. The phrase is borrowed from legal terminology used in the regulation of public utilities, such as street-car lines and gas companies. Radio transmitting stations are not public utilities, and yet the test of a public utility must be applied to them for the two basic reasons already given, viz., the potential interference of each radio transmission with every other, and the fact that the number of channels is sharply limited.

The test of "public interest, convenience, or necessity" is being applied in broadcasting to mean that the rights of the listeners are superior to those of the broadcasting stations. This means that, as far as possible, interference must be avoided. It means that rural listeners, remote from any station, as well as city listeners, must be given service. It means that excessive duplication of programs by many stations cannot be permitted, and that high-power stations cannot be located in the midst of large populous areas. Perhaps the most important implication is that the total number of broadcasting stations must be limited to the number necessary to prevent undue interference. Each of these correllaries of a purely legal principle requires extensive engineering data for its application.

**Broadcasting.** The broadcasting band, which has hitherto occupied the chief attention of the Commission, exhibits a number of very special engineering problems. Here the width of each channel is 10 kc, which is necessary for satisfactory musical reception. Even this is not sufficient for musical reproduction of the highest quality. With only 90 such channels, and more than 600 stations on them, there was naturally very great interference prior to the November, 1928, allocation. To remedy this the Commission had to choose among various alternatives. It decided as a matter of policy not to reduce radically the total number of stations. It was then necessary to (a) limit the simultaneous operation of an excessive number of stations be making many of them divide time; (b) assign frequencies carefully selected with regard to geographical separation of stations, to reduce inter-channel interference (i.e., disturbance of reception of a station on one frequency by other stations on adjacent frequencies); and (c) limit the power of stations so they would not cause interference to other stations on the same frequency.

The accomplishing of this constituted the allocation of broadcasting stations which the Commission put into effect on November 11, 1928. For a detailed description of the allocation from the engineering viewpoint, see my article.[1] The principal features of the allocation are indicated in the following table:

| | High-Power, 5 kw and up | Regional, 500–1000 w | Limited Service | | Local, 10–100 w | Total |
|---|---|---|---|---|---|---|
| | | | 5 kw | 1000 w | | |
| Number of Channels | 40 | 35 | 4 | 5 | 6 | 90 |
| Station Assignments per channel | 1 | 2½ | 2½ | 5 | 25 | — |
| Number Station Assignments in U. S. | 40 | 90 | 10 | 25 | 150 | 315 |
| Number Station Assignments in each zone | 8 | 18 | 2 | 5 | 30 | 63 |

The expression "station assignment" indicates full-time operation 24 hours a day, by a station, or by a group of stations sharing time.

The most striking of the problems involved in the allocation was the carrying out of requirement (c), which determines power limitations. Stations assigned to the same frequency have not, up to the present, been able to maintain their frequencies with sufficient accuracy to prevent the existence of a slight difference (or beat) frequency, producing what is commonly known as heterodyne interference, or whistles. Unfortunately the heterodyne interference reaches out to enormously greater distances from a station than the program. Consequently the operation of two or more stations on a channel results in an area of destructive interference far in excess of the area in which program service is provided. For instance, the program of a 5-kw station can be heard with fair intensity under good conditions at 100 miles, while the heterodyne interference from two such stations is heard at 3000 miles. Two stations of 5 kw or more therefore cannot be assigned the same frequency in the United States. It is possible, on the average, to put two or more 1-kw stations on the same frequency if they are at least 1800 miles apart, and two or more ½-kw stations if they are at least 1200 miles apart. All stations subject to these restrictions have only a small service area, and give no service to remote rural areas. Such distant service is given only by stations having exclusive use of the channels to which they are assigned.

In order to provide rural service, 40 channels are each used by one station exclusively. The stations on the exclusive channels not only serve very great areas, but deliver a more satisfactory intensity at every point within those areas. Their service is better for all concerned,

[1] "Analysis of Broadcasting Station Allocation," Proc. I. R. E., 16, 1477–1485; November, 1928.

the greater the power they use. This fact is not commonly understood by others than radio engineers. It is clear when the distinction between the exclusive and the other channels is comprehended. Service on the non-exclusive channels would be utterly ruined if the power limits fixed by the facts of heterodyne interference should be exceeded, and in consequence such stations cannot in general use more than 1 kw. But on the exclusive channels the service is better the higher the power level, and indeed such stations will not be serving the public most effectively until the level reaches hundreds of kilowatts.

There is some hope that the limitation of power and service on the non-exclusive channels may be overcome. If the frequencies of stations on the same channel are maintained to a certain very high accuracy, the heterodyne or whistle becomes inaudible. The technique of frequency control is fast approaching this goal and success has been attained in isolated instances.[2] The satisfactory service area of such "synchronized" stations is not yet known. It is likely that some additional fading and interference effects will be introduced, but it is believed that the net service area will be substantially greater than when heterodyne interference exists. The significance of this is that the present power limits for stations on shared channels can be raised, better service given, and wider areas served. Synchronization is therefore looked for as the next great advance in broadcasting.

This discussion of broadcasting has been largely with reference to night conditions. Broadcast transmission is entirely different in the daytime. Transmission distances are much less, and somewhat greater power can be allowed the stations. Furthermore, additional stations can be licensed for daytime operation only. While the problems are not as acute as are those of night-time transmission, they are being handled with care so that daytime broadcasting may be developed as a valuable service.

The difference between day and night transmission conditions raised one technical problem of considerable moment, viz., determination of the time when day ends and night begins, and thus at what hour daytime stations should close. Investigation had revealed that the change from day to night radio conditions extends over a period of something more than an hour and a half, beginning about a half hour before sunset and closing an hour after sunset. The most reasonable time to choose as the transition point is the moment of sunset, and this was done in the Commission's General Order No. 41.

Most of the regulations of the Commission involve engineering

[2] J. H. Dellinger, "The Status of Frequency Standardization," Proc. I. R. E., 16, 579; May, 1928.

problems. Examples include the General Orders on chain program limitation, visual broadcasting (television), increased power in daytime, and prohibition of damped waves. The Broadcasting Committee of the Institute of Radio Engineers has been of great assistance to the Commission by the studies it has made of certain subjects leading to new regulations. These are on such subjects as: the requirement of an artificial antenna in broadcasting stations for use during warming-up periods, etc.; the location of high-power stations with respect to populous areas; requirement of highly accurate frequency control; allowable ratio of day to night power; permissible intensity of harmonics; percentage modulation; and fidelity of transmission.

**Conclusion.** All of the engineering work involved in federal radio regulation has the peculiar difficulty that the facts dealt with are extremely complex. They are indeed rapidly shifting. Not only must allowance be constantly made for the flux of changes inherent in a rapidly developing art, but radio waves themselves exhibit extraordinary vagaries. Orderly radio regulation must proceed on a consideration of the distances at which the waves are received. But distances vary enormously between day and night, from season to season, even from night to night, and are different over different kinds of terrain. Knowing this is not to counsel despair. These vagaries have, after all, certain discernible laws, becoming more and more calculable as the results of scientific investigations accumulate. It is not necessary to throw up our hands and say that the whole situation is chaotic. In spite of their vagaries, radio phenomena are subject to known engineering principles. An engineering principle is nothing but an organized body of facts affecting a practical situation. Violation of such engineering principles in radio regulation would sooner or later reduce the service of radio to the public.

Summarizing, the federal regulation of radio involves extensive and difficult engineering problems. These are characterized by certain outstanding facts or principles. First, radio waves spread out everywhere and potentially interfere with one another. Secondly, at any given stage of radio technique, the available number of communication channels is definitely limited. Another controlling principle, as the art stands today, is that heterodyne interference sharply limits the power that may be permitted any two or more broadcasting stations on the same channel. Finally, radio wave transmission is characterized by extreme vagaries. The facts and implications of each of these principles are subject to constant revision as radio progresses. Such facts constitute the natural limitations of radio. They are inescapable conditions of its government regulation.

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# SOME CHARACTERISTICS OF MODERN RADIO RECEIVERS AND THEIR RELATION TO BROADCAST REGULATION*

By
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***Summary***—*The paper gives a brief discussion of the modern tendencies in radio broadcast receiver design, with particular regard to those characteristics of receivers which are related to the problem of allocation and regulation of broadcasting stations. These characteristics are separated into five classes, as follows: (1) discrimination between channels; (2) discrimination within a channel; (3) uniformity of reception in all channels; (4) uniformity of reception within a channel; (5) range of reception. The conclusions are based upon experimental studies of a large number of broadcast receivers which have been sold commercially, and others which will be sold during the present year.*

RADIO broadcast regulation must deal generally with the problems of providing acceptable radio service to the greatest number of listeners from the greatest number and diversity of sources. In the absence of the unified control of all transmitting and receiving units which is possible in a wire distribution system, constructive regulation frequently involves the reconciliation of interests which are in definite conflict. Congestion of the medium of propagation is inevitable when satisfactory broadcast service requires channel widths approaching 10 kc for sound broadcasting and 100 kc for visual broadcasting. Thus technical developments in broadcast receivers, as well as in broadcast transmitters, are related to the problems of regulation insofar as they promote or retard the most effective utilization of the medium. It is from this viewpoint that the modern tendencies in receiver design are to be discussed. For convenience, the significant characteristics of broadcast receivers will be considered separately, although on account of their interrelations such a division is largely formal.

## 1. Discrimination Between Channels

One of the most important elements determining the "acceptability" of broadcast service is the extent of the listener's privilege of discrimination between programs. The 10-kc separation between channels

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in the broadcast band is one of the few features of American broadcasting which is so well established by regulation and practice that it is unlikely to change in the near future. Modern receivers of what might be termed medium quality and cost are quite generally able to suppress crosstalk from an unwanted signal in the adjacent channel which has the same field intensity as the wanted signal. But it is an inherent characteristic of the existing system that thousands and perhaps millions of listeners are in a region of intense fields from a powerful station, usually of high quality and operating on a cleared channel. The average radio listener is probably permanently reconciled to sacrificing service from the weak stations on adjacent channels for the privilege of obtaining a genuine service field intensity from the high quality station. It is therefore unprofitable for the designer of receivers even to attempt to provide equipment capable of giving service on any one of the 96 American channels at the will of the operator, as a *normal* operating condition. Efforts at improvement in the selectivity of receivers can probably be best directed toward equalizing the selectivity at all parts of the broadcast band.

Practically all types of commercial receivers, including double-detection sets, are now progressively less selective toward one end of the band, usually the high-frequency end. In this respect there has been a perceptible tendency toward improvement in the past two years. This statement is based upon an examination of twenty different receivers offered for sale by American manufacturers in the radio season of 1927–28, and a second group of twenty-four different receivers sold during 1928–29.

The 1927–28, receivers, which will be called group *A*, include almost all the most widely used commercial types, as well as certain types which were for some reason distinctive. In the latter class of group *A* falls one receiver in which the entire selective system is concentrated in a filter between the antenna and the first amplifier, and two receivers having provision for unusually high output levels. With one exception all the receivers of group *A* are designed for antenna operation and all include a single detector. The high-frequency amplifiers of all receivers in the group employ triodes exclusively, and are variously stabilized; some by adjusted losses, some by combinations of losses and partial reactive balance, others entirely by reactive balancing circuits of various types. Four of the group are provided with five tuned circuits, eleven with four tuned circuits, and five with three tuned circuits. The receivers of this group were sold at retail for prices ranging from $85.00 to $440.00.

The second group of receivers, which will be called group *B*, includes eighteen receivers which are on the market at the time of this writing, and six which are scheduled for production during 1929. Group *B* is made up chiefly of antenna operated receivers, all designed for alternating-current supply. It includes two double-detection sets and several sets in which the high-frequency amplifiers employ screen-grid tetrodes. Two receivers include five tuned circuits, fourteen include four tuned circuits and eight include three tuned circuits.

Groups *A* and *B* were so chosen that collectively they furnish a fair picture of design and performance of American broadcast receivers. The characteristics which are to be discussed were determined by a standard experimental technique similar to that recommended in the "Preliminary Draft of Report of Committee on Standardization" as drawn up by that Committee of the Institute in 1928. In the case of tests on single factory-built receivers, each set was adjusted to yield the best performance irrespective of accidental faults, in order to obtain as nearly as possible the ideal data characteristic of each particular design.

Obviously a complete description of the ablity of any given receiver to reject unwanted signals should include an examination, at several spaced frequencies in the broadcast band, of the response of the receiver to interfering signals in two or three adjacent channels on each side of the wanted frequency, since the frequency-response characteristics of all receivers generally exhibit different shapes in different parts of their service range. But for a comparison of a large number of receivers the complications involved in such a detailed study tend to make adequate generalizations impossible. In the present discussion, therefore, attention will be confined to the relative responses of a receiver to a wanted signal and to an unwanted signal of the same field intensity in the next adjacent channel, that is, having a carrier separated by 10 kc from the carrier of the wanted signal. A conservative though generally accepted arbitrary figure for the greatest tolerable interference level is one thousandth of the power output provided by the wanted signal. In other words the unwanted signal should be 30 db below the wanted signal.

Out of the twenty receivers of group *A*, compared at 1000 kc with a wanted signal having 30 per cent modulation at 400 cycles, and an equal unwanted signal 10 kc away, in five sets the unwanted output level is 30 db or more below the output from the wanted signal, and in four sets the unwanted signal is less than 20 db down. In eleven sets, including most of the popular types, the interference level is between 20 and 30 db below the signal level with a general average of 23 db. At frequencies of 600 kc and less the interference signal in an adjacent channel produces an output 30 db or more below the wanted signal in every one of the twenty receivers.

Comparing on the same basis the twenty-four receivers of a year later comprising group *B*, we find no appreciable difference from group *A* at 600 kc, but a perceptible improvement at the higher frequencies. At 1000kc eleven of group *B* yield an unwanted output 30 or more db below the wanted output and only four show a discrimination of less than 20 db.

From the standpoint of regulation it is probably not desirable further to complicate the existing problems of geographical assignments of power and channels by attempting to take account of the non-uniform selectivity which still characterizes most receivers, since it is physically possible to equalize the selectivity of a receiver at all parts of the broadcast band.

## 2. Discrimination Within A Channel

Discrimination against certain side frequencies in a received signal occurs in all radio receivers both before and after demodulation. Under the existing system of channel separation, unwanted frequencies are usually present in the channel of reception, as well as outside of it. The appearance in the output of a receiver of all demodulated side frequencies lying between the carrier and the boundaries of the channel is not necessary for good reproduction. The transmission through a receiver of frequencies 9 to 10 kc removed from the carrier is undesirable on account of the existence of beats between carriers on adjacent channels, and also on account of the undesirability of opening the door to electrical "noise" any wider than is required for acceptable reproduction of complex music. Also, the passage of frequencies within about 15 cycles of the carrier will become less desirable as progress is made in the operation of synchronized or approximately synchronized transmissions from stations whose service areas overlap. In most modern receivers which exhibit the greatest degree of frequency fidelity the 20-cycle output is negligible and the output levels even at 5000 cycles are from 15 to 20 db below those at 1000 cycles. In the twenty receivers comprising group *A*, comparing the electrical output at a modulation frequency of 50 cycles with the electrical output at 400 cycles we find only one receiver whose 50-cycle output in less than 4 db below the 400-cycle output, ten receivers whose 50-cycle output is between 6 and 10 db down, five whose 50-cycle output is between 10 and 30 db down, and four whose 50-cycle output is more than 30 db below the 400-cycle output. In the same group the 5000-cycle output of four is less than 4 db below the 400-cycle output, the 500-cycle output of six is between 6 and 10 db down, six more are between 10 and 30 db down, and in two the 5000-cycle output is more than 30 db below the 400-cycle output. In the twenty-four receivers of group *B* five are less than 4 db down at 50 cycles and thirteen are between 4 and 10 db down at this frequency. But in the same group at 5000 cycles all receivers yield a 5000-cycle output which is 10 db or more below the 400-cycle output and five are more than 35 db down at 5000 cycles. All of these data on both groups are for a carrier frequency of 1000 kc.

Thus the modern tendency in receiver design appears to be still the progressive accentuation of the lower frequencies even at the expense of the higher frequencies within a channel. In all of the most recent receivers, however, the output at 20 cycles or at 7000 cycles is more than 40 db below the speech-frequency output. Many modern loud speakers yield a sound response at 50 cycles which is perceptible compared with the 400-cycle response. Some loud speakers, not provided with so-called overload filters, do not exhibit a significant cutoff below 8000 cycles. But there is little likelihood of such an improvement in the frequency fidelity of the complete receiving system that it should be considered in making allocations under the existing system of channel separation. It is well to bear in mind, however, that the ultimate ideal of receiver fidelity is not perfect uniformity of output from 0 to 10000 cycles.

### 3. Uniformity of Reception in All Channels

There is a steady increase in the uniformity of the response of the radio-frequency filter and amplifiers in commercial receivers over the broadcast band. Out of a group of 20 antenna-type receivers comprising group *A*, ten exhibit a variation of overall sensitivity greater than eight to one between 550 and 1500 kc and only six showed a variation in overall sensitivity of less than three to one. In the more modern receivers comprising group *B*, nine exhibit a variation in sensitivity of less than three to one, eleven show a variation lying between the limits three to one and eight to one and only six vary over a range greater than eight to one. It is interesting to note, however, that even in 1929, at least two receivers of a "popular" type are over fifteen times as sensitive at 1500 kc as at 500 kc. With sets of this type, operated from a standard antenna, and adjusted for normal output on a signal at 1500 kc, a signal of equal field intensity at 700 kc or less would be inaudible. This situation may be contrasted, however, with the case of another receiver in group *B* which for purposes of discussion will be called "receiver *X*." This set is also in the "popular" class of price and distribution and in certain features represents the most advanced progress in modern design. At no frequency within the broadcast band does the sensitivity of receiver *X* depart more than 15 percent from the mean sensitivity. It is provided with a linear detector. Thus if signals of equal field intensity were received in each channel between 550 and 1500 kc without readjusting the sensitivity control, the total variation in output would not exceed 2.3 db.

**4. Uniformity of Reception Within A Channel**

The question of frequency fidelity has already been discussed in Section 2 above, as a matter of discrimination against unwanted frequencies.

Amplitude fidelity involves the presence of non-linear reponse and harmonic generation in the demodulator as well as in all amplifiers. The maximum distortionless output level provided by the audio-frequency amplifier should be generally determined by the preferences and the esthetic taste of the listener, and bears no direct relation to the matter of regulation of broadcasting. Until the year 1928 there was a rapid and progressive increase in the distortionless output capacity of all receivers from levels of the order 0.1 watt up to 6 or 7 watts. Present indications are that the pendulum is beginning a limited reverse swing in the interest of economy, with the advent of more sensitive high-quality loud speakers. The average output level of current radio receivers is of the order 1.5 watts. The question of overload in the carrier-frequency or medium-frequency amplifier has some bearing on the problem of location of powerful transmitters with respect to populous areas. The modern tendency in this respect is entirely constructive. It consists of a growing disposition on the part of designers of receivers to improve and increase those elements of the radio-frequency filter system which precede the first tube in the receiver, and to discard the practice of connecting the first tube directly to an aperiodic antenna system.

The improvement in amplitude fidelity which has the greatest significance, as regards effective utilization of the propagation medium, is the use of demodulators from which the output is proportioned to the percentage modulation of the incoming signal over a range from zero to about 90 per cent, and in which the harmonic generation is negligible even at high modulation levels. The technique of such opeation is now fairly well known, and the advent of high-gain radio-frequency amplifiers provides a timely expedient for the economical application of this technique. In the receivers of group *B*, five employ demodulators of this general type, variously known as "power detectors" or "linear detectors." It was formerly customary to operate the main demodulator in a receiver at an input level of the order 0.1 volt for normal signal output. Input levels from 2 to 10 volts are now not unusual.

In receiver $X$, mentioned above, the voltage gain from the first amplifier grid to the demodulator grid is approximately 50,000. The purpose of this gain is not to provide an excessive overall sensitivity, but to operate the demodulator at an input level of about 3 volts. The average overall sensitivity of the receiver is only 80 microvolts. The maximum distortionless output level from the single low-frequency amplifier stage is 3.2 watts. The demodulator, which feeds this stage, exhibits no appreciable overload distortion up to amplifier output levels of 3.2 watts unless the modulation falls below the extreme figure of 2 per cent.

The use of linear demodulators provides reproduction of good quality from broadcast transmitters of high modulation capability.

A general increase in the average modulation levels of transmitting stations is a most important and useful means of increasing service areas without increasing the beat note interference areas, and some minimum level on modulation capability of transmitters may ultimately be imposed by the government.

## 5. Range of Reception

The sensitivity of the radio receiver of course has a definite bearing upon the coverage areas of broadcasting stations. But it is now generally true that receivers in the low and medium classes of price are sufficiently sensitive to produce suitable entertainment outputs on field intensities of from 25 to 50 $\mu$v per meter in the absence of fading or electrical noise. Field intensities which are regularly depended upon for radio service vary tremendously from one section of the country to another, even today. But owing to the fact that the character and inclination of the "average" radio listener are undergoing a steady change toward the use of radio broadcasting as a means of entertainment from the programs themselves, and not as an indoor sport, the maximum sensitivity of the average broadcast receiver is well above that which can be consistently and satisfactorily employed. The growth of chain broadcasting has also contributed to this situation. In the past two years, moreover, there has been a definite trend away from the attitude that the best radio receiver is the one which has the greatest attainable sensitivity, and designers of receivers are now generally abandoning the practice of adding to the cost of a set to provide a maximum sensitivity of 5 $\mu$v or more. The tendency even in the most elaborate receivers is to choose a sensitivity of 20 to 50$\mu$v or even less, and to apply the high-amplification features of modern tubes directly to the provision of better reproduction, higher distortionless output levels, or to the automatic control of output.

In group *A* of receivers referred to previously, seven exhibit a mean sensitivity between 10 and 100 $\mu$v and thirteen exhibit a mean sensitivity between 100 and 1000 $\mu$v. In the later group *B*, eleven exhibit a mean sensitivity between 10 and 100 $\mu$v and ten show a mean sensitivity between 100 and 1000 $\mu$v. These figures on sensitivity relate to a signal modulated 30 per cent at 400 cycles. The voltages mentioned are those values which when impressed upon the receiver through a local antenna circuit of standard constants, produce an audio-frequencyelectric output of 100 mw. Thus if a receiver has a sentivitiy of 100 $\mu$v it will yield this output level from an antenna of 4 meters effective height exposed to a field of 25 $\mu$v per meter.

As broadcast reception becomes more a matter of service and less a question of chance the noise levels and fading characteristics of the incoming waves become more important in determining the merit of the service than the absolute magnitudes of the average field intensity. The introduction and development of automatic "volume controls" for broadcast receivers is a more significant development than any changes in the sensitivity of receivers that are likely to occur in the future. Devices for holding the output level to within a maximum variation during a variation of over 500 to 1 in field intensity are now available in practical commercial form. A general public acceptance of such controls may not be immediate. But receiver designers will undoubtedly find it commercially profitable to refine the technique of automatic control until a stage is reached where the practical elimination of the effects of fading will bring about a general increase in the accepted service areas of most broadcasting stations.

Aside from the improvements introduced by a general increase in modulation levels accompanied by the corresponding alterations in methods of demodulation in the receiver, there is as yet little prospect of increasing the discrimination of broadcast receivers themselves against atmospheric and local noises. It may be that the further advances in this direction will be delayed until the natural processes of evolution produce a type of human ear or artistic taste which is universally satisfied by music containing no frequencies higher than two or three kc.

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# THE REGULATION OF BROADCASTING STATIONS AS A SYSTEMS PROBLEM

By

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## ABSTRACT

This paper is a brief discussion of some of the outstanding technical problems of radio broadcast regulation with particular reference to the transmitting equipment. It is pointed out that in the interests of continued progress the regulatory program should be based on the following considerations:

(1) Intensive development of the available frequency band:
(2) Close adherence to the technical facts;
(3) Definite expression of performance standards in proper quantitative terms.

A number of the more important transmitter problems are discussed from this standpoint, including the power rating of stations, increments of power, degree of modulation, location of stations with respect to populous areas, permissible intensity of harmonics, frequency, stability, and fidelity.

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# SOME PRINCIPLES OF BROADCAST FREQUENCY ALLOCATION*

By
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THE technical problem of broadcast allocation in a given country is to assign the available radio channels to stations in particular localities in such a way as to give the best possible broadcasting service to the people of the country as a whole. The first consideration is the number of channels which are available for assignment.

In the frequency band 550 to 1500 kc the separation between adjacent channels may be taken as 10 kc, thus giving 96 channels in this range. This 10-kc separation has now become well established in practice, and while there are some reasons to feel that a wider separation would be desirable in order to facilitate the satisfactory transmission and reception of very high quality broadcasting, it seems likely that by a suitable geographical separation between the points to which these channels are assigned it will be possible to employ adequate frequency band widths and still avoid undesirable crosstalk.

While it is convenient to make specific reference to the United States, the general principles under discussion are, of course, applicable to any continental area. At the present time in North America, six channels in this frequency range are used exclusively by Canadian stations, 79 are used exclusively by stations in the United States, and 11 are shared by stations in both countries. This gives a total of 90 for assignment in the United States.

Fundamentally a given channel may be used for either of two kinds of radio broadcasting service depending upon the number of stations which are authorized to operate on that channel.

> 1. A channel which has but one station operating at a time. On a channel used in this way, a high grade of service can be given to the people in the immediate neighborhood of the station. It is, moreover, only on such a channel that service can be given to broad rural areas. Every opportunity is afforded to take advantage of times when transmission takes place over long distances and thus to serve regions which are not adequately provided with nearby stations. Generally speaking, every channel of this

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kind should carry a program of the highest grade, transmitted from a station in which the highest available power and the best technique are employed. Such a channel provides 24 hours of station operation per day, that is, 24 channel hours for the entire country.

2. A channel which has two or more stations operating simultaneously. On a channel used in this way service is given to a number of separate localities, each of rather restricted area. There is, in general, little or no service to be expected in intermediate areas. Channels assigned in this way are, therefore, most useful for serving the cities near or in which the stations are located and are not satisfactory for rural reception. The relative amounts of power employed by the stations on a channel of this kind determine very largely the sizes of their respective service areas. Such a channel provides 24 hours of station operation per day (24 channel hours) to each of several separate local areas.

Assuming that the assignments made on channels devoted to either type of service can be so arranged as to make most effective use of the possibilities of radio transmission, the problem becomes one of determining what is the proper balance between the two kinds of coverage—rural and urban—in order best to serve the people of the broad area involved.

It may be taken as axiomatic that if broadcasting is to be free from continual reallocations and is to consist of a fairly stable system for the transmission of programs to the country as a whole, there must be a fundamental basis in accordance with which both of these general classes of assignments are apportioned to the various parts of the country. After a basis for apportionment has been established and the number of assignments available in a given locality determined, the problem then becomes the selection by the Federal licensing authority of the stations in that locality which can be expected to best serve "public interest, convenience or necessity." While the particular stations licensed in a given locality might not continue indefinitely to be the ones which would serve the public best, the substitution of one station for another on a given frequency assignment would not involve major changes in the frequency assignments to stations in other parts of the country.

It is thus seen that the problem involves two fairly distinct and separable steps; first, the allocation of the channels in accordance with some scheme which will designate approximately the area or areas in which the station or stations to use the channels should be located; and, second, the designation and licensing of the particular stations selected to occupy the available assignments. The purpose of this paper is to consider primarily only the first of these two steps. Each channel assignment to a locality provides 24 operating hours or channel hours. The way in which these hours may be divided up among individual stations by time division is again a matter largely outside the scope of the present paper.

It is conceivable that the basis on which assignments would be apportioned to different parts of the country could be that of population. It is similarly conceivable that an apportionment could be worked out entirely on the basis of area or one could be based on a combination of population and area. Obviously, also, an entirely arbitrary rule might be formulated, which, once established, could be used as a basis for assignments by the Federal licensing authority. Whatever the rule may be it seems essential that there be some such basis on which to build the broadcasting structure of the country. In view of the tremendous competition for the privilege of broadcasting there must be some way in which the licensing authority can determine where to place the limit on the number of stations to which assignments can be granted.

One basis for the apportionment of broadcasting facilities to the various parts of the United States is given in the 1928 amendment to the Radio Act of 1927. The basis embodied in this act is largely one of population. It is provided that broadcasting facilities shall be apportioned equally to the five zones into which the country is divided. Each of the first four zones has a population of approximately 27 million people. The fifth zone has a population of about 12 million, but its area is very large. The law further provides that, each zone having been given its equal share of facilities, the several states are to have shares of the zone total which are substantially proportional to the state populations.

While the present radio law of the United States specifies that so far as possible wavelengths, power, licenses and time of operation shall be apportioned in the way indicated, the most fundamental thing involved is the apportionment of wavelengths and time of operation. More exactly, this means the apportionment of "channel-hours" to stations. The right to operate for 24 hours a day on a given broadcasting channel in a given locality constitutes what may be designated a "full-time assignment." The fundamental limit which is the very cause for the existence of the problem of broadcasting allocation is in the number of assignments available for evening use.

This problem of broadcasting apportionment is not peculiar to the United States. It is before the countries of Europe as a very pressing problem. The European broadcasting stations are, in general, using frequencies or channels apportioned according to a plan known as the "Geneva" plan, although, in view of the somewhat informal basis on which the plan was worked out it is not being strictly followed by all

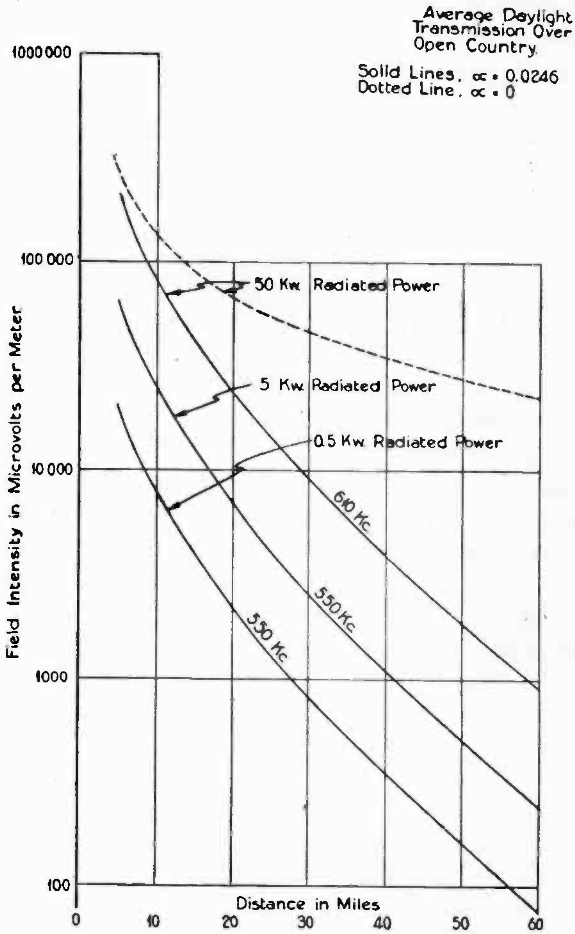


Fig. 1—Relation between Field Intensity and Distance of Transmission.

European broadcasting stations. The two basic plans have recently been suggested in Europe; one, known as the "Lemoine" plan;[1] and another, as the "Poland" plan.[2] Both of these plans contain tables in

[1] Siffer Lemoine, "Allocation of European Broadcast Wavelengths—Some New Points of View," *Experimental Wireless and Wireless Engineer*, pp. 386–396; July, 1928.

[2] "The Problem of International Distribution of Broadcast Wavelengths," *Experimental Wireless and Wireless Engineer*, pp. 3–8; January, 1929.

which relative quotas of broadcasting assignments are suggested for all of the European countries. Each of these plans involves both population and area, and in the Poland plan, consideration of existing stations, different weights being given to different factors in arriving at a combined basis.

There are some reasons why the population density should be an important factor in determining a sound basis of apportionment, but it seems desirable that a basis be established which, in addition, takes account of the fact that the strength of radio signals in the broadcasting range becomes less, generally speaking, the greater the distance over which they have travelled.

It is interesting to consider the single and multiple types of channel assignment in turn and to look at some of the facts of radio transmission which need to be kept in mind in determining the usefulness of these two kinds of channels.

### 1. Channels, Each Having Only a Single Full-Time Station Assignment. These are sometimes called "clear" channels.

The fundamental thing to consider in the case of a clear channel is the nature of radio transmission from a single station in the absence of interference from another station on the same channel. The field intensity or signal strength produced by a given radio broadcasting station decreases as the distance from the station becomes greater. Fig. 1 contains some curves showing the relation between the daytime field intensity and the distance over which transmission has taken place.[3] The available data indicate that the signal strength at a distance at night, while varying greatly from time to time, ordinarily falls between two limits. These limits correspond to

(a) The field intensity which is produced under daytime conditions when the absorption is substantially that caused by transmission over a suburban or agricultural type of region, shown by the solid curves in Fig. 1 and,

(b) The field intensity which is produced in the absence of any absorption of power from the transmitted wave and which

[3] These curves are computed from the formula:

$$E = 19.42 \times 10^4 \frac{\sqrt{p}}{d} \epsilon^{-\frac{101.5 \alpha d}{\lambda^{0.6}}}$$

$E$ is field intensity in microvolts per meter.
$p$ is radiated power in kilowatts.
$d$ is distance in miles.
$\lambda$ is wavelength in meters.
The absorption factor $\alpha$ has been taken as 0.0246, which corresponds with measured values of field intensity in many cases of transmission over suburban territory in the northeastern part of the United States.

corresponds only to the reduction accompanying the spreading of the waves over wider and wider circles. This is shown, for one case, by the dotted curve of Fig. 1.

The limits of the edge of the area served by a given station having a clear channel assignment are affected by

(a) The intensity of the noise—such as static or other electrical interference—which sets a value of signal strength below which reception is unsatisfactory.

(b) The fluctuation in signal or program intensity resulting from the fading of the signal during the course of its transmission. Transmission also is different in different parts of the country and distances which are customarily covered by stations in one locality may be far different from those covered by similar stations in other locations.

Disregarding for the moment the problem of the relationship between assignments on adjacent channels, it seems reasonable that on a clear channel the highest possible field strength and, therefore, the highest possible transmitted power is the condition most to be desired. The location of the station with respect to residential areas is a matter which can be fixed after the amount of power to be used has been determined.

The amount of interference or crosstalk between broadcasting stations on adjacent channels depends upon two major factors

(a) The selectivity of the radio receiver used by the listener who desires to receive one station and exclude the other, and

(b) The *relative* field intensities of the two stations between which selection is to be made.

Assuming that the two stations are about equal in power, the relative field intensities are dependent largely upon the relative distances of the stations from the listener in question. If the field intensities are about equal, that is, if the listener is about midway between the stations, the problem of selection involves merely the selectivity of the radio receiver. If, however, the field from one of the stations is far greater than the field produced by the other, the listener will ordinarily find it much more satisfactory to depend for his program upon the station producing the stronger signal, that is, ordinarily, to listen to the nearer station. Usually also the nearer station produces a program which is freer from fading and in which the static and other noises are less objectionable.

Fig. 2 contains a curve serving as an example of a radio receiver selectivity characteristic. If the receiver is tuned to the frequency $A$ of a desired signal, an undesired signal of equal strength produced by a second station on frequency *B*, 20 kc away, will, by the action of the receiving set itself, be reduced by an amount corresponding to the relative heights of the points *a* and *b* on the curve. In this example the reduction amounts to 70 decibels. In case the intensities of the signals produced by the two stations are not equal the absolute discrimination effected by the radio receiver would, of course, be different

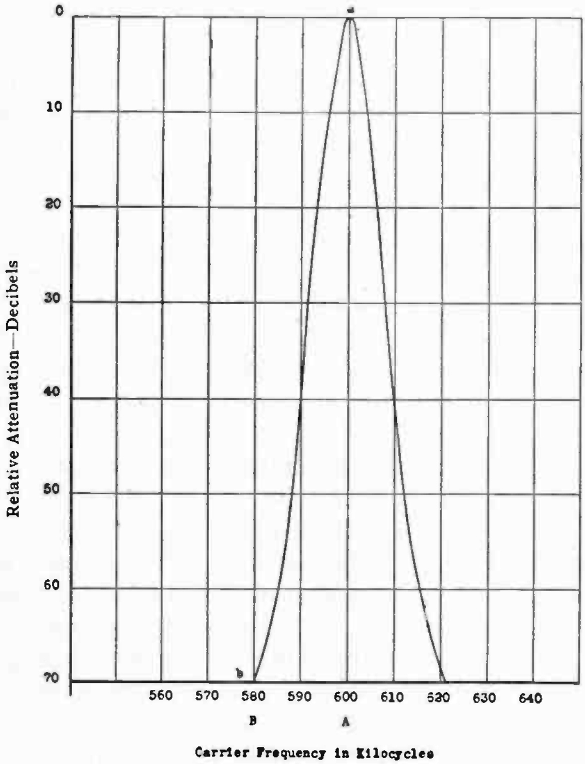


Fig. 2—Curve Illustrating Selectivity of Radio Broadcast Receiver.

although the relative discrimination would be the same. Assume, as another example, that the two field intensities are 50,000 and 10,000 $\mu$v per meter, respectively, a ratio corresponding to approximately 14 decibels. If there were no receiver selectivity, the desired detected signal would be about 28 decibels above the desired signal due to the square-law action of the detector. The receiver selectivity of 70 decibels, however, would reduce the undesired signal 42 decibels below the desired signal.

**2. Channels, Each Having Several Full-Time Station Assignments.**

On a channel to which several full-time stations are assigned it is, in general, necessary to consider the relative or combined effect, at a given receiving point, of the signals which may be received from two of these stations. Since the stations are transmitting on the same frequency the selectivity characteristic of a radio receiver provides no means of discrimination. The area around a given station within which satisfactory reception is possible is, therefore, that area within which the field or signal produced by any other station on that channel is so small as to be negligible in comparison. The absolute value below which the undesired or interfering field must fall thus depends upon the strength of the desired signal. The variability of radio transmission over substantial distances results in a wide fluctuation in the size of the area within which satisfactory service is produced. The curves given in Fig. 3 indicate the range of variation of the field intensities produced by two stations located 500 miles apart. From this it may be seen that considering a point say 150 miles from Station A the better transmission may at certain times come from station A and at other times from station B, depending on the relative transmission from the two stations at the moment in question. At other times neither station would be heard satisfactorily.

Ordinarily, using types of transmitting equipment which have been in general use up until about the present year, the combined effect of the signals from two stations on a given channel is recognizable as a beat note produced in the radio receiver. The frequency of this beat note is dependent upon the difference between the frequencies of the carrier waves emitted by the two broadcasting stations.

The broadcasting art is apparently just now beginning to accomplish in actual operating practice, a control in the carrier frequencies of broadcasting stations which is close enough to reduce the beat frequency below that which is readily reproduced by the ordinary radio receiver. This will largely eliminate the troublesome heterodyne note. The remaining interference will be in the form of crosstalk between the sidebands of the two stations.

In the example considered in Fig. 3, the area covered by either station may fluctuate between a circle about five miles in diameter and a circle as large as 200 miles in diameter.

There can be considered two general classes of these multiple assignment channels:

(a) Channels on which stations are assigned which have high enough power to cover the maximum non-fading area with a substantial field intensity. Stations on such channels should not be too close together geographically if interference on that channel is not to be troublesome.

(b) Channels on which stations having low power are assigned. Since the signals from these stations will only cover a small distance before being so affected by noise as to be unsatisfactory these stations can be assigned closer together geographically.

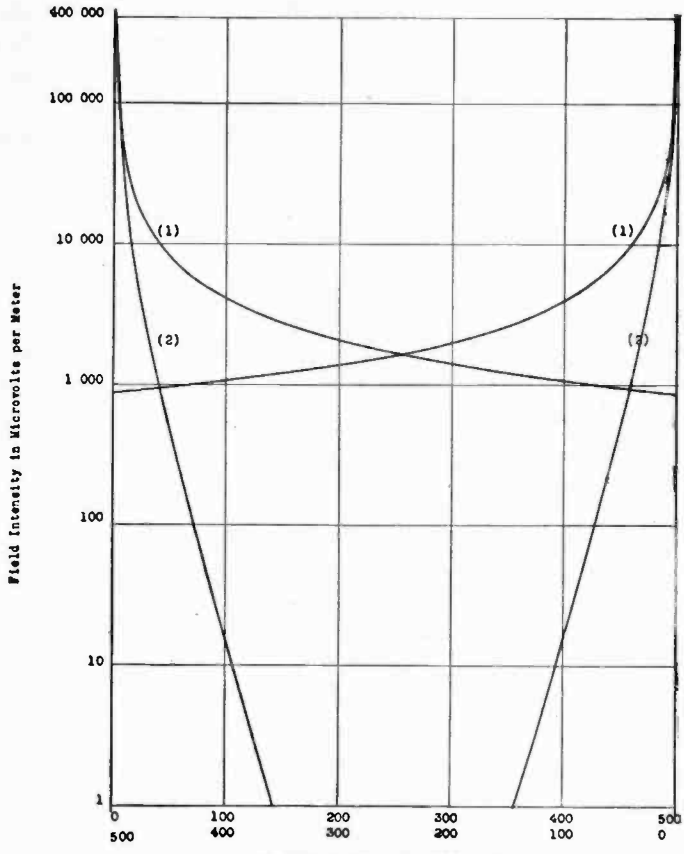


Fig. 3—Relative Intensities of Fields Produced by Two Stations.
(1) No attenuation.
(2) Average transmission over open country—550 kc.

As pointed out above, the general problem of broadcasting allocation involves a determination of the number of available assignments of each of the two kinds under discussion.

One assignment would be available for each clear channel and it may be assumed for the purpose of this discussion that four full-time station assignments could be made to each multiple assignment channel in an area such as the United States. (This may, quite surely, be practicable if there is sufficiently close frequency control). The total number of assignments available for the country would be somewhere between the limits of 90 (assuming 90 clear channels) and 360 (assuming no clear channels). The curve on Fig. 4 shows the number of full-time assignments which would be available assuming any particular number of clear channels between these limits. If, for example, 50 channels are given single full-time station assignments, 40 would remain on which multiple assignments could be made. This would give, under the assumptions above, a total of 210 assignments.

The question is sometimes raised of the relative usefulness of channels in different parts of the broadcast band.

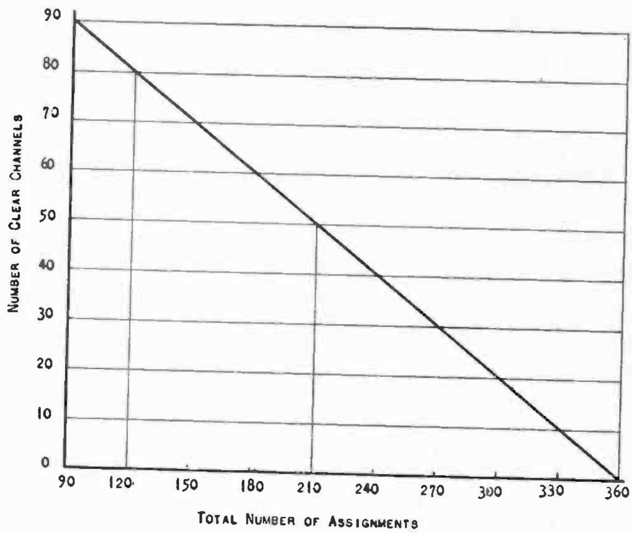


Fig. 4—Total Number of Available Assignments as Related to Number of Clear Channels.

As a general rule, and subject to modification on account of the different transmission in different parts of the country, it would seem desirable that equally high power be used by stations assigned to adjacent clear channels. As may be seen from the curves in Fig. 1, the daytime transmission on the lower frequency channels is ordinarily somewhat better than on the higher frequencies. Since the channels to which single full-time station assignments are made most effective for rural coverage, it would seem desirable that these channels be those which are likely to cover the greatest distances during the daytime regardless of night-time transmission. This would mean that the single assignment or clear channels should, other things being equal, be those at the lower frequency end of the broadcasting range. From the broad standpoint of broadcast allocation it would seem desirable to apportion the channels in different parts of the band among the different portions of the country and thus provide equality in this respect as far as possible.

It has been pointed out that while a channel having but a single assignment gives as good rural service as radio makes possible, it gives best service to the region in the general vicinity of the station having that assignment. The distribution of these clear channel assignments might, from this standpoint, be made proportional to population. That is, the number of "single assignment" channels designated for use in each of several regions or "zones" might be made proportional to their populations. If the zones or geographical units to which these clear channels are assigned are fairly large, and the number of them correspondingly small, more flexibility is possible in making assignments to individual stations. The number of stations which may be assigned to a "multiple assignment" channel does not depend at all upon population density but is dependent largely upon distance. The distribution of such assignments among geographical units might from this standpoint, therefore, be made proportional to area. On account of the fact that a fairly large number of assignments of this class is available for a country as large as the United States, the geographical units to which they are apportioned may conveniently be more numerous and therefore smaller than in the case of the single assignment channels. One way, for example, would be to distribute these assignments (on multiple assignment channels) to the several states in proportion to their areas.

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# A STUDY OF HETERODYNE INTERFERENCE*

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In the days of radio prior to popular broadcasting, substantially the only use of the word "heterodyne" was as a designation for the type of radio receiver whose invention is generally credited to R. A. Fessenden. This heterodyne receiver was, and still is, the most satisfactory type of system for continuous wave operation. It involved the combination of one set of forces, produced by the received wave, with another set of forces generated under the control of the receiving operator; and hence the name "heterodyne" was coined for it, from the Greek words meaning "other" and "force." A history and description of this receiver, together with certain improvements, is given in an earlier paper.[1]

At the moment the most convenient form of heterodyne receiver utilizes the oscillating audion with either self-contained or separate rectification. For heterodyne reception it is desirable, and indeed practically essential, that the frequency of oscillations generated at the receiving station shall be under exact control of the receiving operator. Such control makes it possible for this operator to choose at will a frequency of beat-note signal response that is best suited to his ear, to his audio-frequency apparatus, and to the conditions of interference. It is well understood that when two continuous radio-frequency oscillations are superimposed and rectified, the result will be a variation of substantially simple wave form having a frequency equal to the difference between the two interacting frequencies. This type of action when applied at radio frequencies has come to be known as the heterodyne principle. It is old in its acoustic and optical analogues, and dates from about 1901 in radio. It is variously used, not only in reception, but also for measurement, for the production of standard frequencies, for frequency transformation in speech-inversion systems, etc.

We now have to consider an interesting situation produced by the organization and growth of an extensive system of continuous-wave radio telephone transmitters operating in the frequency range of

* Dewey decimal classification: R170. Original manuscript received by the Institute, April 11, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

[1] John V. L. Hogan, "The Heterodyne Receiving System", Proc. I. R. E., 1, 75; July, 1913.

550 to 1500 kc and used for broadcasting. In order to accommodate the maximum number of transmitting stations in this limited band of 950 kc and to allow reasonably high modulation frequencies (2500 cycles without overlap between two stations on neighboring channels), the transmitters have been nominally adjusted or assigned to frequencies separated by 10 kc. Thus, including the terminal frequencies, 96 channels are made available.

If at a given point signals are simultaneously received from two transmitters operating at 10 kc difference in frequency, and if the receiver does not by its selectivity reduce substantially to zero the currents produced by one of the two stations, the rectifier output will contain a 10,000-cycle current. This may easily be picked out of the detector circuit of an average broadcast receiver, by means of a resonant circuit, and amplified sufficiently to operate a loudspeaker having a good response to high audio frequencies. It is ordinarily overlooked by the broadcast listener because its effect is minimized by several cumulative factors. In the first place, the geographical distribution of broadcasting stations and wave frequencies is designed to prevent waves of substantial intensity and only 10 kc difference in frequency from occurring in any part of the United States. Secondly, the usual receiver has an audio system which will not respond strongly at 10,000 cycles. Thirdly, this frequency (which is more than an octave above the fundamental of the highest note on the piano keyboard) is not easily heard by the majority of listeners.

Thus, if there were exact regulation of broadcast transmitter frequencies, there would be practically no heterodyne interference in broadcast reception. But the fact is that broadcast transmitters are permitted to wander from their assigned frequencies by as much as 500 cycles, and often deviate by far greater amounts. This deviation from assigned frequency produces two species of heterodyne effect, either of which may seriously trouble those who are listening in.

The first class of these effects is the result of heterodyne interference between stations nominally operating on adjacent channels, and, therefore, supposed to be 10 kc apart in frequency. If the higher frequency station is actually 500 cycles low while the lower frequency station is 500 cycles high, their difference will be 9 kc. This differential will not ordinarily produce a troublesome background note, for average receiver response to 9 kc is not much better than to 10 kc. But should the two waves be permitted to approach each other still more closely say to 8, 7, or 6 kc, listeners will be disturbed by the well-known "peanut-whistle" accompaniment to their received music and speech. The remedy for this type of heterodyne interference is to insist upon maintenance of broadcast transmitter frequencies within less than 500 cycles.

The second class of heterodyne interference produced by frequency deviation is of far greater seriousness to the broadcast service. When a channel is occupied by two or more transmitters operating concurrently, any receiver so located that it can intercept signals of even relatively small field intensity from both stations will have produced in its rectifier output a current variation of the differential frequency. If the two transmitters are operating at exactly the same frequency the differential will of course be zero, and heterodyne interference as it is usually considered[2] will not occur. If either station departs from its normal frequency, however, a continuous a.c. component will appear in the audio system of the receiver. If the net deviation is such as to produce a differential of even 100 cycles, the resulting beat-tone may be quite distressing and if the differential frequency lies between this value and the maximum of 1000 cycles (i.e., the maximum that would be permissible under strict enforcement of the present regulations) the effect upon received speech and music may be even worse. Such frequencies are within the most commonly used musical range, to which the usual audio systems give maximum response, and consequently could not be better chosen if one's intention were to produce the most aggravating character of tone interference.

What can be done to minimize or eliminate this type of heterodyne interference? Nothing so far suggested for use at the receiver has been successful in doing away with audible beat interference unless at the same time it eliminated or reduced the receiver response to musical tones of the same or similar frequencies. Failing a new method of attack at the receiving end (which there seems no reason to expect will be forthcoming) one is driven to consider the transmitter organization.

In general, there are three things that can be done. The obvious and simple cure is to assign only one transmitting station to each channel, i.e., to "clear" all channels. On the present band assigned for broadcasting this would permit simultaneous operation of only 96 stations in the United States and Canada. While with proper location and power for each station such an organization might deliver the most reliable and most varied radio service to the greatest number of listeners, it would not satisfy the present urgent demand for community, local, and regional services. However, insofar as channels

[2] Synchronized or approximately synchronized transmitters may produce various types of interference the discussion of which is beyond the scope of the present paper.

are and can be cleared the heterodyne interference on those channels is removed and the stations using them are permitted to give the maximum service possible.

Recognizing that a certain number of channels should be devoted to such local and regional services as will permit the assignment of from two to perhaps twenty simultaneously-operating stations per channel, what can be done about reducing heterodyne interference on these channels? The factors one has under control are only the location of each of the stations and the power (and modulation percentage) it is to use, for all the stations on one channel are assumed to operate at the same frequency. But that very assumption brings to light another factor that can be controlled, viz., the deviation from assigned frequency that will be permitted in any case.

Probably the most important of these factors is the matter of geographical location of the stations assigned to any one channel. How important this is can be seen at once by considering two limiting cases. For example, if two transmitters assigned to use the same wave frequency but actually differing by 500 cycles (half the maximum permitted under present regulations) are located immediately adjacent each other, it is obvious that for the same power and modulation their service areas will substantially coincide. However, when both transmitters are in operation neither will be competent to give any desirable program service for the reason that a strong beat tone of 500 cycles (thus having a pitch about one octave above middle C) will be heard in any receiver located in or even well beyond the joint service area. In general, for this case, the beat tone will be louder than the signal modulation of either transmitter. This situation, fortunately, it has been possible to avoid in practice; the condition has existed in each of several localities for a short time both in the early days of broadcasting and recently, but has always been promptly recognized as producing an intolerable type and amount of heterodyne interference.

The antithetical limiting case is that of two transmitters located at maximum distance from each other (say 3000 miles, with reference to the continental United States) and, as before, assigned to the same channel or frequency. Let us again assume that the actual operating frequencies of the two stations differ by 500 cycles. Then the question of whether or not heterodyne interference will exist by reason of a substantial geographical overlap of the two waves will depend upon a number of factors as follows:

(1) The radiated power (and modulation) of each station.

(2) The conditions governing wave transmission at the frequency and at the time under consideration.

(3) The location of the receiving point with respect to each station.
(4) The sensitiveness of the receiver.
(5) The field intensity of noise at the receiving point.
(6) The character of radio service desired or expected at the receiving point.

It should be obvious that no simple rule can be laid down that will permit immediate determination of the question of whether or not heterodyne interference will result from any given setup of stations. There are, however, a number of practical limiting values that have been determined by long observation of broadcasting conditions, and these may be used to outline more or less completely the border zones that lie between conditions that are certain to produce interference and those that are certain not to produce interference.

Considering the second assumed case, viz., two stations 3000 miles apart and differing in frequency by 500 cycles, we can say at once that as a practical matter no heterodyne interference will be produced if each of the two plants radiates 50 watts of power or less. It may be useful to consider why this is so. In the first place neither station can be expected to produce anywhere or any time a signal stronger than the "unabsorbed" value of its radiation, if our observations can be trusted. Even on the best winter night, then, the signal will be no greater than

$$E_f = \frac{5.8\sqrt{P}}{d} \tag{1}$$

where $E_f$ is field intensity in millivolts per meter, $P$ is radiated power in watts, and $d$ is distance separating sender and receiver in miles.

In the second place, very little useful program service can be rendered at a point so distant that less than 0.1 mv per meter is delivered. By the relation (1) this is seen to be 410 miles from the 50-watt transmitter, under the most favorable conditions. Actually the average night winter-time service will be had over only a much smaller distance for even such feeble signals as 100 $\mu$v per meter, but for preliminary interference determination it is safest to assume the maximum transmission distances that can occur.

The next question, then, is what comparative signal can the distant (second) station deliver at a point 2590 miles from the first. Considering again the "unabsorbed" or maximum value, this is shown by (1) to be 0.0158 mv per meter at the distance of 2590 miles. The ratio of desired to interfering field intensities is, then, 100 to 15.8 or 6.32. This low value of the ratio will produce not only strong heterodyne interference but also cross-talk between the stations, but of course only at times of most favorable transmission. Such times will occur, however, and probably more often during a winter night as the wave frequency used approaches the 1500-kc end of the spectrum assigned to broadcasting. It is not unusual for 50-watt transmitters to be heard reasonably well at distances of 400 miles. Consequently, it will not be unusual for another 50-watt station to produce heterodyne interference or even occasional crosstalk at the extreme ranges of the first, even though it may be located across the continent.

The obvious conclusion is that if *all* heterodyne interference is to be eliminated from the broadcasting band, stations of power even so small as 50 watts must not be assigned to the same channel, although they are separated geographically by transcontinental distances. But one may well ask whether such extreme protection of the service of a small station is in the best interest of the listeners of the country. Would not more people be better served if some interference with weak signals were permitted, so that groups of listeners centered about each transmitter might be provided with a greater variety of programs at better intensity levels?

For example, let us suppose that a minimum useful signal is of 1 mv per meter intensity, and that, as the measurements of the Bureau of Standards have shown, the average night-time signal has about one-half the "unabsorbed" field intensity. Thus, cutting the coefficient of equation (1) in half, we have the relation:

$$E_f = \frac{2.9\sqrt{P}}{d} \tag{2}$$

A 50-watt transmitter will, on this basis, deliver the assumed 1.0 mv per meter signal at a distance of 20.5 miles. This figure is readily recognized as more nearly what may be expected on average good nights, in the absence of interference, from a 50-watt plant. The second station, now 2980 miles from the receiving point, will produce a signal of only 0.0069 mv per meter, and the ratio of field intensities will be 1000 to 6.9, or 145. Such a ratio is not competent to produce severe crosstalk though it may cause a heterodyne whistle, for it is generally agreed that a value of 100 to 1 is necessary to make crosstalk negligible and of as much as 500 to 1 for the practical elimination of a medium-frequency beat. Nevertheless, with an average ratio of 145 it will be seen that the service zone of 20 miles radius around each transmitter should be free of interference except as a slight whistle drifts in and out.

In the above we have assumed that the two stations differed in frequency by 500 cycles, each being off frequency by 1/2 the amount permitted under present regulations. The audio systems of most broadcast receivers are extremely effective at frequencies of 500 to 1000 cycles per second, but relatively inefficient at frequencies of 50 cycles or less. If, then, the stations assigned to the same channel were required to maintain their frequencies to within 25 cycles (as can readily be done with well designed and commerically available apparatus) the pitch of the beat tone could be carried down below the sensitive range and the interference produced by it made little or no more troublesome than that caused by crosstalk. With such frequency control the heterodyne whistle above referred to would be eliminated and the stations would be serving their respective zones without interference.

So far we have given no direct consideration to noise level at the receiving point, although this is the primary factor in selecting the field intensity necessary to produce a service signal. It is well recognized that a signal of 10 mv per meter is necessary to give reliable service where real and continuous freedom from noise is desired, and that even this is inadequate in some cases. Since a field intensity ratio of 100 to 1 gives, with modern receivers, a discrimination of about 40 db in the audio circuits, and since 40 db represent approximately the difference between ordinary speech and an audible but hardly intelligible whisper, one may conclude that average noise levels rise to values well above 0.1 mv per meter. Thus, interference from waves of less than 0.1 mv per meter intensity, if of a frequency not more than 50 cycles from that of the desired wave, may be less troublesome than the noise interference. This would mean that the 0.0069 mv per meter interference occurring in the second case discussed above would often be negligible with respect to noise interference. It explains why, as a practical matter, 50-watt stations need not be kept 3000 miles apart in order to avoid mutual interference under average conditions.

But let us consider the question of increased power. We have seen that two 50-watt plants if well separated may be expected to deliver a 1-mv per meter service in their respective zones of 20 miles radius. If their power be increased to 5000 watts each the same field ratio of 145 to 1 will be had at a point 20 miles from one and 2980 miles from the other, but the field intensities will be multiplied by 10 for the same conditions. In other words, the desired signal will be 10 mv per meter and the interfering signal 0.069 mv per meter. Even this latter value is well below the noise level often observed, but unless the frequencies of the two stations are closely regulated and their differential brought to 50 cycles or less, the interfering whistle will be present frequently enough in winter time to be rated as producing heterodyne interference. Moreover, a 5000-watt station might well expect to serve an area greater than 20 miles in radius, since it will normally produce a 1-mv per meter signal at 200 miles. In this case the interfering signal from the second station, now 2800 miles away, will be 0.073 mv per meter and the ratio 1000 to 73 or 13.7, which will give substantial crosstalk and a very bad heterodyne whistle unless the 25-cycle deviation limit is required. Even then the crosstalk and quality interference indicated would suggest that 5000-watt stations should not be assigned to the same channel within continental limits. Of course they would produce no crosstalk in their legitimate service areas during daylight or during nights of high absorption, but the services of both stations would suffer on good winter nights.

Such an analysis, however incomplete, serves to emphasize that the heterodyne interference problem is strictly a practical matter. Until one defines that character of broadcast service that he intends to protect from heterodyne interference, no rules can be formulated. Even then he must decide whether he wishes to preclude the possibility of beat interference at any time, whether he will permit occasional interference and protect average winter-night conditions, or whether he will merely arrange matters so that each station on a shared channel will reliably serve a small area immediately adjacent to its transmitting antenna. The practical station allocations as to power and separating distance will differ widely depending upon which end is intended. If it is desired to provide for the simultaneous operation of a large number of transmitting stations, so as to give outlets for the local features and activities of a large number of communities, the last-defined condition is the only one that can be met. Listeners not located within these small areas must then be served by powerful stations scattered over the country and each operating at night upon a cleared channel.

It may be interesting to conclude this analysis of heterodyne interference in the broadcast band by looking briefly at one of the channels as set up at this writing. Considering 570 kc, for instance we have the possibility of eight stations in simultaneous night-time operation, as follows:

| | | | |
|---|---|---|---|
| 1 | WSYR | Syracuse, N. Y. | 250 w, or |
| | WMAC | Cazenovia, N. Y. | 250 w |
| 2 | WNYC | New York, N. Y. | 500 w, or |
| | WMCA | New York, N. Y. | 500 w |
| 3 | WSMK | Dayton, Ohio | 200 w, or |
| | WKBN | Youngstown, Ohio | 500 w |

| | | | |
|---|---|---|---|
| 4 | WWNC | Asheville, N. C. | 1000 w |
| 5 | KGKO | Wichita Falls, Tex. | 250 w |
| 6 | WHA | Madison, Wis. | 750 w, or |
| | WNAX | Yankton, S. D. | 1000 w, or |
| | WPCC | Chicago, Ill. | 500 w, or |
| | WIBO | Des Plaines, Ill. | 1000 w |
| 7 | KUOM | Missoula, Mont. | 500 w, or |
| | KXA | Seattle, Wash. | 500 w |
| 8 | KMTR | Hollywood, Cal. | 1000 w, or |
| | KPLA | Los Angeles, Cal. | 1000 w |

To study in detail the effects of each of these stations upon each of the others would be too extensive an undertaking for the present paper. We may, however, note the following conclusions based upon good average winter night-time transmission conditions:

WNYC and WMCA should produce a 1-mv per meter signal at 65 miles radius. A point on this circumference is only about 135 miles from WSYR, which station will deliver there a 0.34 mv per meter field. The ratio is about 3 to 1, and both crosstalk and severe heterodyne interference necessarily follow. A point on the same circumference, in the direction of WKBN, is about 330 miles from that station. WKBN should deliver to that point an average field of 0.19 mv per meter, giving a field intensity ratio of 5.2 to 1 as against the 100 to 1 that is needed to minimize interference. The interfering field from WWNC is 0.17 mv per meter and the ratio not quite 6 to 1. Even from KGKO the field is 0.032 mv per meter and the ratio therefore only 31 to 1. It is quite evident that few if any of the stations on this channel can ever attain their normal winter-time range, because of the limitations enforced by crosstalk and heterodyne interference.

All of this leads inevitably to the conclusion that the duplication of stations on any channel necessarily restricts the service area of each to the region immediately surrounding its transmitting antenna. In daylight, or at other times of high absorption, its signals will not travel far before falling below the noise level. At times of low absorption or low noise level (or both) the service area will be limited first by heterodyne interference and second by crosstalk. The areas served by each station, however, may be substantially increased if all are required to maintain their carrier frequencies with not more than 25 cycles deviation from the assigned frequency. Even then, however, a field ratio of 100 to 1 must mark the limit of the useful service zone.

In the broadcast band, then, heterodyne interference may be eliminated or minimized by:

(a) Operating no more than one station at a time on each channel, within the continental United States and at night. This will permit service to reach remote or rural points.

(b) Operating more than one station on each channel, but requiring each to maintain its carrier frequency within 25 cycles of the assigned value. When such stations are located sufficiently far apart to avoid crosstalk between them, this will permit service to reach relatively limited areas immediately surrounding each station.

One other type of heterodyne interference should be mentioned. This is the occasional squeal or whistle of varying pitch that is heard when a radio wave of continuously changing frequency swings through the carrier being received. It is sometimes noted when a broadcast station tests "on the air," or when a neighbor using a type of radiating receiver allows it to oscillate strongly. Fortunately neither of these causes is much of a factor in broadcast reception today, so that we no longer concern ourselves with the desirability of legislating against the use of radiating broadcast receivers.

Outside the broadcast band one hears relatively little of heterodyne interference. The low-frequency waves from 10 to 60 kc or thereabouts, carrying long distance continuous wave telegraph and facsimile services, are under rigid control by those who use them. The various channels have been selected to avoid both crosstalk (if that word is permissible where telegraphy and not telephony is concerned) and heterodyne interference. The medium-distance waves from 60 to 120 kc are also telegraph waves in the main, and while not as definitely assigned to specific point to point services as those of lower frequency, are nevertheless used in such a way as to avoid beats between pairs of transmitters in simultaneous operation. The marine and other services using waves from 120 to 550 kc are relatively flexible, and, largely following the precedents of years of spark telegraphy, operate under conditions where interference may be expected at almost any time. The remedy here is usually either to change to another and temporarily unused frequency, or to wait until the interfering station is through sending.

The frequencies from 550 to 1500 kc, constituting the broadcast band, have already been considered in some detail. It is here that heterodyne interference is most prominent, because of the simultaneous operation for hour after hour of a large number of transmitting stations.

In the vast high-frequency range above 1500 kc, which is rapidly coming into more and more extensive use, we should apply carefully the principles that have been taught by our experience in broadcasting. The strictest frequency stability requirements commensurate with the state of the art should be made, and duplicate station assignments to the same channel must be scrutinized with care if unnecessary interference is to be avoided. It is particularly important to keep clear the channels assigned to long-distance public radio telephony, to the various radio picture services being developed, and to relay broadcasting. All of these serve or will serve large numbers of people, and in none of them can the effect of interruptions be overcome by the simple expedient (so common in the telegraph services) of repeating a word or two.

Perhaps 90 per cent of the radio receivers now in use at frequencies above 1500 kc are capable of radiating substantial amounts of power, and consequently of disturbing reception at many points around them. The heterodyne interference produced by the improper use of such receivers may destroy long distance telephonic or telegraphic reception, may cast a blanketing pattern on the screen of a "television" receiver, or may spoil a musical program being rebroadcast to thousands of listeners. In the high-frequency spectrum, as has already been done in the broadcasting band, radiating receivers will have to be discarded. This, together with proper channel spacing, careful carrier frequency control and thoughtful geographical assignments of power and waves, will go far to prevent the development of heterodyne interference problems in this newest field of radio.

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# AN OUTLINE OF THE RADIO INSPECTION SERVICE*

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***Summary***—*The purpose of this paper is to present a brief history of the Radio Inspection Service of the Department of Commerce from its inception July 1, 1911, up to and including the present day, together with an outline of the scope and general nature of the work performed by this important agency of the Government. The subject matter included in this paper may, therefore, be classified as historical and administrative, the latter including matters of engineering and law enforcement.*

## Historical

THE Radio Inspection Service of the Department of Commerce was established and placed under the supervision of the Bureau of Navigation of the Department of Commerce and Labor[1] following the passage of the Wireless-Ship Act, approved June 24, 1910, to take effect on July 1, 1911.[2] Under this statute it was unlawful for any ocean-going steamer of the United States, or of any foreign country, carrying fifty or more persons, including passengers and crew, to leave or attempt to leave any port of the United States unless such steamer was equipped with an efficient apparatus for radio communication, in good working order, in charge of a person skilled in the use of such apparatus and that such apparatus was capable of transmitting and receiving messages over a distance of at least one hundred miles day or night. The statute further provided that the apparatus required shall not be deemed to be efficient unless the company installing it shall contract in writing to exchange, and shall, in fact, exchange, as far as may be physically practicable, to be determined by the master of the vessels, messages with shore or ship stations using other systems of radio communication; and, further, that the master or other person in charge of such a vessel which leaves or attempts to leave any port of the United States in violation of any of the provisions of this Act shall, upon conviction, be fined in a sum not more than $5,000 and any such fine shall be a lien on any such vessel, and such vessel may be libeled therefor in any district court of the

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[1] The Act of March 4, 1913, among other things changed the designation of the Department of Commerce and Labor to the "Department of Commerce" and the title of Secretary was changed to "Secretary of Commerce."

[2] An Act to require apparatus and operators for radio communication on certain ocean steamers, approved June 24, 1910.

United States within the jurisdiction of which such vessel shall arrive or depart and the leaving or attempting to leave each and every port of the United States shall constitute a separate offense. The concluding section of the statute required the Secretary of Commerce and Labor to make such regulations as were necessary to secure the proper execution of the Act by Collectors of Customs and other officers of the government. The statute did not apply to vessels plying between ports less than two hundred miles apart.

The original plan called for the appointment of four Radio Inspectors for ship inspection work. The districts to be covered by these inspectors consisted, (1) New York and New England ports, (2) Atlantic ports from New York to Florida, (3) Gulf ports and (4) ports on the Pacific. Owing to the failure of Congress to authorize the full appropriation originally asked, it was possible only to appoint two Radio Inspectors.

The Inspectors appointed were Mr. W. D. Terrell of New York and Mr. R. Y. Cadmus of Bay City, Mich. They were selected from the classified Civil Service list on the basis of their experience in telegraphy, knowledge of electricity, wireless apparatus, and administrative ability. Following their appointment they were sent to the Bureau of Standards at Washington, D. C., for a short course of training in electricity and radio. Upon completion of their work at the Bureau of Standards, Inspector Terrell was assigned to duty at the port of New York, with jurisdiction over New York and New England ports, and Inspector Cadmus was assigned to duty at San Francisco, Calif., with jurisdiction over ports on the Pacific Coast.

The statutory duty of the Radio Inspectors was to examine and test the radio equipment on board all vessels, foreign and domestic, clearing from ports in the United States, subject to the Ship-Act, in order to determine, prior to vessels' clearance for sea, that the radio equipment was in good working order as required by law. It is of interest to note that the 1910 Wireless-Ship Act made no reference as regards wavelengths or call letters, nor were there any requirements regarding the licensing of the stations or the operators employed therein. The principal intent of the law was to provide safety of life at sea by requiring apparatus and operators on certain ocean steamers, also to prevent the use of apparatus incapable of intercommunicating with ship and shore stations employing other radio telegraph systems.[3] The Congress of the United States is the first legislative body to enact

[3] Statement of Admiral H. N. Manney, U.S.N., cited in publication entitled "Hearings Before Senate and House Committees in Connection with Radio Legislation." 1908–1913, p. 45, 46.

a law on this important subject,[4] and the 1910 Wireless-Ship Act marks the formal recognition by the United States of radiotelegraphy as an indispensable agency for promoting safety of life at sea. It is generally recognized, however, that other nations were considerably in advance of the United States in other important essentials relating to the regulation of radio communications.

The first year of operation under authority of the 1910 Wireless-Ship Act clearly demonstrated the importance of the enactment, and on July 23, 1912, Section 1 of the 1910 Act was amended to take effect on October 1, 1912.[5] The amended Act made mandatory the providing of two or more operators skilled in the use of the radio apparatus, one or the other of whom shall be on duty at all times while the vessel was under way, an auxiliary power supply, independent of the vessel's main electric plant, capable of enabling the transmitting set to send messages over a distance of at least one hundred miles day and night, and the installation of an efficient communication system between the radio room and the bridge in good working order at all times. The amended act applied to vessels licensed to carry as well as those actually carrying 50 or more persons, including passengers or crew or both.

The equipment, operators, watches, and service in the case of vessels of United States registry were placed under the supreme authority of the master, and every wilful failure on the part of the master to enforce at sea the provisions of this Section rendered him subject to a penalty of $100.00. The amended Act so far as it relates to vessels navigating the waters of the Great Lakes went into effect on April 1, 1913, and on July 1, 1913 in the case of ocean going cargo vessels.

The next important radio legislation considered in the United States was the Berlin Radio Telegraph Convention.[6]

The Berlin Radio Telegraph Convention was the first International Radio Telegraph Convention to be signed by the United States. The membership of the Convention consisted of twenty-seven countries. The Convention contained twenty-three articles, the Supplementary Agreement three, Final Protocol seven, and there were forty-two Service Regulations.

It is a pleasing commentary that the Berlin Radio Telegraph Con-

[4] Annual Report of the Commissioner of Navigation, fiscal year 1910, Wireless Regulation, p. 28.

[5] An Act approved July 23, 1912, amending section 1 of an Act entitled "An act to require apparatus and operators for radio communication on certain ocean steamers," approved June 24, 1910.

[6] Berlin Radio Telegraph Convention, signed in Berlin on November 3, 1906, ratified by the Senate of the United States on April 3, 1912 and proclaimed by the President of the United States, May 25, 1912.

vention,[7] proclaimed by the President of the United States on May 25, 1913, marks the formal recognition by the United States of radio communication as an indispensable agency of International Commerce.

The Berlin Convention continued in force until July 8, 1913, on which date the London International Radio Telegraphic Convention proclaimed by the President went into effect.

Following the adoption of the Berlin Radio Telegraph Convention the Congress of the United States passed an act to regulate radio communication.[8]

On August 13, 1912, the Congress of the United States passed a comprehensive radio law containing eleven sections and nineteen regulations. The sections contained the general substance of the law whereas the regulations, although having the force of law, were in the form of service instructions. The 1912 law continued in force until February 23, 1927, on which date the Congress of the United States passed a radio bill entitled "an act for the regulation of radio communications, and for other purposes."[9]

The next important radio legislation considered in the United States was the London International Radio Telegraphic Convention.[10]

The London International Radio Telegraphic Convention, proclaimed by the President July 8, 1913, was the second International Radio Telegraphic Convention to be signed by the United States. The membership of this convention consisted of forty-four countries including their possessions and protectorates. The Convention contained twenty-three articles, the Final Protocol three, and the Service Regulations affixed to the Convention contained fifty articles, the last five of which were cited under Miscellaneous Provisions.

The administration of the radio law embodied in the Acts of June 24, 1910, July 23, 1912, the act of August 13, 1912, repealed by the passage of the Radio Act of 1927, and the London International Radio Telegraphic Convention was lodged in the Bureau of Navigation of the Department of Commerce until February 26, 1927, on which date these activities were removed from under the jurisdiction of the Bureau of Navigation and placed under the immediate supervision of the Secretary of Commerce. Mr. Wm. D. Terrell, Chief Radio Supervisor, Bureau of Navigation, was placed in charge of the newly formed Division and given the title of Chief, Radio Division.

[7] A convention is a treaty concerning commercial rather than political matters. 12 A.L. and P. 6 Sect. 5.

[8] An act to regulate radio communication, approved August 13, 1912.

[9] The Radio Act of 1927.

[10] London International Radio Telegraphic Convention signed at London July 5, 1912, ratified by the Senate of the United States on January 22, 1913 and proclaimed by the President of the United States, and took effect July 8, 1913.

The Radio Act of 1927 contained forty-one sections and represents the most extensive national legislation on the subject of radio to date. Under this Act five zones were established and five commissioners appointed, each a citizen of the United States and each a resident of a State within the zone from which he was appointed. The Commissioners were appointed by the President for terms ranging from two, three, four, five, and six years, respectively, from the date of the taking effect of the Act, with headquarters located in Washington, D. C.

Section 5 of the Act provided that from and after one year after the first meeting of the Commission, created by this Act, all the powers and authority vested in the Commission under the terms of this Act except as to the revocation of licenses shall be vested in and exercised by the Secretary of Commerce except that thereafter the Commission shall have power and jurisdiction to act upon and determine any and all matters brought before it under the terms of this Section.

For the purpose of this paper, time and space will not permit a full statement of the many involved matters set forth in the Radio Act of 1927. It is important, however, and mention is here made of the close relationship that exists between the Radio Division of the Department of Commerce and the Federal Radio Commission. The duties of both agencies are set forth in the law, and each have rather well defined duties. Yet, it is a difficult matter to determine in many instances just where the work of one leaves off and the other begins. The Radio Commission is not responsible to any executive officer, but rather reports direct to Congress. Its duties are both administrative and judicial, whereas the duties of the Radio Division are largely administrative, and as a general proposition the Division reports direct to the Secretary of Commerce, although there are certain matters which require it to report directly to the Federal Radio Commission. The Department of Commerce is directly charged with the enforcement of the Act of June 24, 1910, amended, to require apparatus and operators and the examination and licensing of radio operators. In addition to these duties, the Radio Division through its field inspection force makes regular inspections of radio stations ashore and afloat, and conducts investigations of the various forms of interference affecting the several radio services. The Radio Division from time to time makes investigations and inspections at the request of the Federal Radio Commission in addition to those which it makes regularly under its general authority. These inspections include both general inspections and inspections for licenses of the several classes of stations licensed by the Federal Radio Commission.

On March 28, 1928, Congress passed a law continuing the powers and authority of the Federal Radio Commission as conferred under Radio Act of 1927 until March 16, 1929.[11] The following other important changes were embodied in this act. Section 3 limits the license period of broadcasting stations to three months and all other classes of stations to a period not to exceed one year.

The second paragraph of Section 9 of the Radio Act of 1927 was amended to include an equality of radio broadcasting service both of transmission and reception. The amended Act also required an equal distribution of broadcast station licenses, bands of frequency or wavelengths, periods of operation and equal power to each zone by increasing or decreasing power when applications are made for licenses or renewals thereof, provided that if and when there is a lack of application from any zone for the proportionate share of licenses, wavelengths, time of operation of station power to which such zone is entitled, the licensing authority may issue licenses for the balance of the proportion not applied for from any zone, to applicants from other zones for a period of ninety days each, and shall specifically designate that said apportionment is only for said temporary period. Allocations shall be charged to the state, district, territory, or possessions wherein the studio and not the transmitter is located.

On March 4, 1929,[12] Congress continued the powers and authority of the Federal Radio Commission under the Radio Act of 1927, until December 31, 1929. Beyond extending the life of the Commission for the period herein cited the only other important change brought about under this Act was to the effect that the term of each member of the Commission shall expire on February 23, 1930, and thereafter Commissioners shall be appointed for terms of two, three, four, five, and six years, respectively, as provided in the Radio Act of 1927. The Act further authorized appointment of a general counsel at a salary of $10,000 per annum and assistant counselors not to exceed three, at a salary of $7,500 each per annum. The Commission is authorized under authority of the Act to appoint such other legal assistants as it may from time to time find necessary for the proper performance of its duties.

On October 4, 1927, the International Radio Telegraph Convention convened in Washington, D. C., and concluded its deliberations on November 25, 1927. At this Convention eighty nations were repre-

[11] An Act approved March 28, 1928, continued for one year powers and authority of the Federal Radio Commission under the radio Act of 1927, and for other purposes.

[12] An Act approved March 4, 1929, continuing the powers and authority of the Federal Radio Commission under the Radio Act of 1927, and for other purposes.

sented, including their possessions and protectorates. It is of interest to note that the International Radio Telegraph Convention held in Washington in 1927 represented the largest gathering of foreign government and private radio interests assembled to date in the history of Government. The Convention contained twenty-four articles, thirty-four Service Regulations and seven supplementary regulations. The Convention was signed at Washington on November 25, 1927, ratified by the Senate on March 21, 1928, signed by the President on October 8, 1928, and proclaimed January 1, 1929.

It is a significant matter that before there were any laws promulgated for the control of world-wide radio communication it was realized by government and commercial engineers and others that the world in which we live from the standpoint of electrical communications, particularly radio, is a small place, and that radio communication constituted a means by which the nations of the world and vessels navigating the several oceans and other important waterways might be joined together as a single unit, thus bringing into general use a new instrumentality for the rendering of a great public service over land and sea. It is now evident from what has transpired in the field of international radio communication, both in an engineering and a legislative way, that the ideas expressed by the early investigators of this important subject were well founded.

It will be of interest, and mention is here made of the following radio conferences that were held during the years 1919 to 1929, none of which were subject to legislative enactment: the EU-F-GB-I Protocol held in Paris in 1919; the preliminary conference held in Washington in 1920, for drafting proposals and procedure for consideration at the Internation Radio Telegraph Conference to be held in Washington, 1925, which was postponed until 1927; the Inter-American Committee on Electrical Communications held in Mexico City in 1924; the 1925 agreement of the Government of the Unites States, Great Britain including Ireland, Canada and Newfoundland to prohibit vessels under their jurisdiction from using the 300-and 450-meter wave when within two hundred fifty miles of the coast line of the countries herein named.

### Administration

For the purpose of facilitating the administration of the radio law and the engineering duties incumbent upon the Radio Inspection Service an increase in the personnel of the Inspection force was made and the following Radio Inspection Districts established:

**District 1.** Headquarters at Boston, Mass.: Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, Connecticut.

**District 2.** Headquarters at New York, N. Y.: New York (county of New York, Staten Island, Long Island, and counties on the Hudson River to and including Schenectady, Albany, and Rennselaer) and New Jersey (counties of Bergen, Passaic, Essex, Union, Middlesex, Monmouth, Hudson, and Ocean).

**District 3.** Headquarters at Baltimore, Md.: New Jersey (all counties not included in second district), Pennsylvania (counties of Philadelphia, Delaware, all counties south of the Blue Mountains, and Franklin County), Delaware, Maryland, Virginia, District of Columbia.

**District 4.** Headquarters at Savannah, Ga.: North Carolina, South Carolina, Georgia, Florida, Porto Rico. (Headquarters now at Atlanta, Ga.)

**District 5.** Headquarters at New Orleans, La.: Alabama,[13] Mississippi, Louisiana, Texas, Tennessee*, Arkansas, Oklahoma, New Mexico.

**District 6.** Headquarters at San Francisco, Calif.: California, Hawaii, Nevada, Utah, Arizona.

**District 7.** Headquarters at Seattle, Wash.: Oregon, Washington, Alaska, Idaho, Montana, Wyoming.

**District 8.** Headquarters at Detroit, Mich.: New York (all counties not included in second district), Pennsylvania (all counties not included in third district), West Virginia, Ohio, Michigan (lower peninsula).

**District 9.** Headquarters at Chicago, Ill.: Indiana, Illinois, Wisconsin, Michigan (upper peninsula), Minnesota, Kentucky, Missouri, Kansas, Colorado, Iowa, Nebraska, South Dakota, North Dakota.

## Engineering

Radio communication has developed so rapidly during recent years that time and space will not permit of a full statement of the multiplicity of technical problems involved in the work of the radio inspection force.

Following the establishment of the radio inspection service and for several years thereafter, the technical problems consisted largely of those relating to the inspection, testing, and adjustment of the several types of spark transmitters and associated apparatus; the latter comprising of the generating plant for supplying electricity to the motor generator which forms an essential part of the primary circuit of the radio transmitter; the storage battery emergency power sypply; charging circuits and the measuring instruments for determining

[13] States of Alabama and Tennessee now in Fourth Radio Inspection District.

the values of voltage, current, and power. In addition, the inspectors were required to examine and test the several types of receiving sets then in use. The receiving apparatus was of a rather simple type and employed principally crystal detectors. Wavemeters were employed for adjusting the transmitting apparatus to the several wavelengths then in use. Following the inception and use of the wavemeter which comprised a simple circuit, Fred A. Kolster, physicist, employed at the Bureau of Standards, invented an instrument later known as a Kolster decremeter.[14] This instrument was both a wavemeter and a decremeter, and was considered one of the most important radio inventions at that time. This instrument not only enabled the wavelength value of a transmitter or a receiver to be determined, but also served to measure the pureness and sharpness of the emitted wave. This instrument served a very useful purpose and is still employed for measuring damp wave emissions.

In addition to the inspection of commercial radiotelegraph stations ashore and afloat, the inspection force was required to inspect and test a large number of experimental radiotelegraph stations engaged in development and research and privately owned stations, the latter known as amateur stations. The inspections were made for the purpose of preventing interference and to insure compliance with the radio laws in other particulars. The 1912 law among other things required both station and operator licenses, the work of inspecting radio stations, ashore and afloat, for the several classes of licenses was an additional duty incumbent upon the radio inspection force.

The examination of applicants for the several classes of operator licenses was largely performed by the field inspection force. This work included the preparation of the examination questions, the conducting of the examinations, rating of papers and issuance of licenses to the successful candidates. Operator licenses were issued for a period of two years, therefore it was necessary to issue renewal licenses to operators having the necessary service for renewals at the end of that period.

As time went on, the radio art developed rapidly; radio stations and services increased in number and in kind. In addition to the spark transmitting stations, arc and high-frequency alternator transmitting stations came into considerable use ranging in power from 2 to 200 kw. As the arc and high-frequency alternator were radiators of continuous wave signals it was necessary to develop receivers that would efficiently respond to such signals, hence the vacuum-tube receiver came into quite general use.

[14] F. A. Kolster, "Direct reading instrument for measuring logarithmic decrement and wave length of electro-magnetic waves," Bureau of Standards Scientific Paper 235, 1914.

Regulation 15 of the 1912 law restricted private stations, i.e., amateur stations both as to power and wavelength. The power was limited to 1000 watts with wavelengths not to exceed 200 meters. In the course of a few years the amateurs developed a very efficient communication system which later became national and international in scope. The radio industry owes considerable to the American amateur for the pioneer work done in the field of high frequency, long distance, telephone and telegraph communication.

The radio art continued to develop and expand, and in 1921 the first commercial radio telephone broadcasting station was established and licensed. Subsequent to 1921 stations of this class have increased in number to some six hundred stations, and the service furnished by this class of station numbers among the most important in the field of radio communication. Following radio telephone broadcasting, photo radio was developed on a commercial basis, and service is now being carried on between the United States and Europe. Television was next in line, although at this writing the work is largely experimental. High-frequency radiotelephone broadcasting and radio beacon stations on land for furnishing bearings to ships at sea and to aeroplanes moving over land have come into general use, as has the beacon receiver for ship and aeroplane use. At this time important experiments are under way in connection with the development of radio beacon transmitters for the mobile stations.

In 1927 radiotelephone service was established on a commercial basis between the United States and England, which service has since been extended to the principal countries in Europe. The several radio services herein cited have, as in the case of others, greatly increased the technical work of the radio inspection service. It is generally recognized by engineers and others that there are definite engineering limitations on the use and expansion of radio. It is, therefore, essential that the most careful consideration be given to the development of this new instrumentality of commerce. In order to deal adequately with radio problems, so far as it concerns the radio inspection service, the Department of Commerce has considerably increased its field force. In addition to the main offices of the field inspection service, sub-offices have been opened in Philadelphia, Pa., Buffalo, N. Y., Kansas City, Mo., Duluth, Minn. (in the summer), St. Paul, Minn. (in the winter), and Los Angeles, Calif. There has been for several years a sub-office located at Norfolk, Va.

In order to deal effectively with the engineering work of the field inspection force, the Department of Commerce has purchased and now has in operation six radio test cars. Each test car represents a complete mobile radio laboratory and is equipped with apparatus for measuring the operating frequency of broadcasting stations, field intensities from which field contour maps are made, secondary standards of frequency for calibrating frequency meters and complete equipment for conducting radio operators' examinations. The receiving system installed on the test cars covers a wide range of frequencies and may be operated independently for use in connection with the study of directional reception and numerous other problems involved in the study of reception from the several classes of radio transmitting stations in operation. The test cars represent the latest addition to the equipment already supplied the main and sub-offices of the field inspection force. At this writing, deliveries are about to be made of secondary standards of frequencies for use in the field offices. This equipment represents the most modern of its kind developed today and includes receivers designed with a high degree of sensitivity and selectivity and covers the entire frequency band employed in the field of radio communication at the present time.

The Department of Commerce, Radio Division, has plans under way for the installation of a Constant Frequency Monitoring Station to be located near Grand Island in the state of Nebraska. It is expected this station will be completed in the late Fall of this year (1929). At this writing it is too early in the proceedings to go into the matter of the construction and operation of this station; however, it is hoped that it will furnish interesting material for a future paper in the PROCEEDINGS.

## LAW ENFORCEMENT

A fundamental rule of the American Constitutional System fixes the principle that the governmental powers are divided into there departments, namely, the Executive, the Legislative, and the Judicial.

The enforcement of the Radio Communication Laws of the United States and the International Radio Telegraph Convention[15] is vested in two governmental agencies, the Federal Radio Commission and the Department of Commerce. The titles of the statutory Acts of Congress and the International Radio Telegraph Convention, enforced by the Federal Radio Commission and the Department of Commerce are as follows: An Act approved July 23, 1912, amending Section 1 of an act entitled "An Act to Require Apparatus and Operators for Radio Communication on Certain Ocean Steamers" approved June 24, 1910, the Radio Act of 1927, approved February 23, 1927, and the International Radio Telegraph Convention, and general and supplementary

[15] See United States Constitution; Art. VI, Section 2. See U.S. Constitution; Art. II, Section 2, Paragraph 2. 14 A. L. and P., 20, Section 22.

regulations relating thereto, ratified by the Senate on March 21, 1928, effective January 1, 1929.

The 1910 Wireless-Ship Act is enforced by the Department of Commerce, whereas the Radio Act of 1927 and the International Radio Telegraph Convention are enforced jointly by the Federal Radio Commission and the Department of Commerce. Under the existing arrangement the Department of Commerce enforces the law in the field, whereas the Federal Radio Commission enforces the law from its headquarters at Washington, D. C. As previously stated, there is a joint responsibility in the matter of law enforcement and full cooperation is maintained at all times between the Federal Radio Commission and the Department of Commerce.

Section 4, Paragraph f, of the Radio Act of 1927, authorizes the Federal Radio Commission and the Department of Commerce to make such regulations as may be necessary for the proper execution of the Act. These regulations must not be inconsistent with the law and shall only consist of such regulations as have to do with regulating the mode of procedure for carrying out the intent of the law.

## Appendix

### Federal Radio Commission Zones Established Under Section 2 of the Radio Act of 1927

Zone 1 includes the states of Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Delaware, Maryland, the District of Columbia, Porto Rico, and the Virgin Islands.

Zone 2 includes the states of Pennsylvania, Virginia, West Virginia, Ohio, Michigan, and Kentucky.

Zone 3 includes the states of North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Mississippi, Arkansas, Louisiana, Texas, and Oklahoma.

Zone 4 includes the states of Indiana, Illinois, Wisconsin, Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Missouri.

Zone 5 includes the states of Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, the territory of Hawaii, and Alaska.

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# THE PROBLEMS CENTERING ABOUT THE MEASUREMENT OF FIELD INTENSITY*

By
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***Summary***—*A brief recount of some of the major contributions to radio field intensity measurement work is given, showing that these represent a great deal of the groundwork on which future developments will be based. The general problems of this sort of measurement work are discussed, as well as the equipment with which the Radio Division of the Department of Commerce expects to handle them. Typical illustrations of radio transmission in cities are given, showing the necessity and importance of field intensity surveys in the location of radio stations. The prediction is made that the time will come when all radio broadcast transmitters of 1 kw or more power will be located on the basis of radio field intensity surveys.*

An examination of the strictly technical aspects of radio transmission developments during the past year discloses some very interesting and highly important applications of radio field intensity measurements. While the industry has not yet by any means taken full advantage of radio field intensity measurements and surveys, nevertheless there is a very definite trend toward the more complete utilization of the subject as applied to transmitter design and location.

Like every other engineering project there must be laid down a groundwork of fundamental principles before practical applications may be made, and in the case of radio field intensities that groundwork which we have is of comparatively recent origin. In passing it is proper that some of the more important developments be recounted. Among the leaders in the broader aspects of the subject stand the works of Dr. L. W. Austin, which have frequently appeared in the Proceedings of the Institute, as well as in other publications. In line with these we also have the work of G. W. Pickard similarly published. Beside these developments stand those of Bown, Martin and Gillett presented in the Proceedings under the title of "Distribution of Radio Waves from Broadcasting Stations in the City Area." Dr. A. N. Goldsmith's article entitled "Reduction of Interference in Broadcast Reception" appeared also in the Proceedings, and L. Espenschied's article entitled "Radio Broadcast Coverage in City Areas" appeared in the *Journal* of the American Institute of Electrical Engineers. The paper entitled "Some Studies in Radio

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Broadcast Transmissions" by Ralph Bown, DeLoss K. Martin and Ralph K. Potter, also appeared in the PROCEEDINGS of the Institute.

Several other articles in these PROCEEDINGS as well as some appearing in other journals have furnished certain avenues of approach toward the more complete utilization of the possibilities of radio field intensity measurement work, and from them many conclusions were drawn which have now become principles in the industry. Noteworthy among them is the acceptance of the 10-millivolt-per-meter level as essential to good broadcasting service, and the rating of service areas in terms of miles for various powers of transmitters which this figure permits.

In harmony with these principles there have been undertaken during the past year several surveys having for their objective the locations of radio transmitters. A great deal of development work on transmitters has accrued directly as a result of these efforts. The beneficial results of surveys of the fields of transmitters are felt very strongly on several of the latest high-power broadcast installations. The measurement of electric fields permits not only the primary determination of a given station's location, but also a complete analysis of its radiating mechanism and it is upon these two main factors that a transmitter works to its greatest advantage.

In addition to the great value of field intensity work in the broadcast spectrum, projects of considerable magnitude are now under way, and have been for some time, with respect to radio communication between aircraft and ground stations, not only for the exchange of intelligence but also for direction-finding purposes.

The high frequencies present a fertile field for field strength measurements, especially when an examination is made of the methods by which the short-wave channels are being exploited by the nations of the world since the International Radio Telegraph Convention held at Washington, D. C. in 1927. It will be recalled that the various nations are entitled to use certain channels which may only be used by other nations provided no interference results. Under these circumstances one of the most valuable sources of information must certainly be radio field intensity measurements.

Most of these things as outlined are apparent to anyone in the industry, and have been so for some time. With the realization of the necessity of meeting these problems, the Radio Division of the Department of Commerce prepared in 1925 to determine in what way they could best be attacked. As a result it had developed especially for its use a radio field intensity measuring set in keeping with latest known practices in the art. An illustration of one of these sets is shown in Fig. 1. The fundamental principles of operation of this equipment were presented in a paper already published.[1] This set is capable of operating over the frequency range of 6000 to 200 kc per sec. and responds satisfactorily over a signal level range of from 10 $\mu$ v per meter to about 4 v per meter.

The general requirements for such a device are very severe inasmuch as it must by nature be a delicate piece of equipment and yet must, at the same time, be portable. By portable is meant a permanent mounting in an automobile under conditions of travel over all kinds of roads at all speeds. Further than this, the set must be com-

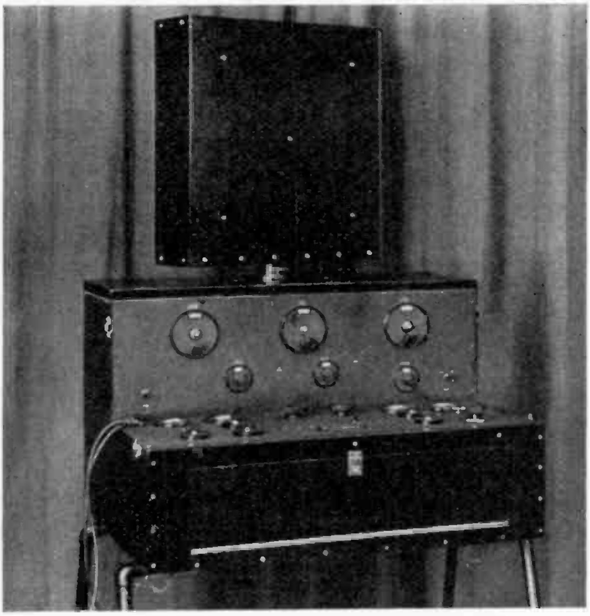

Fig. 1—Radio Field Intensity Measuring Set.

pletely self-calibrating, must be fast in operation, and must be capable of extreme accuracy where it is to be used as an instrument for law enforcing purposes. The overall accuracy of the equipment is guaranteed to be correct to plus or minus 5 per cent. At the same time the equipment must be free and independent of the human element so that uniform results are always obtainable. The first of these sets has been in operation for considerably more than a year, and has met these requirements.

As a result, the Radio Division has now purchased and has in operation six of these equipments, and will shortly secure enough

[1] H. T. Friis and E. Bruce, "A Radio Field Strength Measuring System for requencies up to Forty Megacycles," Proc. I.R.E., 14, 507; August, 1926.

additional similar equipments to supply each of the nine radio districts.

These sets are mounted in automobiles having bodies of special design. Fig. 2 is an illustration of two of these cars, of which there are six now in service.

With this equipment it is planned ultimately to survey the field of every radio broadcast transmitter in the United States as well as to conduct measurements on the high-frequency channels and other services. To date twelve complete surveys have been made in the broadcast band. This work has been done on both coasts and in the north and south parts of the country. Some of the work has been published.[2]

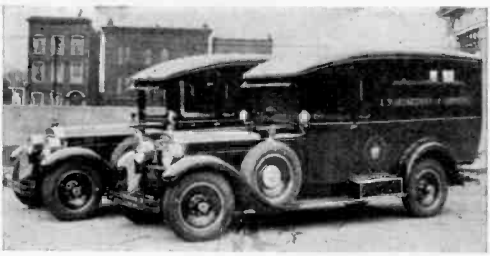

Fig. 2—Cars in Which Are Permanently Mounted Radio Field Intensity Measuring Sets Developed for Radio Division of the Department of Commerce.

In addition to field survey work, the field strength sets are expected to be used for law enforcement purposes such as the detection of increase of power at stations not authorized to do so. With a field strength measuring set and certain predetermined data at hand it is possible to check any change in power at a station and thus determine how much this change is without going inside the station. This has been done in several instances.

Progress was necessarily slow at first, but is gradually assuming greater proportion. This was so of necessity, inasmuch as a great deal of experimental work had to be done before a unified system of operation for all of the equipments could be developed. First in the order of development was the radial system of measurement. In making a survey by this method, radial directions are taken from the transmitter which becomes a center, and measurements are made at inter-

[2] S. W. Edwards and J. E. Brown, "The Use of Radio Field Intensities as a Means of Rating the Outputs of Radio Transmitters," Proc. I.R.E., **16**, 1173; September, 1928. Other material by the same authors was published in Radio Service Bulletin, March, 1927.

vals on each of them. At least ten radials should be chosen for powers on the order of 1 kw, and perhaps more for higher outputs. The measurements are made at 0.3 mile intervals in urban localities and less frequently in suburban and country locations, the measurements to start within a few wavelengths distance of the station and continue on until at least the 5-millivolt-per-meter signal level has been reached. Much practical experience must be gained before successful measurement work can be done, due to the difficulties of securing true signal readings in cities where there are always a multiplicity of wire circuits, steel buildings, and other metallic objects. Methods had to be developed by which accurate determination of the effects of any of these things on the signal level could be noted. By a happy circumstance it was found that a false reading of signal level is almost always accompanied by either an untrue radio compass bearing on the station being measured, or by a very poor minimum signal from the station when the loop or signal collector is rotated. In other words, it has been found that any object capable of causing distortion of the wave front of the advancing wave form very likely also affects its signal voltage level. The immediate result of this finding was the requirement that on the field strength sets used, the loop must be capable of giving a good minimum signal at all frequencies.

Since the surveys are being made in all parts of the country by different men, a standard system of depicting the results of the surveys had to be developed. In doing this certain practises used in topographical work were borrowed and put into use. As an example, after all of the radical directions have been measured, curves are made plotting the measured values of signals against their respective distances in miles; these curves show the variation in signal strength with distance. From these curves may now be taken the significant values of field strengths which are located in their proper places on an accurate map of the locality under survey. Emphasis is usually placed on those values of signals in multiples of ten; that is, lines of strength of, say 100, 90, 80, etc., millivolts per meter are drawn terminating in the lowest value measured, which may be either 1 or 5 millivolts per meter. In special instances this order may not hold but these are generally of rare occurrence. Where instances of this kind develop, they are usually in the nature of a rapid determination of the general nature of the station's field. The procedure is then to determine where the high signal or possible interference level lies and where is the outer border of its good service area. Suggested values may be perhaps 100 millivolts per meter, interference level, and 10 millivolts per meter to 5 millivolts per meter as the minimum good service level. By interference level, in this case, is meant that signal level from a station which is so high as to make difficult the reception of other stations on different and considerably removed frequencies.

In addition to the regular points at which measurements are made for the survey, several places are selected at which signal voltage readings are taken for purposes of antenna analysis. These points are carefully selected near the station and are used for calculation purposes in determining the effective height of the transmitting antenna, its radiation resistance, and its radiated power. These points are selected with great caution to make sure that true readings are obtained which are not greatly attenuated.

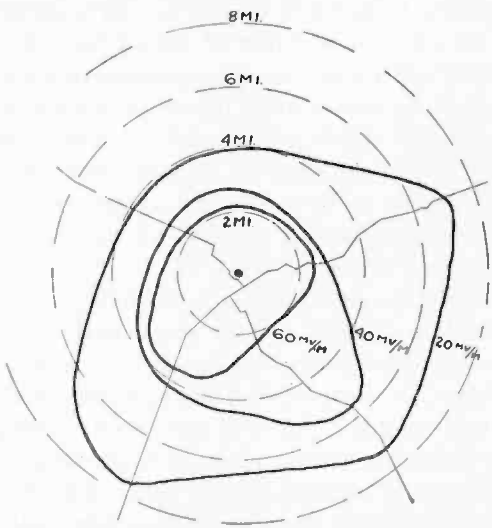


Fig. 3—Field Intensity Contour Maps of 1-kw, 720-kc Broadcasting Station. Antenna I, 7.2 amperes; effective height, 41.7 meters.

The general problem of radio transmission is at best a highly complex proposition, and when a station is located in a city of some size the results which will be obtained very nearly defy prediction. While all cities exert much the same effects on transmission, the general efficiency of transmission in a city is almost entirely a matter of the frequency used. There are shown, herewith, two recent radio field intensity contour maps made on two different broadcast stations operating in the city. Fig. 3 is the field intensity contour of a 1-kw station power, operating on a frequency of 720 kc; Fig. 4 is the field intensity contour of a 5-kw station, operating on a frequency of 640 kc. Both stations are of the latest design, well erected and are located on steel buildings approximately six stories high. The stations are approximately 1/2 mile apart and have the same type of surrounding buildings, street car lines, etc. In other words, except for the frequencies and the power used, the stations are nearly identical, and yet the transmission characteristics are quite widely different, though there is a frequency difference of only 80 kc.

Signals from both stations are seriously attenuated in a southwesterly direct, and but for this attenuation the station in Fig. 4 would have a very good field. An examination of the field of the station in Fig. 3 shows some irregularities in other directions; whether this indicates heavy attenuation in these particular localities for frequencies in

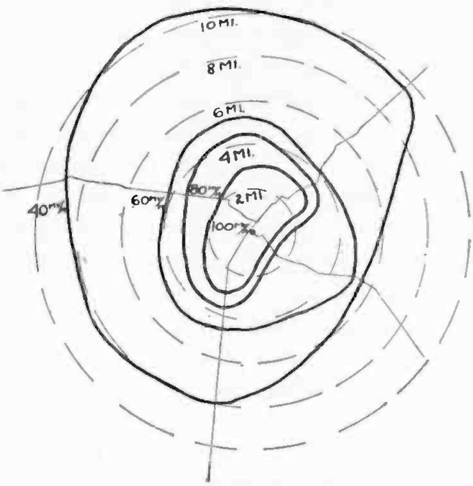


Fig. 4—Field Intensity Contour Maps of 5-kw, 640-kc Broadcasting Station. Antenna I, 20 amperes; effective height, 29.7 meters.

the region of 720 kc, or whether there is a steady increase in attenuation with increase in frequency, is not known.

The above examples are very good for demonstration purposes, and they indicate beyond all doubt the enormous handicap under which signals in the broadcast band radiate under the very erratic conditions of city attenuation. They tend to show the value of field intensity measurements in the location of radio transmitters. A glance at both Figs. 3 and 4 indicates that the severe attenuation in the southwest direction holds for both cases. Were a station to be located in the locality described, and in the range of frequencies under consideration, one of the most important features would be to place it so that the poor transmission caused by the southwest section of the city would fall in the direction of the minimum number of listeners. Very fortunately for the station under discussion, transmission in a southwesterly direction is of no great importance since few broadcast listeners reside in this direction for several hundred miles. In passing, it might be said that this severe attenuation is caused by a very dense system of electric power lines and railroads with their associated wire circuits. The section itself is the manufacturing part of the city, and although reasonably well localized to one area is rather large in size.

It is expected that by means of all of the field strength sets in operation by the Radio Division a great deal of valuable information will be uncovered. This information will not only be of value to the radio station owner but, if he cares of avail himself of it, will certainly become beneficial to the radio listener. At the present state of the art we are going through a remarkable stage of improvement. The value of higher power in broadcasting is being recognized, and through it the public is enjoying better service. The advent of high percentage modulation is being noticed, and its effect seems to be such that we may have to reduce our standard signal level of 10 millivolts per meter to some lower value, perhaps 5 millivolts per meter or even lower. Under any conditions, the combination of high percentage modulation, high power, and intelligent location of stations through field intensity measurement work is certainly going to usher in a period of broadcasting service superior to anything we have ever had before. The guess is ventured that in the near future no station of 5 kw or more power, and very likely less, will be located without at least some consideration of the field which it should produce for best satisfaction. The Radio Division of the Department of Commerce hopes to assist and expedite the use of radio field intensity measurement work in all of its phases, and believes that steps in this direction are in the line of progress and are of value to the public and to the radio industry in general.

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# THE RADIO ENGINEER'S RESPONSIBILITY IN COPING WITH MAN-MADE INTERFERENCE*

By
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MAN-MADE interference is growing in its relative importance as an obstacle to the service value of broadcast reception. Quality of transmission, studio design and management, selectivity of receivers, and quality of reproduction have been progressively improved by the application of sound engineering principles, leaving the suppression of man-made interference as one of the major obstacles to undisturbed reception. Its elimination has been considered largely an operating or field problem for individual elimination in outstanding cases where radio reception by large groups of people has been interfered with. We have been content to let the man-made interference wait for attention until after it is created rather than preventing it in advance by the application of proper engineering design before it arises.

It would be repetition to enumerate the various means used to eliminate electrical interference in connection with electrical appliances, motors, dynamos, and industrial machinery. The power companies under the guidance of the National Electric Light Association have made marked strides in developing methods for outside plant and in distributing information on how to locate power system leaks with reasonable celerity. Most of the power networks are being erected with full appreciation of the power company's responsibilities to the listening radio public. Insulation and testing methods have improved steadily, so that the few instances of serious complaint are distinct evidence of a non-cooperative attitude on the part of the power company rather than the existence of a problem technically difficult of solution.

If we are to make substantial progress in eliminating all important causes of electrical interference, however, the problem cannot be left to the power companies alone, although they have naturally taken the leadership up to this time. The finger of public condemnation is too readily pointed at them when electrical interference is experienced, even though they are not, in the majority of cases, directly responsible for complaints. Investigation has shown that household equipment

* Dewey decimal classification: R170. Original manuscript received by the Institute, February 20, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

is a very frequent cause of interference in residential districts. Such equipment frequently sets up radio-frequency impulses which are released as electro-magnetic waves from power networks, and are also distributed through the power conductors into the radio receivers connected with them. Household equipment is usually used only spasmodically, making it most difficult to identify it as the cause of noisy radio reception by the standard methods of interference determination. Often simple devices used in residential areas, such as vacuum cleaners, fans, electric refrigerators, oil burners, cash registers, and medical equipment interfere only momentarily but none the less annoyingly with reception over an area of several square miles. Such interference once located is not difficult to suppress, and the methods are well known. However, it seems well nigh hopeless to expect ideal reception conditions by searching out millions of isolated and individual cases of electrical disturbance. As long as electrical equipment is manufactured without consideration of its radiating properties, interference will continue to affect home radio reception, unless radio receivers of a much lower order of sensitivity are employed.

Radio engineers have recognized this problem and have attempted to render the radio receiver less sensitive to the influences of power line fluctuations by using chokes to suppress them and incorporating adequate shielding and by-passing of radio and audio-frequency circuits with a view to disassociating these circuits as far as possible from the power circuits. The existence of bypass condensers and protective chokes in the receiver is at least psychological recognition of an obligation to cope with disturbances introduced through the power circuit although, in some instances, it must be said that the designer has little more than this in mind. That there is a considerable variation in the effectiveness of the by-passing and choking employed can be demonstrated readily by comparing the noise at a given point upon several different makes of commercial receivers. I would like to consider man-made interference in a somewhat broader way with a view to determining, if possible, the trends of both electrical appliance and radio receiver design and development as they affect this problem.

Each time an electrical circuit is made or broken or a rapid change in load on a power circuit occurs, radio-frequency impulses are set up and radiated from the power network. Two broad courses are open for the control of such interference; the choice depends upon the activity of the radio engineer. These two courses are (1) altered balance of the broadcast transmission and reception system so that less responsive receivers are required, or (2) "radiation-proofing" of electrical equipment.

Although there has been a tendency toward increased power in broadcasting, we have hardly reached the threshold of development in this direction. It is quite within the scope of the engineer's imagination to visualize ultimately a broadcasting system comprising transmitters of a million watt power. Compared with other systems in daily use this is by no means a large unit; the power bill for such a broadcasting station might run from fifty to one hundred dollars an hour. We use several hundred times that power in transporting week-end excursionists to a single metropolitan bathing beach, and certainly radio broadcasting is of at least comparable importance in our daily lives. While a million watts represent a substantial increase in the power of broadcasting, such power need not be feared as a dangerous monster.

A system of broadcasting with transmitters of this order of power would require somewhat altered receiver design. Obviously we would employ less sensitive receivers, and instead of an exposed aerial system we would use an adjustable pickup means shielded from incoming impulses to a degree determined by the field strength of the nearest broadcasting station. Stations of such power could serve the centers of population with antennas located at some distance from congested centers. It is quite conceivable that receiver development could keep pace with progressively increased powers of the order suggested.

Allocations of wavelengths under these conditions would be simplified because the high grade service range of such stations might well be as much as five hundred miles. Ninety such stations spread geographically over the country would give ten or twelve program choices at any point, and may be compared with present conditions where perhaps less than 40 per cent of the area of the country is within the wide high grade service range of *any* broadcasting station. Furthermore, the initial and maintenance cost of receivers would be lessened, and quality of reproduction improved, with the consequent result that the radio listening public would be enormously increased. This in turn would have a healthy effect on the economic position of the broadcaster.

But such a system of broadcasting would also be considerably more costly than the present annual maintenance expense of approximately thirty or thirty-five million dollars. It might cost one hundred fifty million to two hundred million a year or more to maintain ninety stations of this order of power.

The entire burden of overcoming man-made interference, should developments proceed entirely in this direction, would be placed upon the radio industry.

The other method of attacking the elimination of electrical interference is by cooperating with other branches of the electrical industry. The power companies, one of the most important groups to be considered, can be expected to do their part because their relations with the public would not permit them to stand for any length of time in the position of prime responsibility for interfering with radio reception. We may, therefore, expect progressive improvement in power plant and network design and equipment which will reduce to a minimum electrical interference originating in faulty installation, high resistance, grounding of power lines, and the other well known causes which lie in that field. We may also expect industrial inspection looking toward the elimination of interference resulting from high power electrical machinery, smoke precipitators, electric welding equipment, and similar interference creating devices.

The real difficulty lies in the modernization of household equipment such as electric fans, oil burners, cash registers, electric refrigerators, vacuum cleaners, and violet ray machines. All of these must be designed with elimination of radio interference in mind. It is difficult to estimate the cost to the electrical industry of the necessary modification of such devices to accomplish this objective, but as nearly as can be estimated, the equipment of all vacuum cleaners, washing and ironing machines, oil burners, and sewing machines with chokes and filters so that they can be operated from the same power circuit as a radio receiver of the sensitivity at present used without noticeable interference would have cost the electrical industry ten million dollars for 1928.

Unquestionably, the most economical approach to the solution of this problem lies in eliminating electrical interference at this source rather than over-riding it where its effect is felt. But to thrust the responsibility of silencing electrical equipment upon an industry disassociated from radio is to impose a task of no small magnitude. No progress whatever has been made in fixing the responsibility for radio silence upon the makers of interference creating equipment. Only in isolated instances is the influence of minor electrical equipment considered a problem for any but the radio industry to solve. The radio engineer must exert his influence in electrical standardization. Instead of viewing the electrical industry as competitive and disassociated he must work hand in hand with the appliance, power, and traction industries. The radio engineer through his engineering association's standards committees and through the manufacturers' standardization groups must clearly voice his opinions or he will find eventually that the entire burden of eliminating the effect of electrical interference will necessarily be lodged with the radio receiver itself and the transmitting system which furnishes it with programs, at a cost to the radio industry which I have endeavored to indicate.

A closely allied problem which I cannot refrain from mentioning at this time is that of the importance of power line voltage regulation. Power radio receivers must now be designed to operate on almost any voltage between 105 and 120 volts. Prior to the appearance of the radio receiver, voltage variations from five to eight per cent have had but little effect in the operation of home equipment. But the sensitivity and selectivity of most power operated radio receivers and the life and efficiency of practically every vacuum tube is closely dependent upon the supply of correct line voltages to the power system of the radio receiver. In order to cope with varying conditions adjustment is frequently provided so that the average line voltage conditions may be compensated for. But these means do not meet the diurnal fluctuations frequently encountered, for example, when the industrial load is discontinued at the end of the working day. It cannot be left to the owner of the radio receiver to make constant readjustment of his receiver at different hours of the day and night, and the only practical solution lies in the standardization and stabilization of power line voltage supply. Here again the radio engineer could profitably exert his influence in the councils of the electrical industry on a basis of cooperation rather than with the competitive and isolated point of view toward which he now inclines. The obligation for the cure of both fluctuations in power line regulation and electrical interference is sufficiently debatable that the radio industry cannot afford to overlook any opportunity to secure the friendly cooperation of the electrical industry with a view to solving these difficulties in the most efficient and economic manner. This is a responsibility of the radio enginer and the radio industry which must be promptly assumed. Little progress has been made in this direction up to this time. Failure to assume the responsibility may prove a serious burden to the industry which may ultimately reach large proportions.

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# RADIO COORDINATION*

By
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THE elimination of radio interference is a problem of community coordination. To legislate against the occurrence of interference will accomplish as much and be as sensible as to legislate, for instance, against the occurrence of lightning. Although the actual tracing down and elimination of a specific disturbance may require the services of a specialist, the greatest advances in the highly technical art of locating and eliminating interference will be valueless without complete community interest. For progress in the betterment of radio reception conditions, continued cooperation of manufacturers, newspapers, amateur radio and broadcast listeners' associations, dealers, electric supply utilities, communication utilities, municipalities, electric railways, and perhaps most important of all, "the man in the street," must be obtained.

The problem of interference, at least insofar as it refers to interference with individual or family activities or obligations, is as old as civilization; the expression "a man's house is his castle" is nothing more nor less than a guarantee, not of individual freedom as such, but of prevention of interference. The problem of interference between services to the public is at least as old as the so-called Industrial Revolution; in 1857 Abraham Lincoln before the United States Circuit Court at Chicago argued and won a case of interference which concerned the placing of a railroad bridge across the Mississippi River.[1] The bridge undoubtedly interfered somewhat with river traffic, at that time of immeasurable service to the public, but the same general public also required the additional services to be rendered by the railroads. The problem of interference between the facilities of the electric supply and communication companies has long been recognized, and literally thousands of articles have been written on this subject,[2] which is closely akin to that of radio interference. The first and foremost principle under which two of these great industries

* Dewey decimal classification: R170. Original manuscript received by the Institute, March 9, 1929. Presented at Fourth Annual Convention of the Institute, Washington, D. C., May 13, 1929.

[1] F. F. Fowle, "A Famous Interference Case," The N.E.L.A. Bulletin, October, 1927.

[2] Bibliography on Inductive Coordination, The American Committee on Inductive Coordination, New York, 1925.

exist together today in every section of the country merits quotation:[3]

> "Duty of Coordination.
>
> "(a) In order to meet the reasonable service needs of the public, all supply and signal circuits with their associated apparatus should be located, constructed, operated and maintained in conformity with general coordinated methods which maintain due regard to the prevention of interference with the rendering of either service. These methods should include limiting the inductive influence of the supply circuits or the inductive susceptiveness of the signal circuits or the inductive coupling between circuits or a combination of these, in the most convenient and economical manner.
>
> "(b) Where general coordinated methods will be insufficient, such specific coordinated methods suited to the situation should be applied to the systems of either or both kinds as will most conveniently and economically prevent interference, the methods to be based on the knowledge of the art."

The policy expressed needs no comment.

The harnessing of electricity by man for his peculiar purposes does not prevent it from being a phenomenon of nature. Individual men die; specific dielectrics decay. No power on earth can prevent a condenser in a radio receiver from going bad eventually. Nor can any human power prevent electrical insulation from eventually wearing out. In either case occurs the so-called "man-made interference." The problem of the elimination, or, more properly, the reduction of this interference, cannot be solved by regulation or legislation. It is quite conceivable that in some cases the best engineering solution of an interference case is to let it keep on interfering. It may well be in an imaginable case that the community is best served by suffering from some source of interference provided it receives some greater service in return. The interferer is not necessarily always in the wrong. Judge Davis for instance says:[4]

> "The characteristic feature of the [radio interference] situation presents a conflict between individuals, each of whom is carrying on a legitimate activity. It is not a case of an obvious wrongdoer performing an act denounced by law, custom, or good morals to the injury of his neighbor. The person causing the interference, whether he is engaged in radio communication or is using some electrical device for a noncommunication purpose is in a lawful business within his inherent rights. He is using his own property for his own lawful purposes. The person using his property for radio communication and suffering the disturbance, whether on the sending or receiving end, is equally within his rights and his acts are legal and proper."

The most modern thought, however, seems to be that the public is entitled to the best coordinated service from all sources that it is possible, from an engineering standpoint, to provide. It is thus part of the neighborly duty of each of us, no matter whether we operate an interfering violet ray machine or high-frequency laboratory, and no

[3] Reports of Joint General Committee of National Electric Light Association and Bell Telephone System on Physical Relations between Electrical Supply and Signal Systems. Edition of December 9, 1922.

[4] "The Law of Radio," S. B. Davis; McGraw-Hill, 1927.

matter what our priority or property "rights" may be, to coordinate our electric systems so that they serve the greatest community good. Legislation and regulation do not develop neighborly duties; in a subject as complex as radio interference it is to be feared that they would add only confusion.

The complexity of the problem of location of the source of a complained of radio disturbance requires for its solution a radio and electrical engineer of extraordinary ability. The likelihood of any overhead wires, whether power, telegraph, telephone, or trolley, to propagate radio disturbances originating elsewhere, in much the same manner as any conductor will transmit carrier current or "wired wireless" signals, renders useless the triangulation or goniometer method of interference location in the vast majority of cases. The experienced investigator trusts the direction he obtains with the loop of his portable receiver only insofar as it tells him the paralleling overhead circuit from which he is receiving his greatest pick-up. This overhead circuit may in turn have received the interference from another paralleling circuit and so on. The "hot and cold" or maximum and minimum method of noise chasing, i.e., finding by trial and error the point of maximum disturbance, will best serve the investigator. Even with the use of this method the chances of error are great. With all the discontinuities and possible reflection points on an overhead electrical circuit, the interference may develop nodes and antinodes of effect on the receiver. In order to avoid self-deception the investigator using the "hot and cold" method must be on the alert for variation of coupling between his receiver and the overhead line under suspicion; many a man has been badly fooled by approaching, and thus making a closer coupling with, a vertical conductor on a pole. Care should also be taken that the investigator is not thrown off the scent by noises other than the one he is hunting. In fact his first duty should be to visit and keep in touch not only with the complainant but also with the complainant's neighbors and request their help in the search. Accurately kept logs of the interference are often invaluable in that they may help the investigator to tie up the interference with nearby factory operation, etc. The investigator needs neighborhood cooperation. Once he has determined the general source of the disturbance, common courtesy demands that the investigator immediately lay the problem before the person responsible in the home, factory, wire-using utility, or whatever the source might be.

The problem of elimination of known sources of interference is not an insuperable one. Standard filters, now on the market, will serve effectively in reducing that interference caused by the myriad of electrical appliances now in use. When it is considered that every arc or spark, no matter how infinitesimal, may give rise to a devastating noise in a radio receiver, it is obvious that a list of appliances to which it is necessary to add corrective devices would look like a complete catalog of electrical equipment. For the equipment of electric supply utilities good "radio maintenance" plus ordinary maintenance is desirable. Ordinarily the equipment of the power company is innocent of any radio harm; the much maligned "leaky transformer" is a myth. The electric railway and street car systems have a graver problem in that the sparking that occurs between trolley wheel

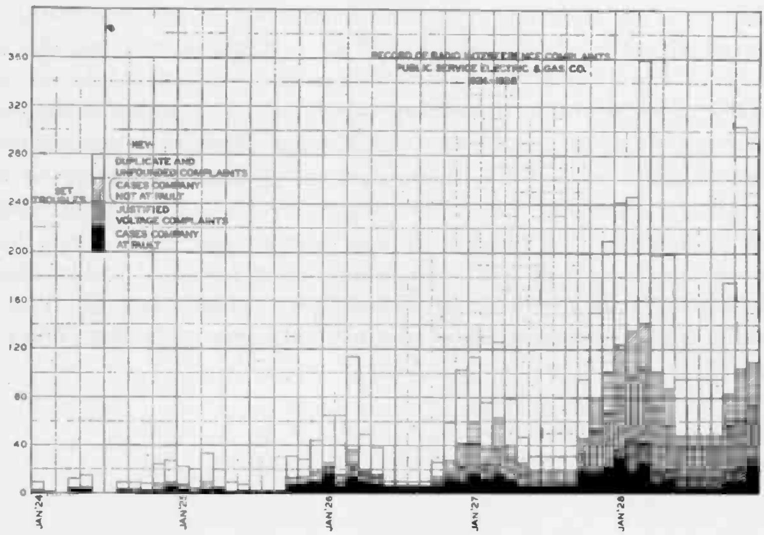


FIG. 1

and contact wire or between wheels and rails is a part of the normal operation of the system. The minor interference that occurs in the equipment of the communication systems is usually readily corrected by the proper placing of filters. For a more detailed account of the sources of interference and possible remedies reference to the August, 1927, Serial Report of the Inductive Coordination Committee, entitled Radio Coordination, Publication No. 267–98 of the National Electric Light Association, is recommended.

There remains the great body of minor noises which it is impossible to locate and some of which it would probably be impossible to remedy. These make up the "noise level" of the community below which operation of a receiver to bring in distant stations will give unsatisfactory results. This is the penalty of living in a civilized community where everything is done electrically. Someone has said that the only place absolutely satisfactory for radio reception would be a desert island reached by a rowboat and even there some complaint would be found against either thunderstorms or the aurora borealis. Even the automobile, of which there are now millions, adds its quota to the community noise level. Its ignition system will ruin reception if the receiver is placed close by, and at a wavelength of 10 meters passing cars drive the experimenter to distraction. It is obviously impractical to shield and ground the wiring and spark coils of every automobile in the country.

There seems to be no conspicuous offender in the generating of radio interference. An analysis of Fig. 1, a graph relating the experience of one of our large power companies with radio interference complaints, shows some disturbing trends in that it appears that the percentage of defective radio sets is increasing. Another interpretation, however, would be that the dealers and service men are becoming less keen in their diagnosis of troubles. Whatever the trend of interference troubles, however, the general problem remains the same. As in most problems that confront our civilization, tolerance is of prime necessity, and most important of all, community cooperation, in which is included a heavy responsibility on the engineering profession, must be achieved.

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# UNITED STATES RADIO BROADCASTING DEVELOPMENT*

By

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***Summary***—*Part I of this paper gives in detail the development of radio broadcasting in the United States from 1907 to 1928, inclusive; Part II deals with the development of a radio broadcast from the studio to the listener. The characteristics and trends of these developments are then used for the purpose of pointing out possible future developments in radio broadcasting in Part III.*

## Part I

At favorable locations we are now able to obtain considerable power in the form of satisfying musical frequencies from the last audio stage of our radio receivers. Though that has not always been the case, it is not to be attributed to any one thing or to a few things. Different viewpoints magnify different steps in broadcasting development to more than their proper proportions. Each class of contributors to broadcasting development sees that development through its profession, trade, vocation, avocation, science or product, and those who are still far from any broadcasting station may feel that broadcasting has developed very little.

Practically every radio device for sale to the public since 1921 has been advertised at one time or another as the one thing that will provide the listener with perfect reproduction. Makers of crystal detectors, vacuum tubes, loud speakers, resistance couplers, transformers, and receivers which take their power from electric light circuits, have been prominent in the making of that claim. As a matter of fact the equalizing of the wire lines to broadcasting stations[36] and the increasing of the power[7,15,37] of those stations were two of the important steps toward the quality we now get and we do not get perfect reproduction yet.[1,38]

To trace the steps in an effort to obtain a fair idea of their relative importance in developing the present reproduction, it is necessary to go back to the beginning[3] where we find that the term radio broadcasting is absurd in a sense because radio and broadcasting are, in a sense, synonyms. The term radio supplanted the term wireless because this means of communication which we named "radio" uses conspicuous wires and because the characteristic wave in this form of com-

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munication explodes from about the antenna; that is, the wave is broadcast along every radius from the antenna. The term radio, taken from radii, was originally meant to indicate that the waves were broadcast. That is the essence of the reasoning of the Standards Committee of the Institute of Radio Engineers[2] as I recall it when they standardized the term radio in 1913. That committee at the same time coined and standardized also the term "audio" for the frequencies we can hear. Their action and the cooperation of the government fixed those words in our language.

True radio is broadcasting, and has been used for that purpose for thirty years,[3] particularly to broadcast distress signals, ships' position signals, and time signals in telegraph code. Also, radio has been used to broadcast speech for more than twenty years. The broadcast of the orchestra type of music has been under development for about twenty years. To broadcast speech required further development from the radio telegraph stage, and to broadcast satisfactory music required still further development.[5,7] In the scope of modern broadcasting, radio has become natural, for broadcasting is what radio is. However, to broadcast over a wide area a large part of the musical scale with fidelity and to deliver a considerable amount of power has required many steps over a period of years in the development of broadcasting devices and in the removal of interferences.

It was an early belief that radio would find more use if it could be made to carry speech. It was believed, for example, that steamships that were reluctant to bear the expense of radio telegraph operators would install radio telephones if the expense of carrying operators who understood code signals could be avoided in that way. Therefore, early attempts were made to provide a radio telephone.[1]

The first radio transmitters in service could not transmit speech because they made short, noisy groups of waves from spark discharges.[3] To carry speech the waves could not be in such noisy groups. Continuous waves or their equivalent became obviously necessary to produce radio telephony.

Several continuous wave generators were developed.[1,30,66] Of these the arc radio generator was the most practical because of its simplicity. It was about as simple as an arc light.[22] It was an electric arc flowing in a gap between a cool copper electrode and a carbon electrode and in an alcohol flame—sometimes in a magnetic field. A small coil of wire and an electrical condenser were connected in parallel to the arc. The coil and condenser determined the number of radio waves that would be produced. The simplicity of that device made it possible for many people to try to develop radio telephony with it in many places. Therefore, several professional and amateur radio people made such radio phones in several places.[23]

Four of the years are of peculiar interest; 1907 because it was in a

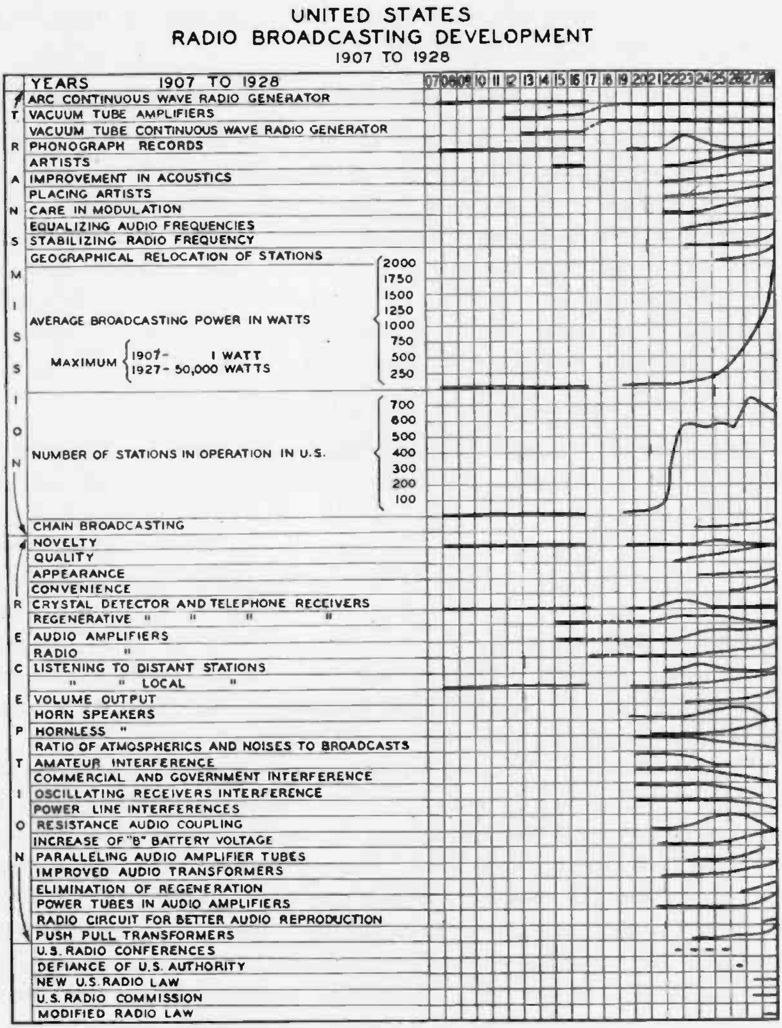


Fig. 1

way the beginning; 1917 and 1918 because in this period broadcasting was prohibited but the abnormal quantity of radio apparatus and activity for the war during that time contributed to the very rapid growth of broadcasting; and 1921 because from then on broadcasting has been growing rapidly and at about that time broadcasting emerged from the socalled trial stage into the worth-while service stage.

By referring to the chart marked "United States Radio Broadcasting Development" we can follow with fewer words the steps from the first broadcasting of a little music, to the present far flung broadcasting of more satisfactory music.

## Chart of United States Radio Broadcasting Development

In this chart, the left half is devoted to the steps or factors which have been used in the development of broadcasting. At the right the chart is divided into vertical sections representing years. Little curves are shown in the spaces under the years and opposite the steps or factors to indicate when those steps or factors first appeared and when they became prominent in the development. The curves relating to broadcasting power and to the number of stations are drawn to scale. The other curves are not to scale.

### Arc Continuous Wave Radio Generator

As we see by the chart, broadcasting by use of the arc began in the winter of 1907 and 1908. At that time President Roosevelt sent the United States naval fleet around the world. These vessels had been equipped with arc telephones.[25,26,27] The navy operators placed phonographs before the microphones of those arc telephones playing phonograph music into the microphones and thereby broadcasting music. That music was picked up by the other ships of the navy, by commercial ships, and by numerous shore stations as the fleet proceeded on its way around the world. That took several months. Now broadcasting can go around the world in a fraction of a second.

During 1908 Dr. DeForest broadcast music from a station in New York City, using an arc radio telephone transmitter, and during the same year, using a similar apparatus, I broadcast music from a station at Manhattan Beach, New York. We both used phonographs except when we talked into the microphone ourselves. There was, however, one important exception to that during 1909, when Dr. DeForest installed a microphone in the Metropolitan Opera House on the stage and broadcast Caruso's voice. That was probably the first case of directly broadcasting the work of a distinguished artist. At that time we were fundamentally trying to develop a radio telephone;[29] however, we considered the possibility of broadcasting as it is done now, but at that same time, 1908, there was on Broadway near the corner of 40th Street a device called the "Cahill Telharmonium," which was built for the purpose of broadcasting music over wire lines such as telephone lines. That Telharmonium device failed to meet popular favor and caused us to have some doubt about the possibility of the public desiring to hear music broadcast. We believe now that device failed to be popular because of the quality of the music and for economic reasons.

A printed record of the optimistic thoughts at that time on the possibilities of radio broadcasting is on page one, in column three, of the New York Times of February 14, 1909, entitled, "De Forest Tells of a New Wireless." The article states that it quotes from a speech which Dr. De Forest had given the night before at Fraunce's Tavern. The article reads in part as follows:

> "I look forward to the day when by this means (wireless phone) the opera may be brought into every home. Some day the news and even advertising will be sent out to the public over the wireless telephone."

Broadcasting with the arc type of continuous radio wave generators continued in various parts of the United States until unnecessary stations were closed by order of the Government when we went into the world war in 1917.

Early in the use of the arc it was apparent that the distance which could be reached was almost entirely limited by the amount of power that an ordinary telephone microphone could handle.[1,29] Also, the arc generator was lacking to a considerable extent in stability, making it not wholly desirable for telephone transmission. In addition, the arc was not well adapted for generating a considerable amount of power on the shorter wavelengths as used then, which waves are better adapted for the transmission of speech. The microphone, of course, was limited in the amount of movement that could be obtained for varying the power by the amount of energy which could be picked up from the sound waves in the air due to the voice or music. Therefore, it became obvious early that either a microphone which would regulate a very large amount of power compared to the amount of power in the air waves which were driving the microphone was necessary,[1] or else some device was necessary to amplify the sound frequencies or audio frequencies that could be obtained from the movement of an ordinary microphone driven by the ordinary air waves. This latter device proved to be the device which would make it possible to handle a greater amount of power; that is, an amplifier was provided[39] which would amplify the audio frequencies obtained from the microphone.

## Vacuum-Tube Amplifiers*

In 1911, it became fairly apparent that the vacuum tube, then called the "audion," could be used to amplify telephone currents and

* See reference 39.

this use of the vacuum tube as an amplifier gradually increased until in 1914, 1915, and 1916 they were not only placed on the market somewhat but were used considerably by the United States Government.

When this country entered the war in 1917, the government ordered various types of these vacuum-tube amplifiers in very large quantities and thereby produced an overstock of such amplifiers including the vacuum tubes which were a necessary part. Also, the war caused the govenment to train a very large number of people relative to radio subjects so that after the war was over there was an excess of amplifier material and an excess of people who were interested in radio. Amplifiers were manufactured to a very large extent during the war, and, of course, have been very highly developed since that time. These amplifiers were one of the very important factors in building up broadcasting.

The vacuum-tube amplifier as such and as a radio generator[40] was the largest contributing factor to the satisfactory use of the loud speaker, which is the conspicuous part of the broadcasting of the present day.

## Vacuum-Tube Continuous Wave Radio Generator

In 1913, or earlier, it was discovered that the vacuum-tube amplifier was not only capable of amplifying audio frequencies such as are used in telephone work, but was also capable of amplifying radio frequencies, and it was found that by taking some of the amplified radio frequency and feeding it back into the vacuum tube it was possible to make the vacuum tube become a continuous wave radio generator. The portion of the radio frequency which was not fed back could be used for radio signaling purposes and therefore was useful for that purpose. Also, it was found that such radio-frequency generators were capable of working well at wavelengths such as are suitable for radio telephony. Since Edwin H. Armstrong partially disclosed his results in discussion following a paper delivered before the Institute on December 2, 1914, there has been continuous activity in the development of vacuum-tube radio generators.[40] This use of the vacuum tube as a radio-frequency generator became quite noticeable by 1915 and 1916, and resulted in the manufacture of radio telephones which consisted of a combination of the vacuum-tube audio-frequency amplifier and the vacuum-tube radio generator.

In 1915, during the month of September, radio telephony was accomplished from the naval radio station at Arlington, Virginia, to Mare Island Navy Yard, California, using these vacuum-tube generators and vacuum-tube amplifiers.[16] That demonstration contributed indirectly to broadcasting development. That radio telephone experiment was also heard in the Hawaiian Islands and in France.

With the beginning of the war the government desired radio telephones, and therefore both the army and navy ordered the building of a large number of radio telephones comprising vacuum-tube amplifiers and vacuum-tube generators.[4] The number was far beyond the needs of the government at the close of the war; also, the close of the war found a large number of these radio telephones on ships and at other points. Even the sub-chasers were equipped with radio telephones and a great many of these radio telephones were actually used for broadcasting phonograph music just as the little arc phones had been used before the war. The type of radiophone, known as CW936 now on exhibition at the Smithsonian Institute, was a common example.

Our amateurs with their adventurous and pioneering characteristics that have done so much for radio took a great interest in these radio telephones.[57] Many of these amateurs were ex-service radio men.

### "The Broadcasters Were Phonograph Records"

The first broadcasting was nearly all by the simple broadcasting of the voice or by placing a phonograph in front of the microphone of the radio telephone whether that radio telephone was of the arc type or the later vacuum-tube type. In the years immediately following the war, particularly 1919 and 1920, a number of people apparently used the tube type of radio telephone to broadcast voice and phonograph music.[11] One of these persons was Frank Conrad who lived near Pittsburgh, Pennsylvania.[7,11] He broadcast phonograph music and the people of Pittsburgh became so impressed that the Westinghouse Electric and Manufacturing Company, at Pittsburgh, also became interested. In November, 1920, they obtained a United States government license to broadcast information and music. Because they obtained the first specific license for such a purpose, it is sometimes said to be the beginning of broadcasting; rather, it was the beginning of the ending of the opinion that broadcasting is child's play. Immediately after that time many other broadcasting stations using tube generators went into service. Our amateurs were the first audience.[49] Probably in all of the United States, 5000 amateurs were equipped to listen at that time. A great deal of the first advertising of radio receivers was directed at them; for example, the Westinghouse advertisements.[44,46] For a time the Westinghouse Company was the most prominent in broadcasting.[45] In the vernacular, the prestige of the Westinghouse Company sold the broadcasting idea to the public. The idea had existed for a long time. If the American Telephone and Telegraph Company had used their 1915 station for broadcasting they probably would have sold the idea five years earlier.

## Artists Broadcast

By the latter part of 1921 and particularly in 1922, artists were brought in to sing or play on instruments taking the place of the phonograph records. Artists, of course, had previously been used, for example when De Forest had broadcast Caruso's voice in 1909, and I have heard artists broadcasting and have seen them broadcast from the arc broadcasting station in San Francisco as far back as 1915 and 1916. Beginning about 1922 and continuing in increasing numbers to the present time, artists have been used for broadcasting purposes. The use of phonograph records for broadcasting purposes began to fall off in 1923 and the phonograph is less extensively used for broadcasting purposes at the present time, the effort being to provide the broadcast listeners with higher quality of music than could be obtained when the phonograph was used. Chain broadcasting instead of records has been employed more and more since 1923 to distribute the productions of distinguished speakers and artists over a wide area. However, specially cut records reproducing low notes and adapted for special release in approximately simultaneous reproduction at various stations are advocated at the present time.

## Improvement in Acoustics*

The next step on the part of broadcasters to provide the broadcast listeners with improved quality was in the improvement of the acoustics in the rooms or studios where the artists sang or played. It was soon found that the walls must be properly softened and draped to provide as good quality as can be provided from such artists and those improvements have been continuing up to the present time.

The softening of the walls was overdone at first by beginners, resulting in stronger low notes and too little reverberation for high notes. The stronger low notes were not apparent to the listener, however, because the common amplifier transformers did not pass them on to the loud speaker. The presence of people in the studio decreases reverberation; therefore, drapes are now shifted to offset the excess or lack of people in the studio.

* See reference 7, 18, 32, 41.

### Placing Artists†

It was also discovered that it is necessary to place the artists relative to the microphone, or the microphones, where a number were used, relative to the instruments in such a way that a proper balance of the music would be picked up, and to prevent blasting or overloading of the microphone.

### Care in Modulation

It was also found that considerable care was necessary in modulation of the radio carrier wave to prevent distortions and undesirable sounds being sent to the broadcast listeners and to decrease the shifting of carrier frequency. Since the putting into use of the master oscillator and power amplifier it has been possible to increase the modulation without changing the radio frequency, with the result that the relative service range has been increased with respect to the total power used and to the nuisance range of the carrier.

### Equalizing Audio Frequencies

After all of these efforts had been made to provide the broadcast listener with some satisfactory music, it was found that the audio-frequency circuits used in broadcasting discriminated against the higher audio frequencies, permitting the lower audio frequencies to go through with more power than the higher audio frequencies. Therefore, beginning about 1923 and continuing to the present time, various improvements in the equalizing of the audio frequencies have been put into effect so that the listener may get a better degree of fidelity from his radio receiver. Also, so that distortions or added interfering noises may not result, orchestra productions which may vary in power from a million to one are changed by controls to ratios of about ten thousand to one in the broadcasting circuits.

### Stabilizing Radio Frequencies

As early as 1923 it was found that it is necessary to stabilize the radio frequency of the station in order to provide better fidelity in the transmission of the mechanical or audio frequencies. Improvements in stabilizing the radio frequencies have been going on ever since and are being carried on persistently at the present time. Now the stations are controlled by standardized crystal oscillators, and the modulation is sometimes after the generation to provide more accurate radio frequency.[19,35,37]

† See reference 10.

The better transmitters are controlled by temperature-controlled crystals. Laboratory results indicate that crystal controls that can be held accurate to one cycle or better for the frequencies used in the broadcast band are practicable. It is expected that heterodyne squeals between stations in the same channel will be eliminated and practical synchronization may result from further accuracy in frequency maintenance.

### Geographical Relocation of Stations*

By 1925 it was found that a geographical relocation of some of the stations was necessary in order to provide densely populated districts with a good strength of broadcast signal without providing interference in the reception from other broadcast stations. Therefore, beginning in 1925, some of the stations which were formerly located in the cities, as for example in New York, were moved to less densely populated districts, and this practice is being continued.

### Average Broadcasting Power†

As will be seen in the chart, there is a curve indicating the average broadcasting power in watts used in the United States between 1907 and 1928. These powers were taken from the best available records, however, there has not been a uniform standard in power rating; therefore, this curve must be considered with that in mind.

In 1907 and up to about 1917 when the power was limited by the amount of power that could be handled by microphones, the actual transmitted power used for broadcasting was probably seldom in excess of one watt. At the present time the maximum power used for every day broadcasting is as high as 50,000 watts.

The curve of average broadcasting power indicates that the present average is over 1900 watts. According to government records there were still some small broadcasting stations in 1928 of no more power than were first used in 1919 and 1920, namely, of about five watts. Fair service broadcasting is roughly estimated by some at 5 watts for one mile, 500 watts for ten miles, and 50,000 watts for one hundred miles,[15] but five watts may be heard 1000 miles on a winter night and any amount of power will usually fade at one hundred miles, all of which causes confusion and misunderstanding on the part of the uninitiated.

Increasing the power not only gave stations greater ranges but it overcame or rode over noises due to atmospherics and other electrical disturbances. Where power has been increased it has contributed

* See reference 15.
† See reference 21.

materially to the quality that can be obtained from radio receivers. Also increasing power has frequently resulted in interferences such as heterodyne notes, cross talk in channels, and cross talk between channels.

While we are dealing with the United States only, it is well to mention that the rest of the world recognizes broadcasting and the value of power. For example, according to the Department of Commerce report for February, 1928, over 200 stations in the Eastern Hemisphere used more than 200 watts for broadcasting and nearly 30 stations in South America used over 500 watts.

### Number of Stations in Operation*

The curve showing the number of stations in operation shows that there were very few stations in operation from 1907 to 1917 when they were closed in 1917 by the war and a few again in operation in 1919, increasing in 1920 and jumping upward in 1921 and 1922 to over 500 stations and continuing at over 500 stations until in 1926 when the total number of stations, during that period, was kept fairly level by the United States government acting through the Department of Commerce. However, in 1926, the authority of the government practically broke down and there was a sudden increase in stations so that in 1927 there were over 700 broadcasting stations in the United States. The new law went into effect also in 1927 and stopped the rise at about 710. Since then the number has decreased to nearer 600 and under the November 11, 1928 allocation the number of stations on the air at the same time is decreased. As yet there is no apparent limit to the number who would broadcast if they could get permission.

On December 1, 1921, the Department of Commerce assigned broadcasting of music and entertainment to one wavelength, 360 meters, and the broadcasting of agriculture and weather reports to another wavelength, 485 meters.

From then on broadcasting expanded to take up nearly all of the little used band of waves between the amateurs at 200 meters and the distress wavelength at 600 meters.

On April 8, 1922, the Department of Commerce assigned class "B" stations to broadcasting on 400 meters. Class "B" stations were of 500 watts or over, and were not permitted to broadcast phonograph or other mechanical music.

On April 2, 1923, the 10-kc separation between broadcasting stations was put into effect, class "B" stations were placed on the waves from 300 to 345 and from 375 to 545 meters. Stations were left on

* See reference 21.

360 meters under the title of class "C." Class "A" stations of low power that broadcast phonograph music were placed on about 230 to 300 meters.

In about February, 1925, the band was widened by assigning stations as low in wavelength as about 205 meters, and in April, 1925, to as low as about 200 meters.

Since then the broadcasting band has settled down to from about 200 to 545 meters, or from 1500 to 550 kc. Of these frequencies, 730, 840, 910, 960, and 1030 kc are used by Canada only, while 580, 600, 630, 780, 880, 890, 930, 1010, 1120, 1200, and 1210 are shared with Canada; 690 is shared between Canada and the U. S. Naval station NAA, making a total of 90 carrier frequencies now in use in the United States for broadcasting music, entertainment, etc. The assignment of stations to clear and common channels has changed until since the zone requirement of the Act of 1928 (amending the Act of 1927) went into effect, only one station at a time has been allowed to operate on each of forty frequencies at night, while from two to twenty-five stations have been permitted to operate at one time on the other fifty frequencies.

The increase in power was brought about by the demand for not only the kind of broadcasting service that would enable a listener to hear a broadcasting station, but would enable the listener to get good quality reproduction from a broadcasting station.[37] The number of stations provided all over the United States and in the United States possessions enabled practically all of the people in the United States and in its possessions to hear a broadcasting station, the quality depending somewhat upon the amount of power of the station and the distance from the station. Increasing power has always apparently contributed to improvement of quality up to at least seventy miles from a station. Beyond seventy miles the quality or the entire signal may be lost at times due to fading. Fading may occur over much shorter distances at times. If receivers were suitable and enough wavelengths were available, a good distribution of high quality could be obtained by placing high power stations over the entire country about 100 miles apart; but that is an ideal that seems to be far from the practical possibilities.

## Chain Broadcasting

In providing quality by the use of famous artists it was found that the greatest number of such artists are available near the theatrical centers of the larger cities, and that it is more expensive or sometimes impossible to take them to out-of-the-way broadcasting stations.

The theatrical centers of large cities did not prove to be the normal place to locate the broadcast transmitters. Therefore the studios were constructed and located to suit the artists and connected to the broadcasting stations by wire lines.

Owing to fading and noise levels of man-made interference, and atmospheric interferences, it has proved impossible up to the present time to build a sufficiently powerful broadcasting station to give consistently good quality over any large portion of the United States. Therefore, exceptionally good artists are collected at one studio and a number of broadcasting stations in different parts of the United States are connected by wire lines to that one studio. That method of furnishing the program from one studio to a number of stations is called "chain broadcasting." The successive stations and intermediate wire lines make up the chain.

This "chain broadcasting" started seriously in 1923 and has increased until there are several such chains in operation now, with sometimes thirty or more stations on one chain. In 1927 as many as 69 stations, using 28,500 miles of wire, were said to have been used in one chain broadcast.[36] One chain broadcasting system is said to have had at the end of 1928 sixty-three broadcast outlets and 14,800 circuit miles of wire.

"Chain broadcasting" in which the stations transmit on the same frequency has been in operation for about five years, with two stations WBZ and WBZA at Springfield and Boston, Massachusetts.

All of the foregoing steps were toward not only the distribution of broadcasting but very largely, if not chiefly, toward the production of better quality for the greatest number of broadcast listeners.

## Reception

In the matter of broadcasting development there are, of course, two ends to the broadcasting. One is the transmission end which we have been considering and the other is the reception end which we will now consider.

The type of receiving apparatus is very important to the quality and strength of the sounds delivered by the loud speaker. The latter gives out to the best of its ability what is received, and poor reception should not be blamed on the speaker. Poor reception due to faults ahead of the speaker cannot be improved by the speaker to any great extent.

## Novelty

From 1907 to 1917, and from 1919 to 1922, listening to broadcasting was largely a matter of novelty, the novelty of receiving music from out of the air and the novelty of receiving music or speech from very great distances. Many of the early listeners were not particularly interested in the music or in anything the broadcaster said except what he said about the location of his station. Listeners desired to receive from as great a distance as possible, and from as great a number of stations as possible. However, all of that novelty did not wear to the present time. It reached its peak in the winter of 1924 and 1925, and the matter of receiving great distances or numerous stations no longer appeals to relatively as great a number of people. The clearing of forty channels on November 11, 1928 made more long distance reception possible with the result that such reception increased somewhat during recent winter months. Many novelty hunters and pioneers are now looking forward to television to provide a thrill.

### Quality

As early as 1922 there was some apparent desire for quality broadcast reception rather than an interest in the novelty of the thing. That desire for quality has continued steadily until the desire for quality is now the common desire on the part of the broadcast listeners in the United States.

### Appearance and Convenience

There was, of course, a desire particularly on the part of women for good appearance of the radio receiving apparatus and a desire for radio receiving apparatus that was convenient. And the convenience has reached quite a high point particularly during the years 1926, 1927, and 1928. The single control receiver and the receiver that operates from the lighting circuit are far more convenient than former receivers.

### Crystal Detector and Telephone Receivers

In the early broadcast reception, back in 1907, and continuing to 1922, the simple crystal detector and telephone receivers were used. With the advent of considerable broadcasting, they increased in numbers reaching a maximum in about 1922 and 1923, and then decreased until at the present time comparatively few of them are used. With such an arrangement the reception was limited to one or two people listening with head telephone receivers.

### Regenerative Detector and Telephone Receivers

Also, in the arc broadcasting, as early as 1914, and until the time of the war and in the tube broadcasting after the war, the regenerative tube and telephone receivers were used. Their use reached a peak in about 1923 and since then has gradually fallen off. The regenerative detector and telephone receivers were probably the most efficient method of receiving broadcast from the standpoint of the ratio of attainable distance to the amount of power and apparatus used. However, the regenerative receiver spoiled the quality of the sound. As used, it frequently favored low notes and frequently produced interference in other receivers.

## Audio Amplifiers*

Audio amplifiers were used before the war and after the war, but did not come into great active use until slightly after the activity in the rejuvenated broadcasting in 1921. But those early amplifiers were best suited to amplifying only one or a few audio frequencies, such as the 1000-cycle note used in telegraphy. Their use has been on the increase since that time, both in numbers used and in the quality of the amplifiers used. Audio amplifiers are primarily for giving power in the output circuit of the receiver. It is this power that makes the use of a loud speaker possible.

## Radio Amplifiers†

During the war there were developed some radio amplifiers and various forms of these were used for the reception of broadcast when broadcasting became active after 1920, but they did not come into general use until the latter part of 1923. Their use increased steadily until now practically all radio receivers contain radio amplifiers.

## Reception of Distant Stations vs. Reception of Local Stations

As was said before, the first era in popular broadcast reception was that of novelty and of listening to distant stations. This reached a peak in the winter of 1924–1925, and has decreased. In 1922 many believed that broadcast listeners would lose all interest in a short time because they recognized nothing but novelty in broadcasting.[48] Lack of quality and lack of financial support were also frequently prophesied for future broadcasting. Reception of local stations was, of course, per force, what was done in the early broadcasting before the war, and beginning about 1922 the reception of local stations has steadily increased, inasmuch as reception of local stations was preferable to listening to distant stations, the quality being so much better. Therefore, we have a steady increase in local station reception where people are so situated that they can listen to local stations. Any station over

* See reference 39.
† See references 43, 47, and 65.

70 miles away fades. Also, a radio circuit which will pick up stations over a long radius will pick up the atmospheric disturbances within that radius. Chain broadcasting is a result of the desire to listen to local stations.[36] A large part of the rural population listen to distant stations either because there are no local stations or because there are no satisfactory local stations. Many metropolitan listeners can receive only local stations because their receivers will not cut out the locals and bring in the distant stations.

### Volume Output

The volume output of the receiver was very small from 1907 to 1922; after 1922 the increase in power of the transmitting stations occurred and the use of radio and audio amplifiers became effective. By the combination of the increase of transmitted power and the use of radio[43] and audio amplifiers in the receivers it has been possible to obtain a much higher volume output.

### Horn Speakers*

With the possibility of obtaining a higher volume output so that it was no longer necessary to listen to a broadcast by clamping the head telephones to the ears, the horn type loud speakers came into the market in greater numbers.[46] Such speakers have existed for a number of years,[28] for example, in railway stations for announcing the arrival and departure of trains and for such special uses. Those same types of horn speakers were then put into use as broadcast loud speakers, and continued to be widely used up to about 1925, since when there has been a decrease in the amount of their use. The horn speakers gave cavity sounds due to the horn. Also, the diaphragms used in the horn speakers were usually of metal or mica and therefore gave metallic or sharp sounds. The early horns themselves were metallic, which contributed to the metallic sounds. The bi-polar telephone receivers used with horns rectified the sounds to some extent, making false higher sounds and spoiling lower sounds.[54] The horn speakers concentrated the sound in one direction, which was not entirely satisfactory for reception of broadcast at any part of the home. The horn speakers were more or less unsightly and were objected to from the standpoint of their appearance. Most of the cabinet or console type of radio receivers made before 1928 contain horn speakers but their unsightliness is covered up. Some of the horn speakers which were carefully designed and were of considerable length gave very satisfactory results; however, their size (6 to 8 feet in length, with a bell opening of 30 to

* See references 53 and 54.

40 inches in diameter) rendered them impractical for the general radio user.[53] At the present time, some people prefer the older type of horn speakers because they do not muffle the high notes and harmonics as much as the later forms of speakers with softer diaphragms. They are used for high quality extensive public music and voice as in talking pictures of the Vitaphone and Movietone systems,[33] and public address systems.

## Hornless Speakers*

Hornless speakers were put into use as early as 1921, and began to be popular in about 1925. Their popularity has continued up to the present.

The early hornless speakers were not as sensitive as the horn speakers, and therefore did not give sufficient volume until the output of the broadcast stations and the amplifying power of the radio receiving sets had been increased. They, therefore, came in at a time when the improvement in the quality of the output of radio receivers had been considerably increased. The bi-polar type of driver with its distorting effects was not so applicable to them; therefore, its defects were not inherited by the hornless speakers as a rule. The moving coil or "dynamic" driver was one of the first used in loud speakers for radio reception, but it did not become popular until the recent advent of more available power. The condenser type of speaker has been repeatedly offered and now shows some likelihood of coming into use.

## Ratio of Atmospherics and Noises to Broadcast

Noises are not eliminated by the structure of the loud speaker when the speaker is capable of reproducing a reasonably satisfactory portion of the musical scale. A high quality broadcast without noises when fed to many forms of speakers gives some pleasing results.

Broadcasts are not only spoiled by improper transmission of sound or audio frequencies, but they are spoiled by interferences such as static or atmospherics which are due to natural electric discharges in the atmosphere, and also by interferences caused by sparking on electric circuits for motors, lights, etc. By increasing the power of the broadcasting stations the ratio of the strength of the interferences due to atmospherics and other similar noises has been greatly reduced in localities not too far removed from the high powered broadcasting stations. The noises have been so overridden by the increased power of broadcasting stations with high modulation that even in the summertime in some parts of the city of New York there are only a

* See references 59, 60, and 61.

few times in which atmospherics interfere with the quality of received broadcast to such an extent that the listener shuts off his receiver.

### Amateur, Commercial, and Government Interference*

Another form of interference which was annoying in the early popular status of broadcast reception was that due to amateurs who were sending on spark transmitters. However, the amateurs largely of their own accord[48,52] beginning in 1922, through their organized methods rapidly discontinued the use of such transmitters until now we have practically no interference from that source. The commercial and government spark and arc stations also produced interference. There is still some interference from commercial spark stations on ships. The sibilant and transient characteristics of spark and arc interference made them more apparent as a rule from the hard diaphragm used in horn speakers, than from the softer muffling type of paper hornless speakers.

### Oscillating Receiver Interference

Another form of interference was prevalent in the forepart of the popular broadcasting era beginning in 1921; that was due to oscillatory receivers. The regenerative type of receiver was often so adjusted that it oscillated, thereby becoming approximately a 1-watt transmitter which produced a squeal in other receivers. That has been gradually discontinued since the latter part of 1925.

### Electric Light and Power Line Interference†

The interference from power and lighting lines, x-ray machines, etc., has been decreased somewhat since 1925, due to protests on the part of the public.

### Resistance Coupling in Audio Amplifiers‡

Since the beginning of popular broadcasting and the use of audio-frequency amplifiers, there have been used what is known as resistance coupled amplifiers. These amplifiers when properly constructed do not discriminate to a detrimental extent against any of the sound or audio frequencies, and therefore in themselves do not spoil music. However, they do not amplify as much as the transformer coupled amplifiers. Therefore, transformer coupled amplifiers were used mainly in the beginning when there was not so much power to amplify, but it soon

* See reference 71.
† See reference 71.
‡ See references 43, 67, 68, 69, and 70.

became apparent that they were spoiling the quality of the music as received by the broadcast listener. Early transformers were copied after transformers which had developed to pass the spark and arc telegraph note, or pitch, of about 1000 cycles. They had not been designed to handle the musical scale. The manufacturers of resistance coupled amplifiers informed the broadcast listeners that the transformer coupled amplifiers did not reproduce the bass notes of the music, nor did they reproduce the high notes as satisfactorily as they should. At the same time the listeners were informed that resistance coupled amplifiers reproduced all notes equally well. Therefore, beginning in 1923 and reaching a peak in 1925, the resistance coupled amplifiers were put into considerable use by people who wanted better quality in their broadcast reception.

## Increase of Plate Voltages

It was found that the vacuum tubes could not be used to produce the desired loud sounds with the voltages that were being used on the "B" battery circuit, without distortion. Lack of low notes, rasping sounds, and changes in pitch resulted from this distortion. By increasing the "B" battery voltages more power was delivered to the loud speaker with less distortion, and therefore since 1925 there has been an increase in the plate voltage.

## Parallel Tubes in the Last Stage of the Audio Amplifier

Even with the increased plate voltage it was found there was still some distortion; therefore, in 1926 and 1927 two tubes were used frequently in parallel in the last stage of the amplifier as a further attempt to get enough distortionless power for the loud speaker.

## Improved Audio Transformers

By the beginning of 1926 all of the manufacturers of audio-frequency transformers had seen from the growing popularity of resistance coupling and large transformers that it was necessary for them to improve their transformers so that better reproduction could be obtained through the audio-frequency amplifier. Accordingly they put on the market improved audio-frequency transformers using a greater amount of iron, a better quality of iron, and more suitable windings to transform audio-frequency currents without the former undesirable distortion which had been obtained when using such transformers. The general improvement has been very noticeable.

## Elimination of Regeneration

In 1926 and 1927 it also became apparent that the use of regeneration in receivers intentionally or unintentionally was detrimental to the output of sound obtained from the receiver; therefore, more active steps were taken to do away with all regeneration, careful shielding[56] of coils from each other, neutralization, phase shifting, and various other arrangements and methods were employed to prevent the low, hollow sounds and heterodyne squeals due to regeneration.

## Power Tubes in Audio Amplifiers

Since it had been found that paralleling tubes were desirable to get better quality, new tubes were designed called audio-frequency output tubes or power tubes to be used in the last stage of the radio apparatus. These handle a sufficient amount of current to operate the loud speaker at more volume and with less distortion due to the tube. These higher power tubes came into active use beginning the latter part of 1926, and are continuing to the present time as a noteworthy factor for increasing quality.

## Radio Circuits for Better Audio Reproduction*

At the first of the year 1928, some public attention was given to improved radio-frequency circuits which will receive all of the radio frequencies involved in a broadcast transmission sufficiently well to better preserve the quality of the music. This is called broad band reception. It is intended to receive all the radio frequencies produced by one station equally well so that the higher notes and harmonics will arrive at the speaker in proper force. Also band reception of this type is intended to exclude all other frequencies such as crosstalk from adjacent channels, thereby reducing interference. There is need for great improvement along those lines and along the lines of making receivers that will cover the entire broadcasting band uniformly.

## Push-Pull Transformers in Audio Amplifiers

For a number of years there has been used an arrangement of transformers for the last stage of audio-frequency amplification called the push-pull, which when properly constructed and used with the proper tubes has been very beneficial in producing high quality music. This arrangement has come into service considerably in 1928 to improve the quality of broadcast reception.

* See reference 38.

## United States Radio Conferences

Related to the apparatus both in transmission or reception, other means have been used to improve the quality of broadcast reception. For example, in 1922, 1923, 1924, and 1925, Secretary Hoover of the Department of Commerce called a conference of people engaged in all phases of broadcasting and people listening to broadcast for the purposes of trying to control the broadcasting so that more satisfactory results could be obtained by the broadcast listener.

## Defiance of United States Authority

That conference action benefited the transmission and reception of broadcasts but was discontinued in 1926 because a broadcaster in Chicago defied the United States authority and used a wavelength not authorized. When the Department of Commerce brought suit the courts upheld the action of the broadcast station, thereby curtailing the power of the Department of Commerce.

## New United States Radio Law and Federal Radio Commission*

The matter of delivery of satisfactory high quality broadcast to the listener was of such importance that the 69th Congress in 1927 passed a new radio law intended to correct the weakness of the government and enable the government to aid the public in obtaining satisfactory radio service, and furthermore, for that purpose a special Federal Radio Commission was appointed. The chief inspiring objective of that law and of a large part of radio and acoustical engineering of the past twenty years has been to deliver to all broadcast listeners all notes of the musical scale at their proper strengths, without interference.

The following is an extract from a report of the Federal Radio Commission:

> The passage of the radio act of 1927 presented a situation without parallel in the history of American executive departments. A wholly new Federal body was called into being to deal with a condition which had become almost hopelessly involved during the months following July 3, 1926, when it had become clear that the Department of Commerce had no authority under the 1912 radio law to allocate frequencies, withhold radio licenses, or regulate power or hours of transmission. The new law itself was, of course, totally untested, and the Federal Radio Commission was called upon to administer it with no clear knowledge as to the limitations which might be created by subsequent court action.
>
> The act embraces the whole field of radio communication, but public interest was concentrated almost wholly on the single section of it

† See reference 73.

devoted to radio broadcasting. The problems of point-to-point radio communication, of radio-telegraphy, of marine wireless, of power transmission, etc., though of vast importance, did not present such an urgent need for immediate action as the utter confusion within the broadcasting band. Public opinion assumed that the prime purpose of the law in creating the Federal Radio Commission was the immediate establishment of a sound basis, in the interest of the radio broadcast listener, for the orderly development of American broadcasting.

For this reason the work of the Federal Radio Commission from its first meeting on March 15, 1927, up to June 30, was devoted almost exclusively to clearing up the broadcasting situation. With the physical capacity of the available channels, or wavelengths, already far exceeded by the number of stations actually in operation, and with no provision in the law for the Federal acquisition or condemnation of broadcasting stations in order to reduce the total number, the commission found it necessary to evolve some plan whereby, without any unconstitutional exercise of arbitrary authority, the listening public could receive more dependable broadcasting service, and whereby a gradual and orderly development could be counted on to bring about a progressive reduction in radio interference.

The following record, taken largely from the orders and bulletins of the commission, outlines the steps whereby this plan was evolved and put into execution. These steps were, in brief, four: First, the determination of the best scientific opinion through a series of public hearings; second, the internal organization of the commission, handicapped as it was by lack of funds, to handle the enormous amount of documentary material which was required; third, the protection of the broadcasters against liability for unlicensed broadcasting until a suitable basis for the new licenses could be worked out; and, fourth, a complete new allocation of frequencies, power, and hours of operation for all of the existing 732 broadcasting stations to provide adequate local separation and a basis for the gradual elimination of distant interference.

Under the radio act of 1927 the Federal Radio Commission was formally organized on March 15, 1927, as follows:

Rear Admiral W. H. G. Bullard, of Media, Pa., commissioner from the second zone, chairman; Judge Eugene O. Sykes, of Jackson, Miss., commissioner from the third zone, vice chairman; O. H. Caldwell, of New York, N. Y., commissioner from the first zone; Henry A. Bellows, of Minneapolis, Minn., commissioner from the fourth zone; Col. John F. Dillon, of San Francisco, Calif., commissioner from the fifth zone.

Sam Pickard, chief of the radio division, Department of Agriculture, was engaged as acting secretary when the commission was organized. Mr. Pickard was made permanent secretary on April 20, 1927.

### Assignment of Commissioners

Chairman Bullard took direct charge of the radio stations in the second zone, embracing Pennsylvania, Virginia, West Virginia, Ohio, Michigan, and Kentucky.

Commissioner Sykes took charge of the third zone, embracing North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee, Mississippi, Arkansas, Louisiana, Texas, and Oklahoma.

Commissioner Caldwell took charge of the first zone, embracing Maine, New Hampshire, Vermont, Massachusetts, Connecticut, Rhode Island, New York, New Jersey, Delaware, Maryland, District of Columbia, Porto Rico, and the Virgin Islands.

Commissioner Bellows took charge of the fourth zone, embracing Indiana, Illinois, Wisconsin, Minnesota, North Dakota, South Dakota, Iowa, Nebraska, Kansas, and Missouri.

Commissioner Dillon took charge of the fifth zone, embracing Montana, Idaho, Wyoming, Colorado, New Mexico, Arizona, Utah, Nevada, Washington, Oregon, California, Hawaii, and Alaska.

Due to the lack of funds, the commission was forced to open its offices at the Department of Commerce, where Secretary Hoover provided a suite of rooms formerly occupied by the Bureau of Navigation. It was possible to engage only a small office force, and it has been necessary to economize in every possible way.

When the Federal Radio Commission was inaugurated it found a chaotic condition prevailing in the radio field, for after Government control broke down in 1926 many broadcasters jumped their waves, seeking more desirable channels, regardless of their existing occupants. Even the channels reserved for Canada were appropriated, and split frequencies were used, with only a slight separation of from 1 to 5 kilocycles in many instances.

The problem confronting the commission was to try and bring order out of chaos by placing the 732 broadcasting stations on 89 wave lengths, so as not to create serious interference. The first act of the commission was to continue in force all radio amateur and ship licenses issued by the Department of Commerce and all coastal, point to point, technical, training, and experimental radio licenses, in order that attention might be concentrated on the pressing problems within the broadcasting band.

### Public Hearings Helpful

For the purpose of providing opportunity for the presentation of general suggestions by the public and by qualified experts as to the methods for reducing interference within the broadcasting law, at its first meeting the commission arranged for a series of public hearings for March 29 to April 1, inclusive.

The subjects assigned for discussion were: Broadening the broadcasting band, limitation of power, reducing frequency separation, simultaneous broadcasting with the same frequency, chain broadcasting, division of time, consolidation of broadcasting service, limiting the members of broadcasting stations, and general discussion.

United opposition to widening the broadcasting band in order to accommodate more stations was expressed at the hearings by representatives of the radio art, science, and industry. Diverse views were presented regarding limitation of the power output, with the general opinion prevailing that this should be determ ned on the basis of area to be served by the respective stations. Stout opposition was registered also against reducing the frequency separation between channels from 10 to 7 kilocycles, while chain broadcasting in the main was indorsed. It was agreed that a division of time by stations is absolutely necessary to relieve to some extent the congestion on the ether channels.

## Modified Radio Law*

In 1928 the radio law of 1927 was modified by the 70th Congress in a further attempt to provide quality broadcasts for all, and particularly to provide equality in the different possessions, territories, states and zones, proportioned according to population, and to continue all of the authority of the Federal Radio Commission.[1]

## Part II

## Route of Radio Broadcast from Studio or Auditorium to Loud Speaker Showing Co-relation of Elements which Necessarily Function to Render Satisfactory the Sounds Emanating Therefrom

In the history of broadcasting development we must consider the route traversed by the modern broadcast to appreciate the steps of development and the obstacles that have been removed to bring out satisfying currents of musical frequencies of sufficient power from the present day radio receiver. For this purpose a chart entitled "Route of a Radio Broadcast" (Fig. 2) has been prepared. The route is mapped out through named squares connected by arrows, plain arrows for audio frequencies and feathered arrows for radio frequencies. Indicated by an asterisk at the bottom of the chart are listed the kinds of vehicles the broadcast uses many times in its journey. Also at the bottom of the chart, indicated by a dagger, are listed some of the causes of detrimental results which produce sounds unsatisfactory to the listener.

### Broadcasters

In the upper left hand square of this chart we have portrayed the normal broadcasters. Broadcasters as here considered are complicated. They consist of wind instruments which have a sound pitch varying from 43 to 4608 sound cycles per second; stringed instruments which vary in pitch from 40 to 3072; the human voice which varies in pitch from 80 to 1,152, and the kettle drums which vary from 85 to 170. In addition we have harmonics of those broadcasters which may vary in pitch up to as high as 20,000. In the history of broadcasting development the first broadcasting by radio could not carry the human voice; all it could carry was code signals, short and long buzzing sounds. The second stage broadcasting could carry the human voice, but that was not sufficient for broadcasting as we now know it. The aim of broadcasting as we now know it is to carry faithfully music which has a range, as we will see by comparison in this first square, far

* See reference 74.

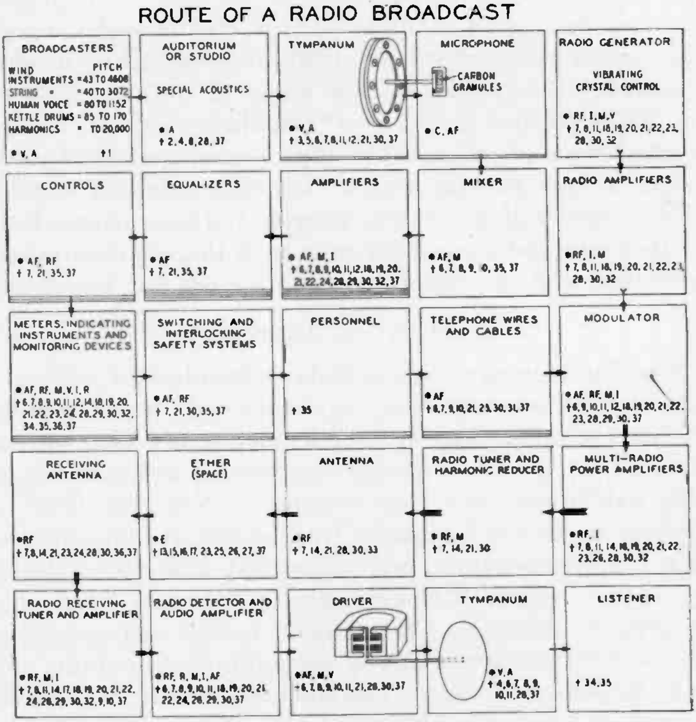


Fig. 2

* Broadcast Vehicles: A—air waves; V—vibrating solids; C—carbon compression and expansion; AF—pulsating or alternating audio current; RF—pulsating or alternating radio current; M—pulsating or alternating magnetism; I—pulsating electron stream; R—rectified current; E—ether waves. 2A, 5V, 1C, 30AF, 12RF, 25M, 25I, 1R, 1+E.

Results which have made broadcast reception unsatisfactory:
W—weakened or lost notes
E—exaggerated notes
D—distorted notes
D—added noises or notes
F—fluctuations

† Some of the causes of the above detrimental results:

1. orchestra characteristics (these may result in W, E, or D of the above unsatisfactory results)
2. sound reflection and absorption (W, E)
3. position of microphone (W, E)
4. sound phase interference (W)
5. damaged microphone (W, N, F)
6. audio-frequency discrimination (W, E)
7. loose parts (N, W)
8. natural periods (E, W)
9. non-uniform impedance (E, W)
10. non-uniform losses (E, W)
11. amplitude limitations (W, N, D)
12. over modulation (D, W, F)
13. radio fading and interference (F, W, N, D)
14. radio-frequency discrimination (E, W)
15. amateur stations (N)
16. government and commercial arc and spark stations (N)
17. oscillating receivers (N)
18. "A" battery faults (N)
19. "B" battery faults (N)
20. "C" battery faults (N)
21. poor connections (N, W)
22. tube noises (N)
23. power and light line disturbances (N)
24. regeneration (E)
25. station heterodyne (N)
26. harmonic heterodyne (N)
27. ratio of atmospherics and noises to broadcast (N, W)
28. detrimental mechanical capacity, magnetic and conductive couplings (N, D)
29. failing batteries (W)
30. leaking insulation (N)
31. induction to pick up lines (N)
32. "A," "B," and "C" battery eliminator variations (N)
33. shifting carrier wave (W, F, D)
34. listener's characteristics (W, E)
35. inexperience and inattention (W, E, D, N, F)
36. local interference and absorption (W, N)
37. cross talk (N)

beyond the range of the human voice. It has been development along the lines of repeating all of the notes or pitches in such a range that has given us our present degree of quality in broadcasting transmission and reception. The broadcast of the winter of 1907 and 1908 was the "Merry Widow Waltz" played by a "His Master's Voice" phonograph into a telephone microphone. The microphone was in series with the antenna of the broadcasting station. The radio generator was the little arc. The listener with his crystal detector and head phones heard the tune of the music and some of the notes from that simple arrangement. Compare that with the complications of present day broadcasting.

### The Studio or Auditorium

In this diagrammatic route of today's broadcasted pitches, notes, or audio frequencies, as they may be termed, they travel from the first square into the auditorium or studio which is provided with special acoustics including walls of special construction and including special movable wall drapes and floor coverings. Not only must certain fundamental notes and harmonics be produced at different strengths to make music satisfactory, but where that music is produced in a room a certain amount of reverberation is necessary. Reverberation is due to many reflections. It augments sounds and prolongs them. Part of the reverberation occurs in the auditorium or studio and part occurs in the listener's home. The amount that occurs in the studio, auditorium, or home depends on the walls, floors, and ceilings of the room and upon the number of people in the room. Also microphones must be so placed in the studio or auditorium that they are not at the focus of augmented notes or weakened notes or where they will be blasted by too much volume. With a definite microphone location the artists must be placed at proper relative distances and the acoustic drapes on the walls shifted to suit the number of people and the locations of the instruments. All of which makes the acoustics a complicated problem requiring considerable material and skill.

### Tympanum

From the auditorium or studio the sound passes in air waves to the tympanum of a broadcasting microphone. While a broadcasting microphone appears to be about 6 or 7 inches in diameter as seen from the outside, the actual tympanum which picks up the energy from the sound waves in air is only a metal disk about 1-1/2 inches in diameter.

### Microphone

The vibrations of that metal disk are transmitted to the actual carbon microphone in the next square through a short connection to the movable compression agent of the carbon microphone. There are, of course, other forms of microphones than carbon microphones, such as the condenser microphone; however, the carbon microphone is the most common form of microphone and is, therefore, the one indicated here. The microphone actually consists of two cells containing carbon granules, one on each side of the tympanum so that the carbon granules in one cell are being compressed while the carbon granules in the other cell are being relieved of compression through the vibration of the tympanum. This alternate compression and release of the mass of carbon granules varies the flow of a direct current which we will term "audio-frequency current." The microphone changes the sound waves to audio-frequency current.

### Mixer*

That audio-frequency current passes downward to the next square marked mixer. The mixer is the device for bringing together the audio-frequency currents from several microphones. In the broadcast of music and speech it is sometimes necessary to use several microphones distributed at different points about the auditorium or studio in order to pick up a balanced output of sound or to make it possible to bring the various sounds to the mixer where they can be balanced by proper adjustments of the various elements in the mixer. All of this is done for the purpose of producing satisfactory sound quality for the listener.

### Amplifiers*

From the mixer we pass to the next square, which is marked amplifiers. It will be noticed that this square and some of the other squares in the route contain more than one line at the bottom of the square. The multiplicity of lines at the bottom of the square indicates that the devices which those squares represent are used at more points in the route than are shown in this chart.

Amplifiers in this case and in this particular location mean audio-frequency amplifiers. Amplifiers consist of a succession of vacuum tubes which amplify the power successively, and those amplifiers are sometimes coupled together by transformers which may increase the voltage. To avoid distortion of sound frequencies amplifier tubes are sometimes coupled together by resistances or inductances which do not amplify the voltage but are simply serving as a means of coupling the output of one amplifying tube to the input of another tube.

### Equalizers*

From the square indicated as amplifiers we next pass to the square indicated as equalizers. Equalizers are arrangements of conducting

* See reference 72.

paths which make up for the loss of sound frequencies that has occurred in the preceding circuits, particularly if those preceding circuits have included comparatively long lines of conductors such as telephone wires and cables or complicated auditorium or studio wiring.

### Controls*

From the equalizers we next pass to the controls which occur in several places in the route, and which in some cases are set more or less permanently, while in other cases they are continually operated by trained personnel. The extreme variation of power from music is often too great to be repeated along the route of a radio broadcast, particularly if that route includes long wire lines as in chain broadcasting.

For example the fainter sounds in a piece played by an orchestra may be weaker than ordinary voice power as used in speaking, or say less than five microwatts. A crescendo may be equal in power to five watts. The power ratio is a million to one, but to prevent the weak sounds from falling below the noises in wire lines and the loud sounds from being distorted in amplifiers it may be necessary to change the ratio of one million to one to a ratio of ten thousand to one. This is accomplished by an expert control operator who allows weak audio frequencies to pass along to the amplifiers and shunts off part of the more powerful audio frequencies so they are not amplified to the same extent before they reach the radio transmitter.

### Meters, Indicating Instruments, and Monitoring Devices*

We next pass to the square which indicates the existence of meters, indicating instruments, and monitoring devices that are used at numerous points in the route both of audio frequencies and radio frequencies. By the use of such devices the personnel are able to manipulate the controls and re-adjust equalizers to preserve the music qualities of the broadcast.

### Switching and Interlocking Safety Systems*

We next pass to the square which indicates the switch and interlocking safety system that is used at several points in the route and in connection with apparatus involved in the route to prevent errors and to make it possible to transfer rapidly from one broadcast to another, thereby contributing to the continuity of radio broadcasting for the better satisfaction of listeners.

### Personnel*

In the next square is listed the word personnel for the reason that personnel is such an important element at many points in the broad-

* See reference 72.

casting route. To make the devices repeat the broadcast satisfactorily and to make up for any obvious errors requires continual attention.

## Telephone Wires and Cables*

In the next square is listed telephone wires and cables. In the subject of radio broadcasting the word radio appears so prominently that we sometimes overlook the fact that much of radio broadcasting is not in the handling of radio circuits and radio frequencies but is in the handling of audio circuits and audio frequencies. As we have shown in the first square, audio frequencies vary from about 40 to about 5,000 per second as fundamentals and have added to them a large number of harmonics which run to a higher value than 5,000, even to audible frequencies as high as 20,000. It is these harmonics that contribute what we call naturalness to sounds. In the route of radio broadcast there may be an almost unbelievable number of repetitions of audio frequencies. For example, a radio broadcast may be picked up, as it often has been, in Washington, D. C. where the United States Marine Band is playing and the President is speaking. Although it is picked up in Washington it may be broadcast from a broadcasting station in Seattle, Washington, in which case the broadcast actually travels from Washington, D. C. to Seattle, Washington, through the cables and wire lines of the telephone company. The common practice in the wire telephone transmission of these audio frequencies is to put them through amplifiers and equalizers very frequently in order to make up for the unequal transmission of the different audio frequencies by such wires and cables and to keep the broadcast music at a power level sufficiently above the noises that may be picked up by the wires along the line. These amplifiers and equalizers are used about every twelve miles in cable transmission, and at about every 250 miles in open wire transmission. Therefore, between such distant points as Washington, D. C. and Seattle, Washington, a great many equalizers and amplifiers have to be used in the attempts to reproduce good quality at the ultimate radio receiver.

It has probably been noticed by many that when broadcasts are picked up at a distant point the quality of those broadcasts as reproduced from a station is not so good as the quality of broadcasts which are picked up in the nearby studio of that station. That is largely because the transmission lines from distant points have, to some extent, damaged the quality of the broadcast more than the quality of the broadcast is damaged between the nearby studio of the station and the actual broadcasting station.

In nearly all cases at the present time, considering each high

* See reference 72.

powered local broadcasting station, the actual broadcast is not picked up at the radio broadcasting station itself but is picked up at a studio or auditorium distant from the broadcasting station and comes to the broadcasting station through telephone wires or cables.

### Audio to Radio

We now come to the radio power of the broadcasting system. All that has been said heretofore has related to the audio part of the broadcasting route. In modern high quality broadcasting stations, the audio frequency is not brought into contact with the radio frequency at the actual radio generator itself. That is one of the changes which has been made in recent years to improve the quality of the broadcast.

At first the audio frequency was brought directly to the radio generator, but it was found that the superimposing of the audio frequency on the radio generator circuit changed the radio frequency of the carrier. The radio-frequency carrier is the fundamental radio frequency of the radio generator. When the frequency of this carrier was changed the radio waves in travelling from the station to the broadcast receiver were also changed in frequency and produced a fluctuating or noisy effect at the radio receiver output.[55] To reduce the fluctuation in carrier frequency some stations under-modulate the carrier. That does not entirely cure the defect, and it produces a smaller music range relative to the nuisance range of the carrier. The separate radio generator with power amplifier has been under development since 1921, but is not as yet universally used.

### Radio Generator and Radio Amplifiers

Therefore, the radio generator is indicated in the square at the upper right hand corner where the carrier radio frequency is generated and from which it passes to a square below where that one frequency is amplified through a succession of amplifiers. Thence it passes to the modulator and joins the audio frequencies. For holding constant the carrier frequency to prevent fluctuations and noises, to prevent heterodyne notes between stations on the same frequency, and to comply with the law, the radio frequency is controlled by a vibrating quartz crystal or checked against such a crystal frequently. Temperature-regulated crystal-controlled transmitters can now hold very accurately to their assigned frequencies.

### Modulation

When the carrier radio frequencies and the audio frequencies join they produce, in effect, a number of radio frequencies equal to twice the number of audio frequencies.

If the audio frequencies which have been brought from the studio cover frequencies from 40 to 5,000 or, we will say, a total of 5,000 cycles, then from the modulator a total of 10,000 radio frequencies and a carrier radio frequency pass to the next square, which we call the multi-radio power amplifiers.

### Multi-Radio Power Amplifiers

As the name indicates, these are very powerful amplifiers designed to amplify the 10,000 or more radio frequencies.

### Radio Tuner and Harmonic Reducer*

From these amplifiers we pass to the next square marked radio tuner and harmonic reducer by a large arrow indicating much more power. The purpose of this arrangement of circuits is to pass all of the 10,000 or more radio frequencies that are necessary for the production of higher quality audio frequencies for the listener, and to eliminate harmonics of the radio frequencies, more particularly harmonics of the carrier frequency which can produce interference in the reception of broadcasts from other radio stations. The radio harmonics are also confined by screening radio circuits and by the use of other harmonic absorbing circuits.

### Antenna

From this square we pass to the antenna of the broadcasting station in which all of the radio frequencies are produced and which radio frequencies in turn produce waves that pass out in the ether indicated in the next square.

### The Transmitting Medium

The ether or space does not always offer one constant path for all of these radio frequencies. Reflections frequently occur in the ether which jumble these radio frequencies so that the effect of some or all of them is decreased, producing what we call fading noises or simple fading that shows itself in a weakening of the received signal at the radio receiver. At a distance of 70 miles and over, every station fades as a rule. Sometimes the fading is noted even by the ear for shorter distances.

### Receiving Antenna

Through the ether the waves arrive at the next square marked receiving antenna, in which they set up the 10,000 or more radio fre-

* See references 35 and 37.

quencies and from which antenna or square we pass to the radio receiving tuner and radio amplifier.

### Radio Receiving Tuner and Amplifier

The purpose of this tuner is to receive those 10,000 radio frequencies, and to exclude higher and lower radio frequencies from other stations. If that tuner and amplifier does not receive all of the 10,000 radio frequencies equally well or amplify all of them equally well, then the final output of music will be distorted. No transmitter or receiver is ideal to the extent that it handles all of the radio frequencies equally well in broadcasting and receiving the musical scale. Some of the most recent developments and one of the most recent tendencies is to so design the radio receiver and the radio transmitter that they will transmit the 10,000 or more radio frequencies more nearly equally well than they have in the past because they are obviously somewhat lacking in that respect and therefore even our best reproduction is lacking in fidelity for that reason.[38] At the same time there is a growing need for more selective receivers.

### Radio Detector and Audio-Frequency Amplifier†

From the square of the tuner and amplifier we next pass to the square indicating the radio detector and audio-frequency amplifier. The radio detector is a rectifier which cuts off the upper or lower half of 10,000 or more of the radio frequencies carrying the 5,000 or more audio frequencies in which by doing so in effect changes those radio frequencies into approximately the original 5,000 or more audio frequencies. The audio frequencies are then amplified by the audio-frequency amplifier, which consists of a succession of two or more tubes coupled together by resistance coupling or transformer coupling. If the resistance coupling is used and carefully built it will couple the amplifiers together and transfer the audio frequencies without much distortion.[67] Up to within about the last two years transformers were commonly so constructed that they did not transfer the lower notes satisfactorily and due to capacity leakage did not transfer some of the high notes satisfactorily. Therefore, considerable distortion of the music was the result. The tendency now is to use high quality transformers and also to use tubes in the audio-frequency amplifier which can handle all of the current necessary to deliver a considerable amount of power in the form of more faithfully reproduced music. The tubes heretofore used have sometimes been limited in their ability to handle faithfully a considerable amount of power, therefore,

† See references 67, 68, 69, and 70.

they distorted the output of the radio receiver. The use of better transformers and higher power tubes has produced a very noticeable increase in quality during the last two years.

### Driver

Passing from the radio receiver we come to the driver of the loud speaker. The driver herein shown is what is usually called the balanced armature type. An armature is balanced between magnetic poles and the armature is surrounded by a winding which carries the output of a radio receiver, the audio frequencies from the radio receiver serving actually or in approximate effect to change the direction of the magnetism of the armature and cause it to alternate back and forth between the poles. The armature itself is a little rod of iron supported at its center on a torsion spring, and the results the device will reproduce depend somewhat upon the natural period of the torsion spring and the natural period of the iron armature. Also, the end of the armature is connected by stiff wire or rod into the next square where the other end is connected to a tympanum.

### Tympanum

The tympanum is in contact with the air, and its movement driven by the movement of the armature moves the surrounding air, producing the sound heard by the listener. The output is more or less affected not only by the natural periods of the torsion spring, and the magnets and the armature, but is also somewhat affected by the natural period of the connecting arm and by the natural period or periods of the tympanum. If the armature is off center between the poles some rectification, distortion and false harmonics result.

Late 1927 and 1928 speakers use a different driver known as the dynamic type. This dynamic type was in use in the loud speakers of 1920 and 1921. It required powerful permanent magnets or an electromagnet which required power, making it comparatively expensive. In 1920 and 1921 it was attached to a flat or corrugated diaphragm or tympanum and horn. Now it is attached to a small conical diaphragm or tympanum and a baffel board or box. With the driving coil mounted directly on the diaphragm the vibrations of such solids as the torsion spring, the armature, and the connecting wire are eliminated.

### Listener

In the next square we indicate the listener, who is the ultimate consumer of the broadcast. The original audio frequencies were produced and judged by ear, were changed to radio frequencies, then back to audio frequencies, and are now again judged by ear. The listener has become more and more critical of quality since 1922; he has had to learn a great deal. The ear is far from a perfect instrument.[63] Harmonics of a low note frequently give the impression that the low note is heard when it is not present.[62] The ear itself is a modulator.[64] These and other ear characteristics combined with lack of knowledge of what has caused distortions have caused many false impressions. But the listener still continues to learn; with increasing knowledge he requests better quality.

## Broadcast Vehicles

The commonly used term for the main radio frequency of the broadcast transmitter is "carrier." That is, the main radio frequency of the broadcast transmitter is called the carrier frequency. Since in the transmission of a broadcast the carrier frequency is not the only thing that carries the broadcast, I have called the other things "vehicles." For example, in the studio the first "vehicle" is air waves, also from the loud speaker to the listener the last "vehicle" is air waves. At the microphone we have the vibrating solid tympanum, and in the driver and in the connections of the driver to the tympanum of the final loud speaker we also have vibrating solids. Therefore, vibrating solids are listed as a "vehicle." The standard frequency crystal of the radio transmitter is the pacing vehicle of the radio generator. In the microphone we also have carbon compression and expansion, which is one of the vehicles. The varying pressure in the carbon changes a current of electricity which may appear there and at other points as pulsating or alternating audio-frequency current. Therefore we consider pulsating or alternating audio current as another vehicle. In the same way the many pulsating or alternating radio currents which are used in the various radio stages of the radio transmitter system are considered as another vehicle.

In various couplings between audio-frequency circuits and in couplings between radio-frequency circuits the inductive method of coupling is frequently employed, in which case these frequencies are not current frequencies but are pulsating or alternating magnetic frequencies. Therefore, pulsating or alternating magnetism is considered as another vehicle. In the vacuum tubes we have a different form of current known as the electron stream, wherein electrons leave the hot filament of the vacuum tube and travel to the cold plate of the vacuum tube. This electron stream is termed another vehicle. Then at the radio receiver we have a detector producing rectified current, in which that process of rectification acts as another form of vehicle. Then, of course, we have the vehicle of the ether waves. All of these different vehicles are preceded by a key letter. *A*, for example, is for air waves, etc., which key letters are incorporated in the above squares indicating the place in these squares in which these various vehicles are used.

Following the list of vehicles at the bottom of the chart, we find the figures and letters, for example, 2-*A*, 5-*V*, etc. That is meant to indicate that in a normal broadcast these various vehicles may be used a considerable number of times. For example, in a normal broadcast 2-*A* indicates that air waves will be used twice; 5-*V* indicates that the broadcast will pass through vibrating solids 5 times; 1-*C* indicates that it will pass through carbon compression and expansion once. 30*AF* indicates that the broadcast is in the form of audio-frequency currents in wire circuits condensers, etc., as much as 30 times; 12 *RF* indicates that the broadcast is in the form of radio-frequency currents as much as 12 times in succession; 25-*M* indicates that the broadcast may be in the form of alternating or pulsating magnetism as much as 25 times in succession in the same broadcast; 25-*I* indicates that the broadcast may be in the form of electron streams as much as 25 times in succession in the same broadcast. 1 R indicates that the broadcast is detected or rectified once; 1 plus *E* indicates that the broadcast may be in one or more paths of ether waves at the same time in one broadcast.

Farther down towards the bottom on the left of this chart are enumerated some of the results which have made broadcast reception unsatisfactory in the past and which have through all these years been more or less gradually and partly eliminated. For example, the letter *W* indicates weakened or lost notes. The letter *E* indicates exaggerated notes. The letter *D* indicates distorted notes. The letter *N* indicates added noises or notes. The letter *F* indicates fluctuation.

Below that list are listed a number of the causes of the detrimental results just referred to. The list includes 37 causes which have in the past produced unsatisfactory output from the receiver, and which have had to be minimized or eliminated to bring broadcasting to its present degree of quality in reproduction. Following each of these numbered causes are letters in parenthesis referring to the results which have made broadcast reception unsatisfactory. For example, in the cause listed after 10, in the list of causes, we find letters (*E*, *W*). 10 indicates that a cause of unsatisfactory broadcasting is non-uniform losses; of the (*E*, *W*) the *E* refers to exaggerated notes, and the *W* refers to weakened or lost notes. They are the result of non-uniform losses. We find in the squares above that 9 appears in numerous squares. For example, in amplifiers and in the square marked telephone wires and cables. The losses in telephone wires and cables are greater for the higher audio frequencies than for the lower audio frequencies; therefore, the higher audio frequencies are weakened and the lower audio frequencies, considering the matter the other way, are exaggerated. This has been somewhat overcome, of course, by the use of equalizers and is being better overcome by improved equalizers. All of the numbered causes refer to the different squares showing where those causes have interfered in the past and in some cases where they interfere at present with the proper reproduction of radio broadcasts. The tendency of course has been, and still is, to remove those causes or to control them so that they cannot interfere with proper reproduction of broadcasts.

## Part III

### Possible Future Developments

The trend of past developments as indicated in the charts and their descriptions presumably points to some of the trends of future developments.

The trend from the beginning to the present has been to improve the quantity, variety, and quality of what the listener may hear, together with improvements in the convenience and appearance of the listener's apparatus.

### Power

The effects of "static" or "atmospherics," the bugaboo of radio, have been the continual subject for elimination without appreciable success in broadcast reception. In broadcasting, their comparative effects have been steadily reduced by using more power at the broadcasting station, thereby riding over the static noises. Weakening of signals in daytime and summer has also been offset by using more power.

Fading at a distance of seventy miles or more has gradually come to be a recognized characteristic in broadcasting. By the use of more power at the stations, and recently by the use of automatic volume controls, the intelligibility of broadcasts have been improved. Those things indicate that more power will probably be used in the future.

The continual increase of power used by broadcasting stations from year to year is one of the conspicuous features of broadcasting development.

At present the average broadcasting station power is nearly 2 kw. If the increase should continue as in the past the average might be 10 kw and the maximum power might be 500 kw in less than five years.

Both broadcasters and broadcast listeners ask for more power. The broadcast listeners ask that their favorite stations be given more power so that more satisfactory results may be obtained. The broadcasters ask for more power so that more people can get satisfactory results from their stations, thereby influencing more people to listen to them.

There is more to recommend great power and increase of power for stations in cleared channels than for stations operating in the same channel with other stations. However, when stations in the same channel are brought to so nearly the same frequency that heterodyne squeals are not heard, or are not disagreeable, the increase of power in these channels may be less objectionable.

Where stations on the same frequency are operated on the same program, as they may be in the future, still more power can probably be used with less objectionable features than now exist with weak stations on the same frequency.

Altogether it seems that the predominant natural demand and possibilities point toward more power both as to average power and as to maximum power.

### Selective Receivers

Related to the amount of power and number of stations, as indicated by the curves, is the matter of cross-talk. Fig. 2 also indicates the places in the route where cross-talk exists.

One kind of cross-talk has existed because one microphone picked up what happens in two studios, or the wires from studios were unintentionally coupled together and fed two programs to one broadcast transmitter. Such cross-talks have been decreasing, and it is expected that they will be almost entirely eliminated.

The other more common and detrimental kind of cross-talk occurs in the ether or space as the number or power of stations is increased. The extent to which such cross-talk comes from the listener's loud speaker depends upon the locations of the broadcasting stations relative to the listener, and upon the selectivity of the listener's receiver as modified by the frequencies and powers of the stations when the listener has his receiver tuned to a station on a cleared channel. Other complications, such as the peculiarities of the listener's locations, the time of day, and time of year, enter into those matters.

When the listener is tuned to a station that is transmitting on the same frequency on which other stations are transmitting, the cross-talk possibilities may be further complicated, depending on his location.

There are over 600 broadcasting stations, about 5,000,000 square miles of non-uniform territory, and over 50,000,000 listeners involved in this. The listeners in rural and metropolitan United States and Canada want cross-talk reduced.

Since 1922 the Department of Commerce and the Federal Radio Commission have tried to reduce such cross-talk to a satisfactory minimum by changing the locations, frequencies, and relative powers of broadcasting stations. The continued results indicate that such cross-talk cannot be reduced to a satisfactory minimum by such methods. Something else evidently must be done. It is apparent that more selective receivers are required. The cross-talk is bound to be in the ether or space; receivers that will select what is wanted are required.

Cross-talk between stations in the same channel must be reduced to as satisfactory minimum as is possible by regulating the power and location of stations or by synchronizing the stations on the same broadcast, but the cross-talk from stations on other channels is evidently chiefly the problem of receiver manufacturers.

The background of past development and present conditions indicate that the receiver of the near future should be a very selective bandpass receiver. From this consideration of the past and present, it appears that the responsibility for cross-talk between channels will lie principally with the manufacturers of receivers, and that cross-talk will be greatly reduced or eliminated by them.

## Measurements

The trend of development has repeatedly brought up such questions as what is effective power and what is service range, indicating the need for better standards and more measurements locally and at distances. That condition should prophesy the wide extension of volts-per-meter and other measurements.

## Harmonic Reduction

The power increases in broadcasting and the expansion of radio to the higher frequencies have pointed out the necessity for eliminating harmonic radiation. The indications now are that such harmonics can and will be materially reduced.

## Audio Engineering

It is a conspicuous part of the development indicated in both charts and in their descriptions that radio broadcasting is a part of radio engineering, wherein audio engineering is very important. A radio broadcast is first audio, then radio, and then audio. For future improvement the audio must improve as well as the radio.

In that connection, it is interesting to our members to note that the word "audio" as applied to frequencies and engineering was coined and standardized by the Standards Committee of this Institute in 1913.

### The Microphone and Loud Speaker

From the very beginning of broadcasting efforts have been made to improve the input microphone and yet that device, although still in need of improvement, has probably changed less than any other element. The terminal device, now the loud speaker, a powerful counterpart of the microphone, has not improved as much as expected. That history may indicate some future radically different audio devices to take their places.

### More Channel Space for Audio Frequencies

Running through the chart Figs. 1 and 2, is continued development to produce "quality" or "fidelity" or "faithful reproduction" for the ear of the listener. That trend of development may be expected to continue.

Part of our available music, to be natural and satisfactory, must contain harmonic frequencies that are higher in frequency than 5,000 cycles. When audio frequencies above 5,000 cycles are broadcast from a station the radio-frequency band of that station is over 10 kc wide, therefore that station's radio frequencies encroach on the next channel to produce cross-talk. Therefore, the desire and effort to produce higher quality may result in an effective demand for widening the channels.

To widen the channels has become more and more difficult in recent years of broadcasting development, due to the increase in radio uses below 550 and above 1,500 kc, and due to the demands for places on the existing 10-kc channels.

This condition may result in the often talked of single-sideband and carrier transmission which only requires a band width about equal to the highest audio frequency that is transmitted, instead of twice that frequency as at present. Such single-sideband and carrier transmission would have room in the present 10-kc channels to carry as high as the second harmonic of the highest fundamental frequencies in music.

### Reduction of Heterodyne Interference

Through all radio broadcasting development and other radio development, accurate and stable frequencies have been a goal that has been steadily approached. In 1913, it was considered a laboratory feat to measure a frequency to within 0.5 of 1 per cent and frequencies were only required to be exact to within about 10 per cent. Now radio laboratories claim to be able to hold frequencies to 0.00002 of 1 per cent, and broadcasting stations claim to be able to hold their frequencies to 0.001 of 1 per cent or better.

The time has apparently arrived when it is practical for broadcasting stations to hold their frequencies to within 50 cycles of a given frequency, and the time has also apparently arrived when the government checking agencies are capable of checking such frequencies sufficiently accurately and fairly rapidly in any part of the United States through the Bureau of Standards equipment and the checking equipment of the Radio Division of the Department of Commerce in its several districts.

This situation of being able to hold and check frequencies accurately, and the development within the recent years of high modulation seemingly predict the elimination of heterodyne squeals that have been characteristic in the channels where two or more stations are transmitting in those channels.

High modulation reduces the heterodyne or nuisance range of a station relative to its service range. In effect, that can mean the reduction of the strength of the heterodyne.

Holding two stations in a channel to within 50 cycles of the same frequency means that the heterodyne note will be lower than 100 cycles. The audio-frequency circuits of radio receivers and the loud speakers are usually comparatively inefficient at such low frequencies and the ear is not sensitive to such low frequencies,—therefore such low heterodyne frequencies are far less disturbing in effect than have been the irritating heterodyne squeals.

Since over half of the present broadcasting channels are occupied by more than one station at a time and since over 80 per cent of the stations are in those channels, decreasing and eliminating heterodyne disturbance in those channels would be a high percentage improvement of great advantage to the broadcaster and to the listener.

## Speculative Possibilities

Relay broadcasting, using for example high frequencies to reach great distances with a minimum of atmospheric interferences and a multiplicity of such frequencies to balance fading effects, whereby a broadcast might be sent around the world and be picked up for rebroadcasting by local stations, has been foreshadowed to some extent in the development up to the present.

Broadcasting of moving pictures to some extent is prophesied from the results of past developments. Even the transmission of talking pictures is prophesied. Considering the limitations to available wavelengths that have been developing, it seems that the most practical method would be in taking the moving pictures rapidly, transmitting them more slowly, and then reproducing them rapidly.

## Opportunity to Promote Rapid Development

Fig. 1 indicates the continual demand for more broadcasting stations. The number of stations continually increased in the past except where they were curbed by the Department of Commerce and later, after that curb had failed, were curbed by the Federal Radio Commission.

Between the failure of the curb by the Department of Commerce and the establishment of the Commission there was a decided increase.

Although the curb on increase by the Commission has been in effect for two years and should be well known, daily attempts are made to add other broadcasting stations. If that curb was suddenly removed there might be as many as 3000 applications for stations within 30 days.

The demand for more broadcasting stations and the desirability and undesirability of more broadcasting stations can be discussed in more ways than we have space for. However, I would like to bring out one point as to how that demand should affect broadcasting.

The demand for more stations may not result in many more stations, but it may result in continuous and comparatively rapid improvement of the stations that are permitted to broadcast. In other words, it may work out that the broadcaster will be required to make his station as good as possible, or get off the air, and let somebody on who will make a good station.

If the demand is viewed and acted upon in that light, then we may expect it to produce better broadcast engineering and better programs.

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| 70 | The Testing of Audio-Frequency Transformer-Coupled Amplifiers, by H. Diamond and J. S. Webb | Proc. I. R. E. | 15 | 9 | 1927 | Sept. | 769 |
| 71 | Interference, by R. H. Marriott | Proc. I. R. E. | 11 | 4 | 1923 | Aug. | 375 |
| 72 | Broadcast Control Operation, by Carl Dreher | Proc. I. R. E. | 16 | 4 | 1928 | Apr. | 498 |
| 73 | Annual Report of the Federal Radio Commission | U. S. Government Printing Office | Year ended June 30, 1927 | | | | |
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## Discussion on
# RADIO DIRECTION-FINDING BY TRANSMISSION AND RECEPTION*

(R. L. SMITH-ROSE)

**Stuart Ballantine:**[1] Dr. Smith-Rose's use of the reciprocity theorem and critical discussion of its validity in connection with the "night effect" interested me very much as I have often had occasion to put it to the same use. As a point of minor criticism I should like to point out that in the form in which this theorem was originally given by Sommerfeld[2] and in which it has been reproduced in this paper by Dr. Smith-Rose, it cannot be legitimately applied to direction-finding systems. Sommerfeld's statement was that if an antenna $A_1$ radiated a certain average power and was received by a second antenna $A_2$, the electric force at the receiving antenna would be the same as it would be if observed at $A_1$ with $A_2$ radiating the same power. J. R. Carson has recently pointed out to me that this statement is valid only for antennas in free space (e.g., at a considerable distance from all conductors such as the earth) which behave as simple dipoles. Carson's criticism is just and the correct statement, as given by him,[3] is as follows: If an impressed force acts in a branch of an antenna $A_1$ and the current in a branch of a second receiving system $A_2$ is observed, this current will be equal to that which would be observed in $A_1$ with an equal impressed force acting in $A_2$. In this form the theorem is applicable to the direction-finder system. Fortunately, the conclusions of Smith-Rose's paper are not affected by the use of Sommerfeld's theorem, and are obviously supported by the proper theorem.

This theorem is particularly useful in thinking about direction-finders and may perhaps be employed to explain some of Dr.Smith-Rose's difficulties with the obscured minima which he observed with the rotating beacon installation. According to the reciprocity theorem the signal received on a vertical antenna from a rotating transmitter coil is precisely the same as that which would be received by the coil if the vertical antenna were transmitting. From 1917 to 1920 I had the opportunity, while engaged in the development of the rotating coil radio compass for the U.S. Navy, of studying the latter situation in some detail. It was discovered that the environs of the coil, refraction at the coastline, currents on land lines, and so forth, destroyed the simple plane wave from the transmitter and produced at the coil an elliptical rotating field (magnetic). When you rotate a coil in such a field the signal does not disappear but merely goes to a minimum. I found that the minimum could be cleared by deriving an e.m.f. of proper phase from the antenna action of the coil by means of an artificially produced electrical unbalance of the capacities to ground, and neutralizing the residual signal by this e.m.f. The device used for this purpose was called a "compensator," and was independently invented in France at about the same time (1917) by Commandant Rene Mesny. The amount of unbalance required for perfect compensation was found to vary with the azimuth. It should be remarked for those who have not had the opportunity of specializing in this subject, that compensation simply clears the minima of signal and permits accurate bearings to be taken; it has nothing to do with the elimination of the "deviation" or azimuthal error of the compass, which is due to the part of the field in phase and is generally unaffected by compensation. The deviational errors are generally evaluated by calibration.

* PROC. I. R. E., 17, 425; March, 1929. Presented before New York meeting of the Institute, February 6, 1929.

[1] Boonton Research Corporation, Boonton, N. J.

The important point here is that the amount of compensation required for a perfect minimum varies with azimuth. In the case of an installation on a battleship the variation is considerable, so great in fact that we found it desirable to actually use an auxiliary antenna for the compensating e.m.f. rather than to depend upon the relatively feeble antenna effect of the coil. In the case of an installation on flat homogeneous land free of surrounding conductors, the compensation required is not only small but varies little with the azimuth; nevertheless some variation is generally present in the ordinary land sites.

We may conclude from the reciprocity theorem that if we find it necessary to have a compensator on a recieving loop which varies with the azimuth, we must do the same thing when using the loop as a transmitting beacon and receiving the signals on an ordinary vertical antenna; otherwise the minima will not be clear at all azimuths. I did not understand from the paper that such arrangements had been made. I wonder if Dr. Hull had any conversations with Dr. Smith-Rose on this point.

**L. M. Hull:**[4] Yes, I believe there was a definite attempt to vary the compensation. It was not mentioned in the paper. It was automatic in this sense; that it was carried out by varying the spacings of the various wires which were strung up around the loop, to produce an antenna effect which varies with the azimuth. Dr. Smith-Rose told me that although he thought the idea was good, the work had not been carried to a successful conclusion.

**Stuart Ballantine:** It seems to me that the necessary variation of compensation could be secured by means of some mechanical contrivance, such as a cam system, similar to those we used with the receiving coils.

It is of course understood that all this relates to ordinary transmission in the absence of night effects. This is perhaps the most important condition.

**A. Hoyt Taylor:**[5] I take it that the reciprocity theorem was called upon by the author merely to support his claim that the "night effect" would produce similar types of errors and of the same order of magnitude by either the transmission by beacon or reception by loop, and I believe that particular conclusion is unaffected by Mr. Ballantine's criticism, except possibly the magnitude.

**Stuart Ballantine:** It may also be remarked that the same deviations that would be observed if the rotating beacon transmitter were used as a receiver will be present when it is used as a transmitter. This would seem to require the calibration of the station and publication of the necessary corrections. According to our experience with the fifty or sixty coastal radio compass stations which were erected from 1918–1920 by the Navy these deviations (maximum values) may range from 1–10 deg., depending upon the site.

**A. Hoyt Taylor:** It is, of course, possible that the British experiments were nearly always made under conditions as nearly ideal as possible; that they just failed to reach idealism in the case of the installation of that loop by having a different radiation resistance in one direction than in the other owing to the proximity of the water on one side and not on the other. That alone may have caused small changes which would account for the beacon variation, because they apparently did not have a master oscillator transmitter. We know from work we have done that we would have to be extremely careful of coupling with

[2] *Jahr. der Draht. Tel. und Tel.*, 26, 93, 1925; Ballantine, Review of Current Literature, PROC. I. R. E., 16, 513; April, 1928.
[3] PROC. I. R. E., 17, 952; June, 1929.
[4] Radio Frequency Laboratories, Boonton, N. J.
[5] Superintendent, Radio Section, Naval Research Laboratory, Bellevue, Anacostia, D. C.

any nearby conductors. The question is whether we are dealing with variations of the transmitter or of the received signal.

I might mention one or two things that occur to me. One is that the thing which is most difficult to get rid of in the way of direction-finding error is the so-called "night effect." Personally, I don't like that term at all because it occurs altogether too frequently in the daytime. I believe I was one of the original discoverers of it, and it is true that I discovered it at night, but it is due to components of the wave coming down from the Kennelly-Heaviside layer with horizontal electric polarization. This can occur during the daylight hours also, so I hope you will get another term for this than "night effect."

It might be well to analyze very briefly the conditions under which we may expect the "night effect" to occur. For want of a better word, we will continue to call it "night." Evidently when your incoming radiation arrives at a low angle with the horizon, the state of polarization will make very little difference in your compass reading. Suppose a wave is arriving from a horizontal direction; then if your loop is set squarely across that oncoming signal with a minimum for the vertical component, the horizontal components will also cancel out. It is only then when the horizontally polarized component has a velocity in the vertical direction, which means only when the wave comes in at an angle with the horizontal, that you get this effect.

If we look over the radio-frequency spectrum, we can, I think, draw certain conclusions as to when we may expect this "night effect," so-called, to be most aggravated. Without going into the reasons for it, we may say that on very long-wave reception we have excellent reasons for believing that the major portion of the energy arrives at relatively small angles with the horizontal. The angle of "come down" is not very far from the horizontal. According to that, bearings taken on long-wave transoceanic stations should show relatively small errors of this type. The fact is that they do show enormously smaller errors than the same stations will show at moderate distances. At distances of 100 miles or so, you get this effect at a maximum for long-wave stations, because the energy which has come down from the layer arrives at a relatively high angle with the horizontal. Such polarization as exists in the horizontal plane therefore has a strong component of its velocity in the vertical. Thus we find that the short distance long-wave stations, as borne out by the curves that were presented here, have the greatest errors due to this cause. Frequently, complete reversals or complete rotations of 360 deg. occur, as I myself observed in the winter of 1919, and so reported, incidentally, with the correct analysis of the cause of this as being due to polarization.

Suppose we go to the other extreme of very high frequency. Supposing we go up to 20 megacycles. Under every condition that we have been able to analyze excepting some rather special but not very frequently occurring cases, we find that 20-megacycle transmission from a distance also arrives at relatively low angles, generally 10 to 20 deg. from the horizontal. We might infer from this that here also would be a region where we might hope to get very good bearings, but such is not necessarily the case. In the case of very long waves arriving at a low angle, it is practically impossible for a horizontal polarization to progress along close to the surface of the earth for any considerable distance without that horizontally polarized component being completely absorbed, but in the case of a very short wave it is possible for this component to come a long distance and actually arrive at our receiver, because the antenna structure is a much larger fraction of a wavelength above the earth. So the two extremes of the spectrum give us under ordinary conditions low angle, good direction-finding, but at the high end of the spectrum there is still much difficulty from horizontal polarizations because it can exist and follow along with the wave even when it is only a few feet above the surface of the earth. Short-wave horizontal polarizations are also more readily reflected from the surface of the earth and the water, and so we have difficulty even with the low-angle stuff on the very high frequencies, though not as much difficulty by any means as we have with the fairly low frequencies and the fairly high angles.

Another point is as to the minimum distance at which you can get these so-called "night effects." I don't agree with the paper as to this minimum distance. It cannot be stated definitely because it is quite evidently a function of the normal range of the ground wave to the station, and that in turn is a very decided function of the frequency on account of the variable absorption of the ground wave; so that that is a matter depending entirely upon the frequency of the transmission and varying according to more or less well-known laws. We can say in general that the "night effect" will be small when we are within the normal ground wave range of the station and the ground wave predominates against the sky wave, and we get fairly good minima, with blurrings of the minima here and there due to a little sky wave.

I do not agree with Dr. Smith-Rose's statement that in the broadcast band large errors are seldom noticed at the distance mentioned in his paper, because I have personally observed variations as high as 30 deg. On a well compensated loop functioning on WRC in Washington at a distance of less than six miles, they don't occur very often, but we do occasionally during the dark hours get large deviations of apparent direction with a simple loop. I imagine those conditions vary a good deal in different parts of the world.

There is one thing I would like to bring out a little more fully than Dr. Hull did, in regard to the Adcock system. The Adcock system is as much less sensitive in pick-up, roughly speaking, than the ordinary loop, as the loop itself is than the ordinary antenna; in other words, it is a differential on the signal from two dipoles, or two doublets, as we call them nowadays, which would perfectly neutralize each other, except that the vertical component of polarization has a phase difference from one direction to the other, and it is only by virtue of that difference in phase—a geographical phase difference if you please—that we get any signal at all. It means, therefore, that to get the best results on the Adcock system we shall have to do exactly what we did in the old days, which I am sure Mr. Ballantine will well remember, when we tried to adapt ordinary receivers, such as had been giving good service on vertical antennas, to loop reception. We had to have recourse to various expedients, such as oscillating receivers on spark reception with a horribly bad note, in order to make them sensitive enough to function on a loop. Radio receivers—thanks to amplification, and so forth—have been tremendously improved so that ordinary loops, even in aeroplanes, are capable of giving us really tremendous signal strengths, but it looks now as though again we shall have to go very much further in receiver sensitivity in order to get the best possible results with the Adcock system. The system itself is, in my opinion, decidedly the best thing there is for eliminating the horizontal component of polarization and permitting a bearing on the vertical components alone.

Dr. Hull pointed out that there was difficulty in attaining the requisite sensitiveness on the very long waves. For the intermediate band of frequencies he stated that they had carried out a great many experiments, probably because they were able to use the superheterodyne principle or something of that sort, to obtain a very high degree of amplification.

One place where we need this Adcock system more than anywhere else is in the high-frequency band. Unfortunately, receiver design is somewhat up in the air today as to just what we shall do to get the necessary multiplication of ten or one-hundred fold in sensitivity, which you ought to have to get first-class results with the Adcock system in the very high-frequency band. It is a problem that radio engineers ought to be thinking about. Because you have high-frequency receivers which will pick up all kinds of disturbances, like automobiles and aeroplanes at several miles' distance, doesn't mean you have enough yet to give us the best we need for this type of directional work. You must remember that the sensitivity of such a proposed receiver would be low to disturbances as to actual signals, so that the signal ratio would not be unduly increased by the higher sensitivity over what we have in the higher frequency receivers today.

There is one other matter upon which I believe I differ a little from the author. He refers in one place to the proposition that it is quite generally believed that radio energy mostly travels along a great circle connecting the transmitter with the receiver. Well, I think it is generally conceded for almost the entire radio spectrum that most of the energy does travel along a great circle distance connecting the transmitter with the receiver, but certain scattering effects are being observed these days. Certainly what we know of the Kennelly-Heaviside layer and its perturbations would indicate the extreme likelihood of lateral deviations of the sky wave which will permit them to come in from really different directions than the true bearing or great circle bearing of the transmitter, so that instead of stating, as the author does, that deviation from the true great circle bearing is not to be worried about until we get above 6000 kc, I would be rather fearful that it might have a considerable influence on conditions even at 1000 kc. I have an idea that the choice of system, in this country at least, is going to work out with the preference for ship navigation in favor of having the compass on board the ship, but for commercial air navigation it is probably going the other way, with a preference in favor of the beacon system because of the simplified radio gear which the aeroplane can carry under those conditions. I believe, however, that it will be a long time before our standard coastal station installations will be abandoned. They will probably be used for many years to come.

There is one point that I would like to see discussed further. When I did that work in the Navy back in 1919 on so-called "night errors," we concluded that the region of 375 kc was about ideally located for radio compass work because at the normal ranges where you would be called upon to take compass bearings, between 100 and 200 miles, the sky wave effect is not very large compared with the ground wave effect, and so fairly good bearings are generally possible. We actually examined continuous wave transmission down to 900 meters and we found even on continuous waves less error from horizontal polarization on that wave than we did on much longer waves. Practically all of the experiments made by the Navy and by the Army showed a much larger error on CW transmissions than they did on spark transmissions, and we attributed that to the breaking up of phase relations and the failure of the phase angles and polarization angles to hold definite sequence so as to form a definite pattern at the loop. What the so-called "night effect" would do with the spark signal was merely to blur the minimum, but not distort it enough as in the case of CW where you could have definite patterns produced with sequence of phase. That conclusion was confirmed by some of the earlier English work, I believe, where they made some comparisons between ICW and CW, but I note that Dr. Smith-Rose says that there is no practical difference between bearings as obtained by continuous wave and by interrupted wave. That statement seemed so contrary to what we actually obtained in practical tests, and to the earlier general opinion on that subject, that I should like to be further informed about that. Perhaps Dr. Hull had some conversation about that with Dr. Smith-Rose.

**L. M. Hull:** I have nothing further on that point, except that I can state that this view was very definitely corroborated by Dr. Smith-Rose's answer to a question which I asked him on that point.

**A. Hoyt Taylor:** I think that was very curious because we did quite a lot of work on spark signals as compared with CW and we thought we observed a very definite difference between the two and the Army's work by Kinsley up at Houlton, Maine, on the spark signals used in Europe or on Arlington signals— the old spark signals with which you set time with the 100-kw spark set— gave the same result, and also some work that the Army did down on the Mexican border on Mexican stations that they were observing down there in the 5000-meter band gave similar results. So that it doesn't seem quite logical to me that there should be no difference at all between the two methods. I should expect the ICW signals, where the phase relationship was interrupted from time to time, to show quite a difference. I wouldn't expect much difference on modulated CW but on isolated or interrupted CW, I would expect it.

**Lester Jones:**[6] With respect to directional variations with radiation on spark signals and ICW signals, I have the impression that a probable partial explanation for it is the following: Where observations were made on spark signals the receivers had to be adjusted to a lesser degree of sensitivity because the spark transmitters generally put out more energy than the ICW transmitters. Where the receiver is more sensitive, as with ICW there is more possibility of having variable feedback between receiver and loop. This would give rise to a variation of sensitivity in the receiver and would introduce a slight error which would be variable depending upon the position of the operator's body and the exact amount of regeneration used in the receiver. I would give a little more shift to the ICW system than to the spark system.

In one of the tests I made, care was taken to eliminate all traces of reaction from the receiver to the loop, which completely eliminated the possibility of this secondary error. This showed that there was no difference between spark and ICW direction shifts. I remember in the beginning of our tests it was very easy to get a secondary error on account of residual feedback from the rotating loop.

**A. Hoyt Taylor:** I didn't mean to state that there was a difference between ICW and spark but rather between ICW and pure CW.

**Stuart Ballantine:** We made some experiments during 1919, independently of those of Dr. Taylor, which were intended to compare the reliability of CW and "spark" signals for direction-finding purposes at 800 meters. Our results agree in general with the experience cited by Dr. Taylor, in that the average variations with spark signals (500-cycle quenched gap transmitters) were nearly always less than those observed with CW signals. The observations were

[6] Technidyne Corporation, New York, N. Y.

made at the radio compass laboratories at Philadelphia Navy Yard, and at Germantown, Pa., and at the radio compass stations at Cape May, Cape Henlopen, and Bethany Beach. These comprised bearings taken on various transmitters (800-meter) within a range of 5 to 200 miles. A typical set of results for spark signals were reproduced in my article, "The Radio Compass"[7]. The deviations for spark signals ranged from 4 to 5 deg.; under the same conditions the arc signals varied by twice this amount. I have always thought that this difference was to be attributed to the homogeneity of the CW signals on the one hand, and to the fortuitous character of the spark as a radio-frequency time event, on the other. A simple calculation shows, moreover, that for the heights of the reflecting layer usually considered probable and at moderate distances (100 miles) the refracted signal may easily fall in between direct signals from a 500-cycle transmitter sparking twice per cycle. The change in musical quality accompanying this has often been observed. The studies of Bown, Martin, and Potter on isochronous fading with modulated CW signals are of interest in connection with this subject.

**H. E. Hallborg:**[8] I am very much interested in the Adcock system, particularly in view of its applicability to short-wave direction-finding. The satisfactory solution of the problem of direction-finding in the wave band of 50 to 200 meters is of particular importance to the air mobile service. It is my impression that the Adcock System should be particularly useful in this wave band.

Dr. Taylor has pointed out, in the previous discussion, that one of the limitations of the system is its relatively low pick-up, necessitating high amplification. Fortunately, this natural limitation obtaining at wavelengths of the order of 850 to 950 meters progressively diminishes as the wavelength of operation is shortened to the 50-to 200-meter band. Consequently the available antenan exposure progressively becomes a larger fraction of a wavelength. The pick-up effectiveness of the system at short wavelengths is thereby automatically improved.

The above is a superficialanalysis of the possibilities of the system for short-wave direction-finding. I would like to hear a further discussion by either Dr. Hull or Dr. Taylor as to whether the accuracy of the system on wavelengths of say 100 meters might be expected to be as good as that shown by the system on longer wavelengths.

**L. M. Hull:** With regard further to the sensitivity of the Adcock receiver, the small, portable, rotating model, of which a picture is shown in the paper, was first designed by Mr. Barfield, I believe, with the idea of using it for taking bearings on broadcast wavelengths. It was provided with a double detection receiver which was as sensitive as could be conveniently fitted to it at the time, and the sensitivity of that particular receiver was found to be inadequate for the purpose. So making a virtue of necessity this particular unit was used in an investigation of lateral deviations at frequencies on the order of 7 or 8 megacycles.

I had the opportunity one afternoon of observing with a similar model the bearings on a German station which was transmitting at about 40 meters throughout the course of the afternoon. I had been told previously that the model had been perfectly compensated, so that there was no appreciable response to horizontal components, and consequently any deviation in the bearing would probably be attributed to true lateral deviation of the waves. In this particular

[7] Yearbook of Wireless Telegraphy and Telephony, London, 1921.
[8] Radio Corporation of America, New York, N. Y.

case I observed a continuous deviation of the bearings, varying by the minute, through a maximum arc on the order of 7 or 8 degrees on this 40-meter transmission from a station at a distance of the order of 400 miles.

Of course, that question of sensitivity is a very important one, but in view of the fact that the technique of receiver design has advanced so by leaps and bounds in the last few years in this country, I believe that it is perfectly feasible to design and use special receivers even with portable Adcock direction-finders of this type, at the longer or intermediate wavelengths.

With regard to the reliability of the receiver, I don't exactly know what you mean. It is, of course, very difficult, particularly at the high-frequency ends of the spectrum, to say definitely that you have perfect compensation of the horizontal limbs. In the case of an Adcock receiver designed for reception at 400 meters or at lower frequencies, the observation of bearings, which are constant to the extent indicated on the curves shown in the paper, would immediately present evidence that the receiver was properly balanced. But so far as I know, it is in general impossible to obtain such constancy of bearings with the Adcock receiver on short-wave stations. It is simply necessary by independent measurements to assure yourself that the horizontal limbs of the collector have been balanced as perfectly as possible, and then to attribute what deviations you may observe to lateral deviations of the wave, which may of course possibly be refracting effects in the ground waves in cases where the deflected wave is not important, or which may be actually oblique deflections of the downcoming waves at considerable distance.

**Stuart Ballantine:** Did they balance that system with respect to ground currents?

**L. M. Hull:** In the model which I saw operating, the effects of ground currents were minimized by setting it as high off the ground as possible.

**A. Hoyt Taylor:** The theory of the system requires that the waves reflected up from the ground shall not introduce errors.

I might say that one way of carrying out your compensation on sufficiently high frequencies, that is, frequencies above 6000 kc, would be to set up a transmitter a few miles away so that you could get a ground wave of some little strength but have your sky wave skip over it. Compensate it then for a true vertically polarised ground wave. You could probably check your compensation pretty well. There is no doubt but that the compensation on the higher frequencies is extraordinarily difficult to keep in order.

As to the question asked by Mr. Hallborg concerning aeroplane bearings, if he will ask me that question a month later, I may be able to give him some information.

**S. W. Dean**[9]: Mr. Chairman, Mr. Smith-Rose and his associates of the Radio Research Board have done a great deal of very fundamental work on problems of the nature of those discussed in the paper, and also on those which involve the propagation of radio waves from a different point of view; that is, from the point of view of variations of signal strength, rather than of bearing. In this connection, Hollingsworth has shown that as you proceed from a long-wave transmitting station in a given direction, the signal strength passes through a series of maxima and minima of decreasing amplitude. This was observed at distances up to a few hundred miles.

Some of these results seem to be somewhat in disagreement with results ob-

[9] American Telephone and Telegraph Co., New York, N. Y.

tained in this country. This disagreement was mentioned by Dr. Austin in his "Report of the Chairman of the Commission on RadioWave Propagation, International Union of Scientific Radio Telegraphy."[10]

I should like to mention a few examples of the difference between results in England and in America, which have come to my personal attention. In one case a portable field strength measuring set was taken on a truck from the vicinity of Long Island up to the northern part of Maine, and observations were made at fairly frequent intervals on transmission from Rocky Point, Long Island using a frequency of 60 kc. The decrease in signal strength as the distance was increased followed a smooth curve closely approximated by the usual type of transmission formula, with no trace of maxima and minima. On the contrary the results obtained in England under similar conditions showed maxima and minima.

One suggestion I would like to make as a possible explanation of this is the difference in the conductivity of the ground in this country and in England. We have quite a number of evidences of that difference. One was mentioned in the paper which Dr. Bailey recently presented here on "The Receiving System for Long-Wave Transatlantic Radio Telephony."[11] This is that wave-antennas constructed in the United States have considerably greater output than those built in England, due to the greater wave tilt in this country. This was attributed to the difference in ground conductivity.

Another evidence (of minor nature) is that in some of the work which we have done in America on long-wave direction-finding, we found considerable errors in the measurement of both direction and field strength caused by underground wires and pipes near the receiving antenna. These errors in direction amounted to 5 or 6 deg. on the European stations, while the errors in field strength amounted to practically 2 to 1 in some cases. While in England I had occasion to look for such errors in a similar set-up of a field strength measuring set with loop antenna, and although there were fully as many buried wires, cables, and pipes, in this case the errors were practically negligible both in direction and in field strength. The apparatus was tested for such errors by comparing the results obtained with fixed measuring sets at stations where there were wires, cables, and pipes under the ground, with measurements made with portable sets in the open country which were not subject to such conditions. It occurs to me that the reason for this difference in results in the two countries may also be due to the difference in conductivity of the ground; that is, the ground being so much more conducting in England shields the buried pipes and cables much better than does the poorly conducting soil in this country. I cannot offer an exact explanation of why that difference in ground conductivity should cause the Radio Research Board in England to observe maxima and minima of signal strength as they progress away from a transmitting station, but the conductivity seems to be the only factor which is definitely known to be different in the two countries.

One or two other experiences which I had while working in co-operation with the engineers of the British General Post Office may shed some light on this question.

At the Post Office Radio Station at Cupar, Scotland, we observed daily for a period of about three months the signal from Rugby, England on 16 kc, at a distance of about 400 miles. Apparently we were located at a point where

[10] Proc. I. R. E., 16, 348; March, 1928.
[11] A. Bailey, S. W. Dean, and W. T. Wintringham, Proc. I. R. E., 16, 1645; December, 1928.

(in the summer daytime) one of these minima existed. The calculated field strength of the station was about 8,000 $\mu$v per meter, as I remember it, but the daytime values were very irregular and averaged about 400 $\mu$v per meter, the bearings being very indefinite and sometimes more nearly at right angles to the true direction than in the true direction. At sunset, however, the field strength began to rise rapidly, and shortly after sunset reached its calculated value and sometimes exceeded it. We had there very concrete evidence of the existence of a standing wave pattern on the surface of the earth, as has been described by Hollingsworth of the Radio Research Board.

Another, and even more striking example of such a condition, occurred one night when we were observing the same transmitting station, Rugby, but this time on 60 kc, as received on two wave antennas approximately 2 miles apart. During the course of the evening the relative strength of the signals on these two antennas varied greatly. At one time, to the great surprise of everybody present, the signal practically disappeared on one of the antennas while being received at considerable strength on the other antenna 2 miles away. I would hesitate to make such a statement except for the fact that there were two other observers present at the time.

I mention these things to emphasize that there is a very real difference between radio transmission phenomena in this country and in England. While interference effects and standing wave phenomena have often been observed in this country on broadcasting frequencies, such effects have not been observed at frequencies below 100 kc, to my knowledge, to as great an extent as has been reported by the English observers.

**William C. Bohn:**[12] I should like to ask if you have ever experienced an improvement in the minimum obtained on a loop when the vertical axis of the loop was tilted.

**A. Hoyt Taylor:** That can be done under certain conditions, but it is not a general cure for the situation.

**L. M. Hull:** With regard to the establishing of a standing wave pattern between the earth and the reflecting layer, it might be worth mentioning that such a pattern is made use of in one of the standard methods of determining the height of the layer by Prof. Appleton. One of his methods consists of making observations on a vertical antenna at a receiving station during "night errors" and observing the occurrence of maxima and minima as the frequency of the transmitter is continuously varied.

**George R. Putnam**[13] (by letter): This paper gives a summary of the interesting investigations carried on in England, during recent years, by Dr. Smith-Rose, and of other available information, in the field of radio direction-finding.

The subject is of especial interest in the United States, where there has been the most extensive development of a radio beacon system; the Lighthouse Service now has in commission 61 of these signals with 14 under construction. Since the first successful signals were established in 1921 near New York, this method of navigation has come into wide use; with the radio compass (or radio direction-finder) on shipboard, it successfully meets a most urgent need of the navigator, giving him the means of taking accurate bearings on invisible signals at great distances. There was never doubt of its universal use in marine navigation, so soon as some practical difficulties were removed, and its possibilities became known.

[12] American Telephone and Telegraph Company, New York, N. Y.
[13] Bureau of Lighthouses, Washington, D. C.

Dr. Smith-Rose describes and discusses a system of navigation by bearings from a "rotating beacon." He compares its advantages with the above-mentioned radio beacon and radio compass system. But it is not a comparable system, and does not fill the same purposes, as the following parallel comparison shows:

| Radio compass located on shipboard with radio beacons at lighthouses and on lightships. | Radio on shipboard, with bearings from a "rotating beacon" on shore. |
|---|---|
| 1. A universal system; bearings available on any radio signal from shore or ship, throughout the world. | A limited system, bearings may be obtained only from these particular land stations. |
| 2. Radio compass is a general navigational instrument, which the navigator can readily use himself, and the possibilities and reliability of which he can become accustomed to. | Navigator is wholly dependent on a system operated on shore, beyond his control; each station may be affected by peculiarities of personnel and location. |
| 3. Of the utmost value in aiding ships in distress (for example, it made possible rescue of crew of *FLORIDA*, Jan. 23, 1929). | Not available for rescue purposes. |
| 4. Of value to vessels approaching each other, in avoiding collision; already thus being used. | Cannot be used between ships. |
| 5. Radio beacon may be placed on offlying lightships (and these are usually the most valuable stations). | "Rotating beacon" is not workable excepting on land; cannot be placed on a ship. |
| 6. Accuracy sufficient for uses of navigation; with proper precautions and use, the reliability of the radio compass on shipboard is now superior to that on shore. | Accuracy is not greater. |
| 7. Radio beacons can readily be placed at any lighthouse, or any lightship. | "Rotating beacon" can be located only on land, or on a fixed foundation. |
| 8. Cost of installation of a radio beacon is somewhat less than that of a good sound-producing fog signal, while it effectively covers an area 200 times as large. Operation adds little to the cost of a lighthouse or lightship. | Cost not given, but evidently not less than for a radio beacon, and probably more. |
| 9. Cost of radio compass on a vessel is not great in proportion to the universal service given by it, and is becoming less. There is no doubt but that inexpensive radio compasses will be available for small craft, and will be valuable even if less accurate. | The additional cost is only small, for a vessel equipped with radio. |
| 10. The radio compass on shipboard is now indispensable on all properly equipped vessels of any size. | The "rotating beacon" would provide simply an additional check for vessels which must carry a radio compass. |
| 11. This system is already established and in wide use. | No "rotating beacon" is in commission. |

Some of the conclusions reached by Dr. Smith-Rose are based on practice different from ours. In this country the radio compass, from the first, has been installed on the bridge or in the pilot house of a vessel, often so located that the bearing may be read directly on the magnetic compass or a gyro-repeater, thus quite eliminating the principal source of error which he describes at length, resulting from the bearing being taken by the radio operator in the radio room. Here the radio bearings are taken directly by the navigator or under his supervision; besides other obvious advantages, the accuracy and reliability of radio bearings taken on shipboard are now believed to be superior to those taken at a shore station by personnel who are less expert in regard to navigation, and who have not the responsibility for, or the means of judging of their correctness.

The radio beacon can always be placed at an existing lighthouse or lightship, for these are the points of strategic importance to navigation which call for radio beacons.

It is evident that with the present state of the use of radio in navigation, ships must be equipped with a general means of obtaining radio bearings from the ship; there is only one general system available for this purpose, and so far as present knowledge goes none other appears to be possible. There can be no economy in any other system as it will not meet the need, and will not obviate the necessity for the radio compass on shipboard.

The above comment bears on the part of this paper wherein Dr. Smith-Rose departs somewhat from his field of research, and touches on navigational applications and lighthouse service economics, perhaps without realizing that several thousand of the principal ships of all countries are now daily using the radio compass on shipboard with satisfaction and success, and that there are well over one hundred radio beacons in operation, maintained by lighthouse services of the maritime nations at lighthouses and on lightships, and that these signals are now depended upon by the navigators perhaps more implicitly than any other; they are undoubtedly the most important aids to navigation.

The research results given by Dr. Smith-Rose are of the greatest interest and importance, and prove the value of the work planned by the Radio Research Board of England. Some of the results given in this paper are confirmed by the seven years'experience in this country in operating a radio beacon system, and by the reports received from vessels; as to other conclusions there is some divergence. As he states, the so-called night effect has not been found a serious hindrance in the use of radio bearings in navigation, under the conditions as applied here; the uncertainties on this account are not systematic, and increased accuracy can readily be obtained by repeated bearings.

The type of radio wave transmission, and the fog or other weather conditions, have not been found to have any influence on the direction of a radio bearing.

Experience here has shown no cases of error due to bearings crossing the shore line, or running parallel to the coast, and this has been confirmed by a considerable number of bearings taken from vessels on the Great Lakes, over land and water. The so-called land-effect is considered to be negligible in the radio bearing practice used here for navigation, and there appears to be no necessity for warnings as to "arcs of good bearings." Also in the system here developed of placing the principal radio beacons on lightships, or outstanding points on the coast, there is little occasion to use radio bearings which pass over the land.

The accuracy of 1 deg. ascribed to land direction-finding stations applies in our experience to the radio bearings taken from ships under good conditions.

I was much interested a coulpe of years ago in observing the experimental work which Dr. Smith-Rose was kind enough to show me. The "rotating beacon" may very likely have valuable applications, either for special localities, or special navigational needs, but it appears important to keep clearly in mind the requirements of radio bearings for general marine navigation, which can be met only by a truly general system.

**J. C. Schelleng**[14] (by letter): In the paper the author mentions that reservations are necessary in the application of the reciprocal theorem to actual radio transmission. In his generalization of the reciprocal theorem, Carson[15] pointed out that it appears necessary that the currents in the system be linear functions of the potential gradients involved.

These conditions are not strictly satisfied in the case of transmission through media such as the ionized upper atmosphere for two reasons.

> (1) Motion of the ions across the magnetic field of the wave itself produces a small additional motion in the direction of propagation. This motion is such a function of the wave amplitude that it can be neglected for the small amplitudes used in practice. With this reservation the reciprocal theorem is probably valid in such cases.
>
> (2) A real failure of reciprocity occurs when a constant magnetic field, such as that of the earth, is considered. The lack of reciprocity in this case has been recognized by several writers. A simple example is the following. An ionized medium containing the points $A$ and $B$ has a magnetic field in the direction $AB$. Perpendicular to this line at $A$ and $B$ are two linear antennas, $A$ is vertical but $B$ is rotated 45 deg. from the vertical. The distance $AB$ is chosen so that when $A$ is energized, the plane of polarization of the resulting wave, in passing from $A$ to $B$ also rotates 45 deg., resulting in a maximum signal in $B$. In this case the wave has been travelling in the direction of the magnetic field. When, however, $B$ is the transmitter and $A$ the receiver, the plane of polarization, instead of rotating back to a position parallel to $A$, rotates an additional 45 deg. in the same direction as before and at $A$ is perpendicular to the antenna. The current in $A$ is therefore zero. The reciprocal relation therefore fails.

For the phenomena to have been reversible would have required a reversal of the magnetic field at the same time as the change in direction of propagation. While proof is lacking, it seems not unlikely that this relation holds in more general cases than the special one given; that is, that in general reversibility is obtained in transmission through such media providing that all externally applied magnetic fields are reversed with the direction of propagation.

That such considerations have a great deal to do with directional errors is, of course, well appreciated by Mr. Smith-Rose. It may be of interest to consider the question in some detail. Neglecting errors due to departure from the great circle path, though such departures certainly exist, at any rate for short waves, deviations in apparent bearing are due to the existence of a horizontal component in the downcoming electric field, which in turn is due to the earth's magnetic field. If the direction of this magnetic field could be reversed, the direction of the disturbing electric component would be reversed and with it the sign of the directional error.

In Fig. 1, $A$ and $B$ are two geographical locations, viewed as on a map. The arrow on the line $AB$ indicates the direction of propagation. The arrow $D$ gives the apparent direction indicated by a loop receiver or transmitter at the point shown. $V$ indicates the use of a vertical transmitting or receiving aerial. $H$ is the magnetic field, assumed horizontal. The shape of the path from $A$ to $B$ is assumed symmetrical with respect to the mid-point.

Fig. 2 indicates that if the magnetic field could be reversed, the directional error would also be reversed.

[14] Bell Telephone Laboratories, New York City.
[15] *Bell Sys. Tech. Jour.*, July, 1924

Fig. 3 is obtained from Fig. 2 by rotating the system of Fig. 2 by 180 deg. about a vertical axis. Such rotation assumes that $AB$ is small enough so that conditions along the path are uniform in regard to ionization, etc. Comparison of Figs. 1 and 3 indicates that under otherwise identical conditions a loop receiver at $A$ indicates a directional error the sign of which is opposite to that observed in the same way at $B$.

Fig. 4 is obtained from Fig. 1 by assuming both the magnetic field and the direction of propagation to be reversed. Fig. 5 is obtained from Fig. 4 by rotating the entire system as before.

Comparing Fig. 1 and Fig. 5, the apparent directions in the two systems (loop receiver and loop transmitter) are seen to be the same as long as the wave always moves from $A$ to $B$.

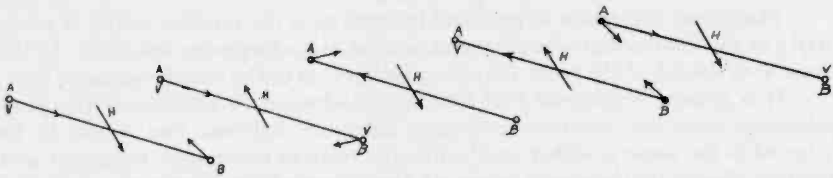

Fig. 1 Fig. 2 Fig. 3 Fig. 4 Fig. 5

Comparing Fig. 3 and Fig. 5 the errors are opposite in sign if the directions of propagation are opposite in the two systems. This case applies to the statement at the end of Sec. 4 of the paper. It would therefore appear at least for a horizontal magnetic field, that *regardless of the disposition of the apparatus the errors are the same as long as the directions of propagation are the same.* It should be repeated, however, that this assumes uniform conditions along the path. The statement also requires some modification if the path is not short compared to the radius of the earth.

If, as seems likely, the present assumptions are correct in general, and if readings in the two directions could be taken closely enough together, equal errors of opposite sign would be obtained merely by reversing the direction of propagation through the same terminal apparatus. An average of the apparent directions in the two cases would therefore be free of error produced by rotation of the plane of polarization.

When the directional errors fluctuate and are positive as often as negative, either the difference in the lengths of the paths of the overhead and the ground wave must vary at random between limits of a wavelength or more, or else the plane of polarization of the overhead wave must vary in general through a range of at least one revolution. Fig. 14 of the paper would appear to represent such conditions. Incidentally this experiment did not afford a test of the instantaneous reversibility of the system, since conditions were fluctuating too rapidly during the ten-minute intervals which were used. It appears from the above considerations that the system is not reversible. Reversibility of the average bearings seems to have been obtained in this experiment and may indeed represent the usual conditions. A state of affairs can be imagined, however, in which the atmospheric wave would be so steady that a more or less constant non-reciprocal atmospheric error would be introduced.

Incidentally this term "atmospheric error" may in some ways be preferable to "night error." It is non-committal as to the exact mechanism (rotation or actual deviation from the path), except that it is due to a wave returned by the upper atmosphere. It can be used without explanation when such effects occur in the daytime, as they do for short waves.

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## Discussion on RECENT DEVELOPMENTS IN SUPERHETERODYNE RECEIVERS*

(G. L. Beers and W. L. Carlson)
(Communicated)

**Frederick K. Vreeland**†: This paper is of especial interest to me because the apparatus described employs a band selector, used as an interstage coupling in an amplifier, as set forth in my paper presented to the Institute January 9, 1928. In the present case the band selectors are employed in the intermediate-frequency amplifier, and they are of the form which employs a mutual inductive coupling between the selector elements, instead of the form that has a bridging inductance coil, which is usually preferable.

This raises a question of practical interest as to the relative merits of selectivity in the intermediate-frequency as against radio-frequency selection. In the apparatus described the radio-frequency selection is of the broad resonance type.

It is usually considered that intermediate-frequency selection is the more selective, since the absolute frequency difference between two waves to be selected is the same in either case, while the relative separation, expressed as a fraction of the frequency, is larger at the intermediate frequency, since this frequency is lower. The figure of merit of a selector is naturally a function of the relative separation, rather than the absolute frequency difference.

The curves given in the paper do not, however, fulfill this expectation, especially when it is realized that eight tuned circuits are employed. The overall frequency characteristic, Fig. 15, lacks the substantially rectangular form, with flat top and sharp cut-off, that characterizes band selection at its best, and the effect of this on the fidelity curve appears in Fig. 16, which shows the 5,000-cycle component reduced to 30 per cent of the normal and the 10,000-cycle component practically out.

It would seem that this result can be traced to two causes: first, the intermediate-frequency selectors, and secondly, the resonant radio-frequency circuits.

Referring to the frequency characteristic of the intermediate-frequency selector, Fig. 7, it will be noted that the curve has a rounded top and sloping sides, instead of the flat, or even hollow top and sharp cut-off of a good radio-frequency band selector. Two factors, and perhaps others, contribute to this result. First, the large *relative* width of the band increases the difficulty of design, a twenty-kc band having a relative width, in this case, of 11 per cent of the carrier frequency, which is 180 kc, as against 3.3 per cent with a 600-kc carrier or 1.33 per cent at 1500 kc, when radio-frequency selection is used. Secondly, a low-frequency circuit has a larger power factor than a high-frequency circuit, for a given amount of space and material. These two factors increase the difficulty of design of selective circuits at the lower frequencies employed in superheterodyne amplifiers. But this difficulty is not prohibitive. It is quite feasible to make an efficient intermediate-frequency selector with good band form, but it requires more material, more space, and more elaborate construction than the corresponding radio-frequency band selector.

A second cause of the rounded and sloping characteristic may be found in the radio-frequency circuits, which appear from the description to be not band

* Presented at New York meeting ot the Institute, March 6, 1929. Proc. I. R. E. 17, 501; March, 1929.
† Vreeland Laboratories, 90 West St., New York, N. Y. Discussion received April 9, 1929.

selectors but broadly resonant circuits, as shown in Figs. 3 and 4. A marked improvement in both fidelity and selectivity could be secured by using more sharply resonant circuits and spacing them in the frequency scale, making a spaced band amplifier of the type described in the above-mentioned paper, or by the use of a single band selector in place of the two broadly tuned circuits. A band selector with a flat radio-frequency amplifier is a very effective combination.

There are also certain disadvantages in the inductively coupled form of band selector here used in the intermediate-frequency circuit. An important feature of the band selector with a bridging coil is that the band width may be varied at will by changing the inductance of the bridging coil. Thus a receiver may be converted, by a touch on a switch, from a full band selector, giving highest fidelity, to a narrow band or even a sharply peaked selector, when this is desired to cut through interference that overlaps the modulation band of the signal. This result is useful when extremely long distance reception is desired, since distant signals rarely have good quality because of ground noise and selective fading, and the band switch restores in a moment all the advantages of full band reception for nearer stations.

The "automatic volume control" is another feature that is analogous in certain respects to a system that has been developed and carefully studied in my laboratory for some time. I prefer the term "automatic governor" for our system because of the obvious analogy to the governor of a steam engine or turbine.

There are several features that we have found useful which differ from the arrangement shown in the paper. One of these is deriving the governing e.m.f. from the audio-frequency output, rather than from the radio carrier frequency. This has several advantages. First, it keeps the output level constant regardless of the degree of modulation, since the thing governed controls directly the governing function. Another feature that cooperates with this is designing the apparatus for quick response and slow recovery, so that changes in the dynamic of music or voice are rendered with their true relative strengths. This also removes the difficulty in tuning referred to in the paper, since the gain remains substantially constant for a sufficient time to tune accurately by ear without a separate indicator. The speed of recovery may be given any desired value, or changed at will. The slow recovery does not affect the speed of response to a suddenly applied signal, which is practically instantaneous. A large antenna suddenly switched on produces hardly a flicker in the output derived from a powerful signal.

A second avantage in operating on the audio-frequency output is that a much larger governing e.m.f. is available. The full e.m.f. applied to the loud speaker may be employed, or stepped up still higher by a transformer without the use of extra amplifiers. The scope of effective governing is thus enormously increased. An applied signal strength of 100,000$\mu$v or more is readily handled, as against 900$\mu$v, the largest value shown in Fig. 13.

This has the further advantage of permitting the governor to operate directly on the anode supply of the tubes, leaving the bias constant at its normal value and so avoiding the distortion that results from an excessive increase in the amplifier bias. This distortion due to bias control unfortunately occurs on the stronger signals, which are the ones most in demand for good tone quality. The most faithful reproduction occurs on the weaker signals, which are usually no good anyway. By governing the anode supply directly complete fidelity is obtained when the governor is operating to the limit on the most powerful signals, as well as on weaker ones, down to the limit of sensitivity of the receiver. Besides giving high and uniform fidelity, this method of governing makes a "sensitivity control" and a "resonance indicator" wholly unnecessary, thus greatly simplifying the manipulation. The operation is wholly automatic.

Operation of a receiver is still further simplified by another feature that I hope soon to be permitted to present to the Institute at length; that is, a remote control system for operating the station selector from a distance. This is naturally combined with the band selector and the automatic governor, and when so used permits the receiving set to be fully operated by a simple and inconspicuous control box, or by any one of several such boxes in different locations, using either a manual tuning adjustment or push buttons controlling individual stations. This reduces receiver operation to the minimum of simplicity and permits the receiver to be located in a closet, with only the loud speaker and control box in evidence, thus eliminating all cumbersome furniture. It is mentioned now as the logical sequel to the band receiver and the automatic governor.

G. L. Beers†: Coupled circuits have been used commercially for several years in superheterodyne receivers to improve their selectivity and fidelity characteristics. There is a decided advantage in having the intermediate-frequency circuits determine the selectivity of a superheterodyne receiver as by so doing the selectivity of the receiver can be made very uniform throughout the broadcast range. This of course is not the case with a tuned radio-frequency band selector, as in the best receivers of this type the band width varies three to one from one end of the broadcast range to the other. This rather serious limitation of tuned radio-frequency band selector receivers was explained in detail in the printed discussions of Dr. Vreeland's paper.

In a commercial receiver manufactured in large quantities like the one from which the data for the curve in Fig. 7 was taken, it is desirable to have a selectivity characteristic which is slightly rounded at the top. Such a characteristic is almost a necessity to enable the average broadcast listener to tune a receiver accurately. If the selectivity characteristic has a hollow top, the average user will tune the receiver to the peak on one side and sideband discrimination will be the result. From the standpoint of fidelity and selectivity, the slightly rounded top is unimportant. After the desired band width at 70 per cent peak amplitude has been decided upon, the relative merit of band selectors can be expressed by the ratios of their band width at 70 per cent peak amplitude to their band widths at 0.1 per cent peak amplitude. A brief comparison of this nature will soon demonstrate the superiority of the superheterodyne receiver over the tuned radio-frequency band selector receivers, which are on the market today. In this connection it is indeed unfortunate that Dr. Vreeland neglected to show overall selectivity curves for a tuned radio-frequency band selector receiver.

The tuned radio-frequency circuits in a superheterodyne receiver are used primarily to reduce undesired responses and as sufficient reduction in these responses was obtained by the use of the tuned circuits, it was unnecessary to resort to coupled circuits.

The statement that resonant circuits coupled by means of a bridging coil have a decided advantage over the inductively coupled type, in that the band

† Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa. Discussion received June 17, 1929.

width can be varied at will by means of a switch, is incorrect. There are several simple ways of accomplishing this result with inductively coupled resonant circuits. Several experimental receivers in which such arrangements have been incorporated have been in use for several years. Here again the advantage is in favor of the selectivity in the intermediate-frequency circuits as any change in the band width of these circuits will cause a uniform effect in the selectivity of the receiver throughout the broadcast range. Varying the coupling in a broadcast receiver of the tuned radio-frequency band selector type will produce only a slight improvement in the band width at the high-frequency end of the broadcast range, since the losses in the individual circuits are too great to give a sharp characteristic.

The objections to an automatic volume control arrangement such as described by Dr. Vreeland are so numerous as to prohibit a discussion of all of them. The chief objections follow:

Dr. Vreeland states that the automatic volume control he has been using maintains a constant audio output level regardless of the degree of modulation of the incoming signal, and yet variations in the sound intensity of the music or speech which are produced by changes in the per cent modulation are rendered with their true relative strength. This combination of results hardly seems possible in view of the quick response and slow recovery claimed for the device.

Let us suppose that such an automatic volume control having a quick response and slow recovery, whose controlling e.m.f. is derived from the audio output, is in use in a radio receiving set. A program is being received from a station whose carrier is modulated 20 per cent, and the receiver is adjusted for the desired output. In accordance with the music the per cent modulation suddenly increases to 80 per cent. The audio output, however, does not change appreciably, but remains at practically the same level due to the quick response of the device. If the per cent modulation now returns to the former level of 20 per cent the audio output will decrease accordingly, since the volume control has a slow recovery and will, therefore, be much less than the output previously obtained with the same per cent modulation. If the per cent modulation remains constant for a sufficient length of time the audio output will gradually increase until it reaches the original level. It is evident that such a system cannot reproduce the variations in sound intensity so essential for the faithful reproduction of either speech or music.

When but one stage of audio amplification is used, sufficient radio-frequency voltage is readily obtained at the grid circuit of the detector to operate satisfactorily an automatic volume control. While not indicated in the curve shown in Fig. 13, the automatic volume control described in the paper will likewise control satisfactorily a field strength of 100,000$\mu$v per meter. The curves in the paper were plotted up to field strengths of only 900$\mu$v per meter to show in more detail the shape of the curve where the volume control starts to take effect.

The distortion encountered by the use of high negative biases on amplifier tubes in obtaining volume control is not eliminated by a volume control which varies the plate voltage instead of the bias, as a brief study of tube characteristic curves will show.

Dr. Vreeland's statement that the automatic volume control he has been using eliminates the necessity for a sensitivity control is misleading. There is actually more need for a sensitivity control with an automatic volume control of the type which he describes. Although the noise in tuning between stations will be reduced somewhat, it will still be objectionable and a sensitivity control will be very desirable. Also during a pause in a radio program, since there is no modulation, the sensitivity of the receiver will automatically be increased until either sufficient noise is received to work the control, or else the radio-frequency amplifiers or the detector will be overloaded. Either of these conditions is, of course, very undesirable.

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# MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards, and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The periodicals can be secured from their publishers and can be consulted at large public libraries.

## R100. Radio Principles

R113 Eckersley, T. An investigation of short waves. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 255–260; May, 1929.

(Abstract of an extensive paper discussing echoes and scattering effects, errors and their sources in direction finding, fading, magnetic storms, and the theory of the action of the Heaviside layer.)

R113 Quäck, E. and Mögel, H. Double and multiple signals with short waves. Proc. I. R. E., **17**, pp. 791–823; May, 1929.

(Results of oscillographic tests of round-the-world signals. Relations to magnetic effects and twilight zone.)

R113 Quäck, E. and Mögel, H. Short range echoes with short waves. Proc. I. R. E., **17**, pp. 824–829; May, 1929.

(Oscillograph records showing short range echoes and round-the-world signals simultaneously.)

R113.1 Parkinson, T. Some observations of short-period radio fading. Bureau of Standards Journal of Research, **2**, pp. 1057–1075; June, 1929.

(Causes of fading are investigated by means of graphic fading records made simultaneously with different types of receiving antennas. Evidence found of fading due to interference; to direction shifts; to rotation of plane of polarization, and to varying intensity of indirect rays; to multiple rays.)

R113.5 Mesny, R. Activie solaire et propagation. (Solar activity and propagation.) *L'Onde Electrique*, **8**, pp. 103–110; March, 1929.

(A summary of results of several investigators attempting to correlate variations in reception with periods of increased solar activity. Results of Espenschied, Anderson and Bailey, of Pickard, and Austin are considered.)

R113.5 Wymore, I. J. Relation of radio wave propagation to disturbances in terrestrial magnetism. Bureau of Standards Journal of Research, **2**, pp. 1201–1211; June, 1929.

(Study of radio reception on low frequencies showing that for daylight reception over distances of 4000 to 7100 km the signal intensity increases following the height of severe magnetic disturbances, while for distances of 250 to 459 km intensity increases before, is normal during, and increases after the maximum of a magnetic storm.)

R125.1 Hell, R. Direktzeigendes funkentelegraphisches Peilverfahr. (A direct reading radio direction finder.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 138–145; April, 1929.

(Discusses a method of using two crossed receiving loops or one loop and a vertical antenna in connection with a switching arrangement and a current indicator for determining course. The indicator shows pilot continuously his position with respect to the course.)

R125.6 Chireix, H. French system of directional aerials for transmission on short waves. *Experimental Wiresless and Wireless Engr.* (London), **6**, pp. 235–244; May, 1929.

(Principles and construction of antennas for uni-directional horizontal beam transmission, using only one pair of feeders.)

R132 Jackson, W. The measurement of the voltage amplification factor of tetrodes. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 252–255; May, 1929.

(A bridge method for measuring the amplification factor and plate resistance (hence mutual conductance) of tetrodes, as affected by changes in battery voltages.)

R133 Hollmann, H. E. Zum Problem der Erzeugung kurzer elektrischer Wellen durch Bremsfelder. (Production of electric waves having a wavelength of the order of 13 to 18 centimeters.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 128–132; April, 1929.

(A thorough investigation into the production of 13- to 18-cm electric waves using a metal T.M.C. type tube. Also a comparison of results with those attained by Pierret and by Barkhausen and Kurz.)

R134 Terman, F. E. and Dysart, B. Detection characteristics of screen grid and space charge grid tubes. Proc. I. R. E., **17**, pp. 830–833; May, 1929.

(Measurements of the "voltage constant" of tetrodes and comparison of tetrodes with triode detectors.)

R145.3 Positive and negative mutual inductance (editorial). *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 233–234; May, 1929.

(Discussion of proper convention to be used in indicating sign of mutual inductance. It is shown desirable to call the mutual inductance positive if, having adopted a convention as to positive direction of currents, an increase of current in circuit 2 causes an e.m.f. in circuit 1 in the same direction as would be caused by an increase of current in circuit (1.)

R145.3 Bashenoff, V. I. The establishment of a general formula for the inductance of single turn circuits of any shape. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 245–251; May, 1929.

(It is shown that the ordinary formulas for single-turn circuits are special cases of the author's general formula. Experiments are made on large and small closed aerials, checking the accuracy of the general formula.)

R149 Shaw, A. E. Cold-cathode rectification. Proc. I. R. E., **17**, pp. 849–863; May, 1929.

(Investigation of discharge phenomena and asymmetric conductivity in gas-filled cold-cathode rectifiers.)

R170 Smith-Rose, R. L. Man-made static—high voltage overhead electrical transmission lines and radio interference. *Wireless Wld. and Radio Rev.*, **24**, pp. 476–480; May 8, 1929.

(A discussion of radio interference due to high-voltage transmission lines. Description of experiments conducted at the National Physical Laboratory by the author.)

R170 Allen, J. G. Radio interference. Proc. I. R. E., **17**, pp. 882–891; May, 1929.

(A consideration of the sources of interference and methods of detection and elimination.)

R200. Radio Measurements and Standardization

R201.6 Soucy, C. I. and Bayly, B. deF. A direct reading frequency bridge for the audio range based on Hay's bridge circuit. Proc. I. R. E., **17**, pp. 834–840; May, 1929.

(A simple and accurate bridge in which the frequency is determined directly by the resistance introduced for balance.)

R261 Lubcke, H. R. Vacuum-tube voltmeter design. Proc. I. R. E., **17**, pp. 864–872; May, 1929.

(Equation for optimum design for a given input range and meter.)

R261 Rhodes, H. E. A simple two-tube vacuum-tube voltmeter. *Radio Broadcast*, **15**, pp. 107–108; June, 1929.

(An apparatus of improved design for audio-frequency work.)

R300. Radio Apparatus and Equipment

R330 Westman, H. P. Two recently announced tubes.—The UY-224 and the UX-245. *QST*, **13**, pp. 41–43; June, 1929.

(Data on screen-grid a.c. heater tube, UY-224, and the amplifier tube, UX-245.)

R341 Neue Glimmlichtgleichrichter. (A new glow discharge rectifier.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 145–148; April, 1929.

(A description of the "Anatron," a product of the firm of Dr. G. Seibt. Also a comparison of this type of rectifier with the audion type.)

R342.15 Podliasky, I. Sur les transformateurs intermediaires et la reproduction sans distortion. (On interstage transformers and reproduction without distortion.) *L'Onde Electrique*, **8**, pp. 111–118; March, 1929.

(Theory of resonance in transformers and its effect on frequency distortion. The effect of tube capacities is considered.)

R342.7 David, P. La qualite de la reception radiophonique. (The quality of radiotelephone reception.) 8th article of a series. *L'Onde Electrique*, **8**, pp. 119–129; March, 1929.

(Audio-frequency amplification. Circuit and speaker considerations involved in preserving quality in audio-frequency amplifiers. Discussion.)

R343 Lucas, P. S. Modern ideas on the portable receiver. *Radio* (San Francisco), **11**, pp. 12–13; June, 1929.

(Complete directions for constructing a compact 4-tube screen-grid set with power detector.)

R344.8 Meissner, E. R. Logarithmic scale for beat frequency oscillator. Proc. I. R. E., **17**, pp. 879–881; May, 1929.

(Equation for shape of variable condenser plates for giving a logarithmic frequency scale.)

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R526.2 Gloeckner, M. H. Der Bordpeilempfanger im Flugzeug. (The direction finder on the airplane.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 132–138; April, 1929.

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R800. Non-Radio Subjects

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(At a frequency of 8000 cycles a transformer with core of so-called Hochfrequenzblick shows a marked superiority to the air core type. A method of controlling voltage and keeping it constant and independent of the load is shown.)

*Proceedings of the Institute of Radio Engineers*
*Volume 17, Number 8* *August, 1929*

## CONTRIBUTORS TO THIS ISSUE

**Batcheller, Arthur:** Born at Wellesley, Mass. in 1888. Studied E.E. for three years at Y.M.C.A. Polytechnic School, Boston, Mass.; for four years instructor in radio and electricity at evening sessions, Boston School of Telegraphy; assistant to electrical engineer, Boston, Revere Beach, and Lynn R. R. for four years; chief electrician for Eastern Steamship Corporation at Boston, 1915–1916; U. S. radio inspector in charge of New England District, 1917–1919; associate partner and founder, Massachusetts Radio Telegraph School, 1919; Radio Inspector in charge of Second Radio District, with headquarters in New York, and Supervisor of Radio, 1920 to date; in 1925 commissioned a lieutenant commander in the United States Naval Service. Associate member, Institute of Radio Engineers, 1914; Member, 1920. Member of Board of Direction of the Institute, 1929.

**Brown, J. E.:** Born September 11, 1902 at East Marion, New York. Attended School of Engineering, Cornell University, 1920–1924; test department, General Electric Company, 1923; Radio Inspector with U. S. Department of Commerce at Detroit, Mich., 1924 to date, engaged in inspection work, development of field strength measuring apparatus, methods and measurements, and frequency measuring equipment. Associate member, Institute of Radio Engineers, 1924; Member, 1928.

**Crawford, Arthur B.:** Born February 26, 1907 at Graysville, Ohio. Received B.S. degree in E.E., Ohio State University, 1928. Member technical staff, Bell Telephone Laboratories, 1928 to date.

**Dellinger, J. H.:** Born July 3, 1886 at Cleveland, Ohio. Educated at Western Reserve, 1903–1907; A.B. degree, George Washington University, 1908; fellow at Princeton, 1912–1913, receiving the Ph.D. degree, 1913; instructor in physics, Western Reserve, 1906–1907; U. S. delegate, Interallied Technical Conference on Radio Communications, Paris, 1921; secretary, U. S. Government Interdepartmental Radio Advisory Committee, 1922–1923; member, National Radio Conference, 1922–1925; technical secretary, American Section, International Union Scientific Radiotelegraphy; since 1907 physicist and later chief of Radio Section, Bureau of Standards, Washington, D. C. Fellow, Institute of Radio Engineers, 1923. Vice President of the Institute, 1924; President, 1925.

**Edwards, S. W.:** Born August 11, 1889 at Dennison, Ohio. Employed by United Wireless Corporation of America, 1908–1913; long-distance automatic calling, Ohio Telephone Company, 1913–1914; appraisal engineering work, Columbus Railway, Light and Power Company, 1914–1917; in charge of Eighth Radio District, U. S. Department of Commerce since 1917. At present Supervisor of Radio, Eighth Radio District, in development of field strength measuring apparatus and methods, constant frequency equipment and secondary standards for use by the Division, design of radio test cars for the Radio Division. Member, Institute of Radio Engineers, 1928.

**Englund, Carl R.:** Born Sioux City, Iowa. Received B.S. degree, University of South Dakota, 1909. Chemist, teacher, and graduate student, 1909–1914. Member, technical staff, Western Electric Co., Bell Telephone Laboratories, 1914 to date. Associate member, Institute of Radio Engineers, 1917; Fellow, 1928.

**Felix, Edgar H.**: Born March 29, 1898. Studied at New York University, Columbia University, and Sheffield Scientific School, Yale University. Radio engineer, Radio Development Section, Signal Corps, 1918; associate editor, *Aerial Age Weekly*, 1919; assistant publicity director and speakers' bureau, Leonard Wood Campaign Committee and Republican National Committee, 1920; publicity director, WEAF, 1922–1924; radio technical director, N. W. Ayer and Son, 1924–1926; contributing editor, *Radio Broadcast*, *Aero Digest*; consultant to broadcasting stations and advertisers; technical writer, radio consultant, National Electrical Manufacturers' Association. Junior member, Institute of Radio Engineers, 1917; Associate, 1919; Member, 1925.

**Harries, J. H. Owen**: Born October 13, 1906 at Brentwood, Essex, England. Engaged in radio work since 1923. Practiced as consultant from 1924 to date. Specialized in audio-frequency research and mains unit design, and has published various results. At present engaged in television. Associate member, Institute of Radio Engineers, 1928.

**Harris, Sylvan**: See Proceedings for March, 1929.

**Hogan, J. V. L.**: Born February 14, 1890 at Philadelphia, Penna. Studied Sheffield Scientific School, Yale University; assistant to Lee de Forest in development of wireless telephone, 1906–1907; independent investigations into detector action, 1907–1910; with National Electric Signaling Company, 1910–1914; International Radio Telegraph Company, 1914–1921; consulting engineer, 1921 to date. Author of numerous technical papers. Member, Institute of Radio Engineers, 1912; Fellow, 1915. Past President of the Institute.

**Hooven, M. D.**: Born May 30, 1897 at Weatherly, Penna. Private, Signal Corps, 1918. Received B. S. degree, Bucknell University, 1920. Radio engineering department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, 1921; Robbins Electric Company, Pittsburgh, 1922; transmission and substation engineer's office, Public Service Electric and Gas Company, Newark, N. J., to date. Past chairman radio subcommittee, and present vice chairman inductive coordination committee, National Electric Light Association. Associate member, Institute of Radio Engineers, 1926.

**Hull, L. M.**: See Proceedings for February, 1929.

**Krueger, Kurt**: Born October 14, 1898 at Mallmitz, Germany. Studied at Technical High School of Berlin, and at the Universities of Berlin and Wuerzburg. Graduated Dr. Phil., Wuerzburg, 1922; assistant to Professor Zenneck, Technical High School of Munich, 1922–1926; since 1926 employed by German Experimental Institution for Air Traffic, Berlin-Adlershof at Department for Radio and Electrotechnics.

**Marriott, Robert Henry**: Born February 19, 1879 at Richmond, Ohio. Took up study of radio engineering, Ohio State University in 1897; engineer designing, constructing, and maintaining radio apparatus and stations with commercial radio companies, 1901–1912; U. S. Radio Inspector, 1912–1915; expert radio aide, U. S. Navy, 1915–1925; consulting engineer, 1925 to date. Member, Institute of Radio Engineers, 1912; Fellow, 1915. First president of the Institute; member, Board of Direction, 1929.

**Nelson, Edward L.**: Born March 10, 1891 at Warsaw, Indiana. Received B.S. degree in E.E., Armour Institute of Technology, 1914; radio research department, Western Electric Co., 1917; technical expert, Bureau of Steam Engineering, Navy Dept., attached to special service party in European waters as specialist on subchaser radio telephone equipments, 1917; lieutenant, U.S.N.R.F. radio telephone officer, London, 1918; radio research department, and radio development department, Western Electric Company, 1919–1925; radio development department, Bell Telephone Laboratories, 1925 to date. Associate member, Institute of Radio Engineers, 1919; Member, 1925.

Plendl, Hans: Born December 6, 1900 at Munich, Germany. Studied at Technical High School of Munich, 1919–1923, becoming graduate engineer in 1923. Scientific work for Professor Zenneck at Physical Institute, Technical High School of Munich, 1923–1925, becoming graduate doctor-engineer in 1925. With Professor Meissner in Research Laboratory, Telefunken Company, Berlin, 1925–1927. With Professor Fassbender, Department for Radio and Electrotechnics, German Experimental Institution for Air Traffic, Berlin-Adlershof.

Schelleng, J. C.: Born November 11, 1892 at Freeport, Ill. Received A.B. degree, Cornell University, 1915. Instructor in physics, Cornell University, 1915–1918; since 1918 with Western Electric Company and Bell Telephone Laboratories working on radio transmitters and transmission. For past few years in charge of studies on high power transmitters, transmitting antennas, and radio transmission. Associate member, Institute of Radio Engineers, 1923; Member, 1925; Fellow, 1928.

Whittemore, L. E.: Born August 20, 1892 at Topeka, Kansas. Received A.B. degree, Washburn College, Topeka, Kansas, 1914; M.A. degree, University of Kansas, 1915. Instructor, department of physics, University of Kansas, 1915–1917; radio laboratory staff, Bureau of Standards, 1917–1923; secretary of Interdepartmental Radio Advisory Committee of U. S. Government, 1923–1924; engineer, Department Development and Research, American Telephone and Telegraph Company, 1925 to date. Associate member, Institute of Radio Engineers, 1916; Member, 1925; Fellow, 1927. Served as chairman, Committee on Standardization of the Institute, 1926 to 1928, inclusive; vice president of the Institute, 1928; member, Board of Direction, 1929.

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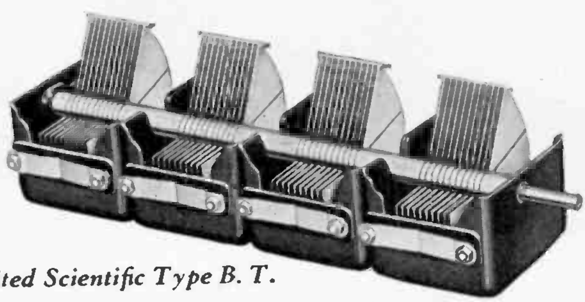

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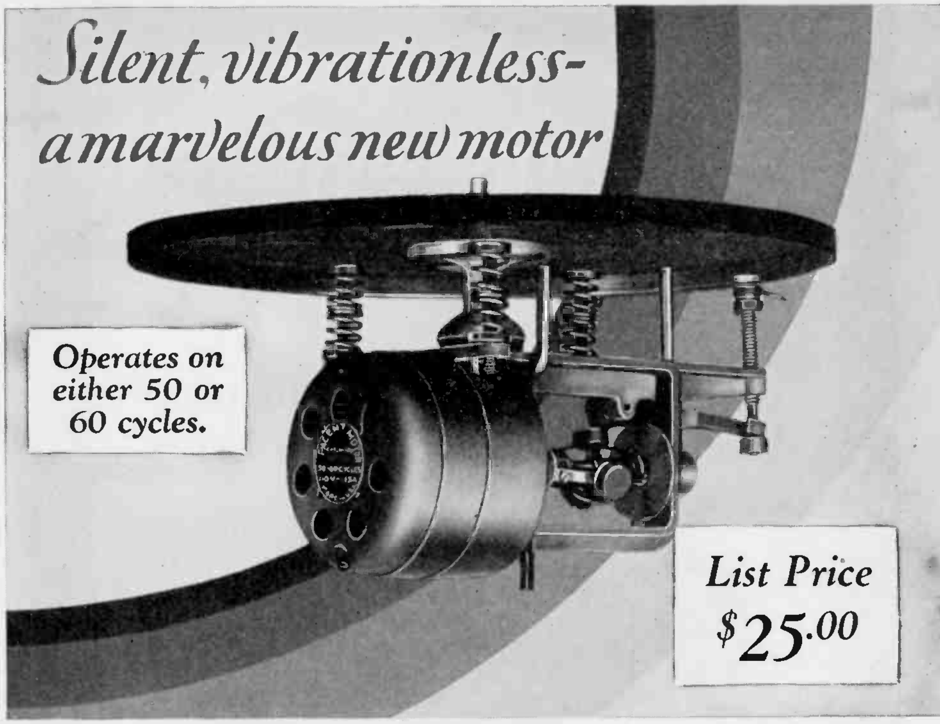


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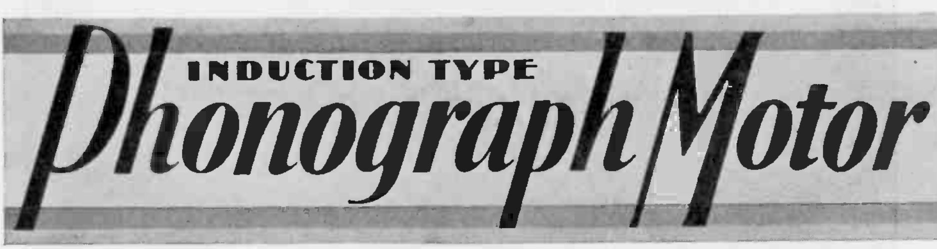

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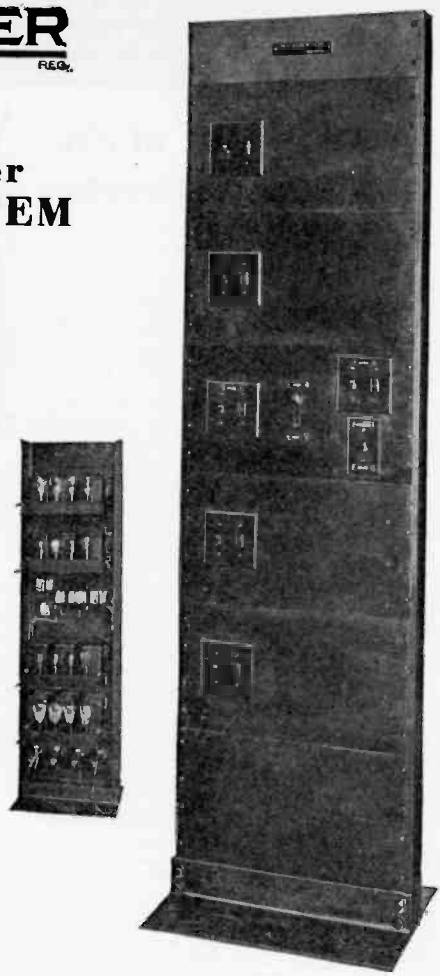

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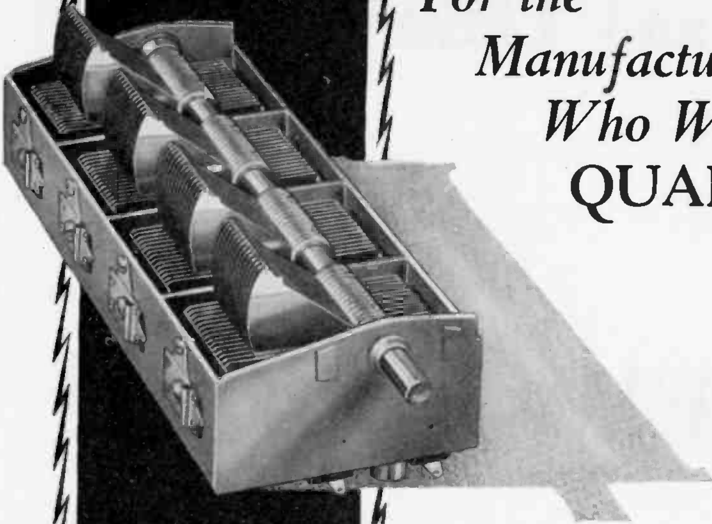

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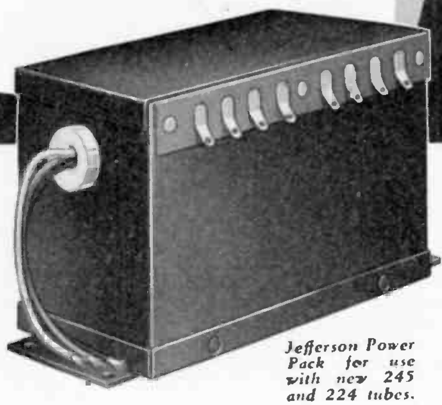

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I hereby make application for Associate membership in the Institute.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

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(Sign with pen)

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(Address for mail)

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(Date) (City and State)

**References:**

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Address............................ Address............................

Mr.................................. Mr..................................

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Mr..................................

Address............................

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The following extracts from the Constitution govern applications for admission in the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

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(Give full name, last name first)

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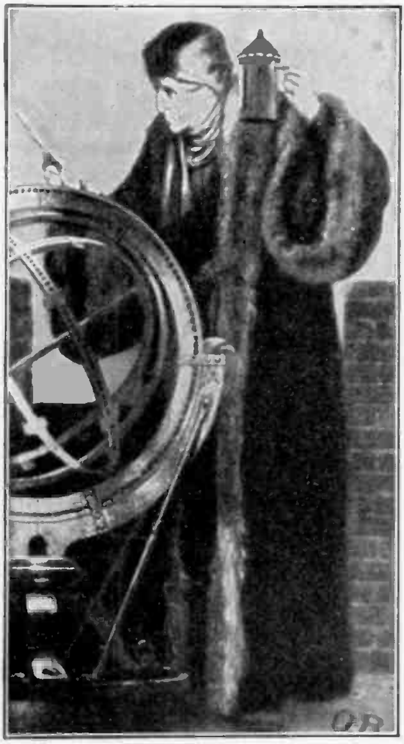

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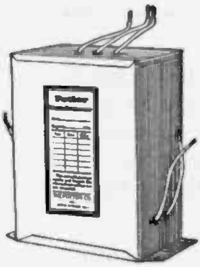

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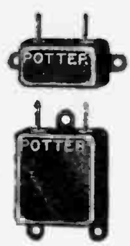


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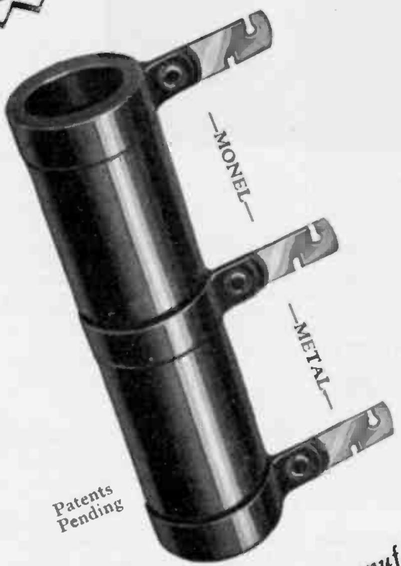


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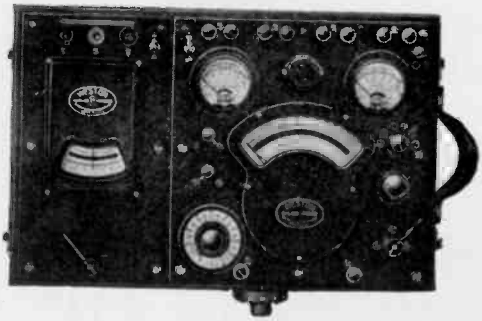

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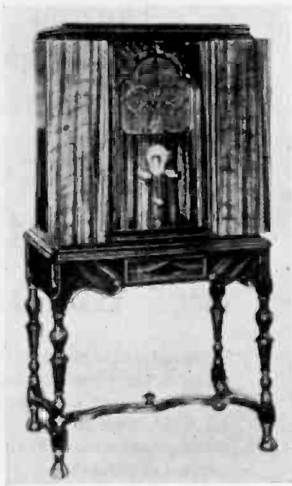

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Members of the Institute are asked to use this form for notifying the Institute office of a change in their mailing address or any change in the listing of their company affiliation or title for the Year Book membership list.

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The Secretary,
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33 West 39th Street,
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Dear Sir:

Effective ........................ please note change in my address
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*for mail* as follows:

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(City and State)

TO NEW ADDRESS

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Also for the membership list for next year's Year Book note change in my business address (or title) as follows, this is / is not my mailing address:

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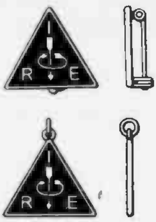
Three styles of Institute emblems, appropriately colored to indicate the various grades of membership in the Institute, are available. The approximate size of each emblem is that of the illustrations.



The lapel button is of 14k gold, the background being enamelled in the membership color, the lettering being gold. The button is supplied with a screw back with jaws which fasten it securely to the coat. This style emblem can be obtained for $2.75, postpaid, for any grade.

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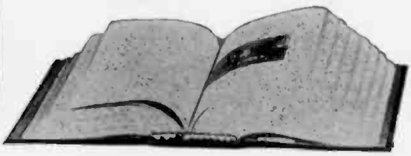
The binder pictured here contains over three inches of filing space. It is designed to accommodate a year's supply of PROCEEDINGS. It serves either as a temporary transfer binder or as a permanent cover. It is made of handsome Spanish Grain Fabrikoid in blue and gold. The binder is so constructed that



each individual copy of the PROCEEDINGS will lie flat when the pages are turned. Copies can be removed from the binder in a few seconds and can be permanently preserved in undamaged condition. Hundreds of these binders are sold each year. Price, $1.50 each, or $2.00 with the member's name or the PROCEEDINGS Volume Number stamped in gold.

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These prices are to members of the Institute.

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A copy of the current year book will be mailed to each member, when available. The 1927 and 1928 year books are available to members at $0.75 per copy, per year.

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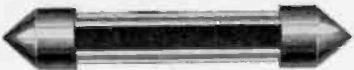

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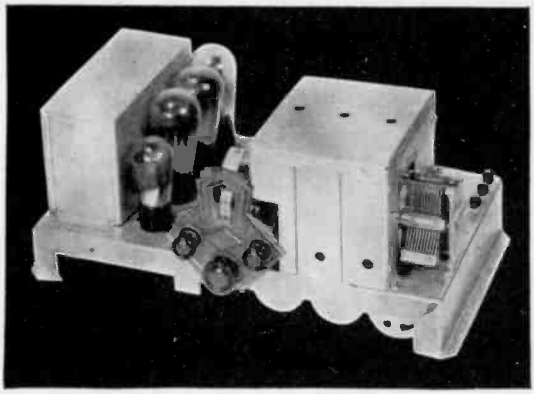

This year there is an entirely new keynote in designs for the setbuilder: CONVENIENCE. Formerly considered as the one feature monopolized by factory-built sets, *perfect convenience in operation* is now brought within the reach of all—and yet with even *better performance* than the *best* "kit sets" of last year—the S-M 720 and 710.

### THE SEVEN-TWELVE TUNER

### A Refinement of the Sargent-Rayment

For the setbuilder who wants the best regardless of cost, S-M is able to repeat the promise made *and kept* a year ago. The Sargent-Rayment 710 was acknowledged to stand head-and-shoulders above all other receivers offered at any price—and the same laboratory which perfected it now offers a further refinement in the S-M Seven-Twelve Tuner. Though not high-priced, the Seven-Twelve will this year duplicate the achievements of its illustrious predecessor and will *far surpass in performance* anything offered to the setbuilder at *any price whatsoever*. Built to realize every advantage of a precision band selector tuner entirely separate from its audio amplifier, the Seven-Twelve uses 224 a.c. screen-grid tubes in three r.f. stages, band-selector tuning, and power detector. Perfectly adapted to give to the 712 a tone quality in keeping with its own outstanding sensitivity and selectivity is the new 677 two-stage power amplifier (245 push-pull). The 712-677 combination will be the setbuilder's ace for 1930—and at a price that will astonish the most skeptical.

*Have you seen the intimate description of these three all-new S-M receivers as first printed in the S-M RADIOBUILDER? If you want to keep up-to-date on the new developments of the S-M laboratories, don't be without the RADIOBUILDER. Use the coupon.*

*Custom-builders who use S-M parts have profited tremendously throughout the past season through the Authorized S-M Service Station franchise. If you build professionally, let us tell you about it—write now.*

### S-M 722

### Band-Selector Seven

Far *better* in actual performance than the famous 720 and 720AC Screen-Grid Sixes, as well as more convenient, the 722 Band-Selector Seven is strictly all-electric, and tuned entirely by a single illuminated drum. It embodies a.c. screen-grid amplification in two r.f. stages, band-selector tuning, screen-grid power detection followed by resistance-coupled first r.f. stage, push-pull 245 output tubes, and provision for dynamic speaker. The 722 makes top-notch 1930 quality no more costly than merely mediocre reception.

### 735 ROUND-THE-WORLD SIX

### All-Electric—Short-Wave and Broadcast-Band

The first completely a.c.-operated short-wave receiver to be offered upon the American market. Built on the same chassis as the 722 illustrated above, the 735 demonstrates in short-wave reception the same mastery of design for the 224 a.c. screen-grid tube which distinguishes the new S-M broadcast receivers. Built into it also is a typical S-M two-stage audio amplifier with push-pull 245 tubes. Plug-in coils give a range of from 17 to 650 meters. Strictly one-dial tuning, full a.c. operation, and provision for dynamic speaker unite to make the 735 a real milestone in short-wave development.

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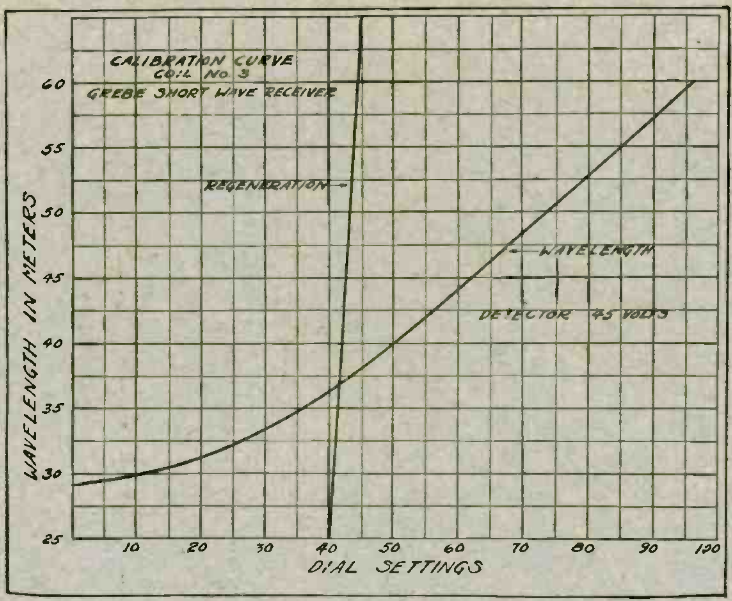


*Reproduced above is the calibration curve of Coil No. 3, Grebe Short Wave Receiver*

# Uniformity of Regeneration Control

A characteristic of the Grebe CR-18 Special Short Wave Receiver which appeals to the technical experimenter is the uniformity of generation control. The curve shown above gives a clear picture of this feature as applied to the use of Coil No. 3, for wave lengths of 28 to 58 meters.

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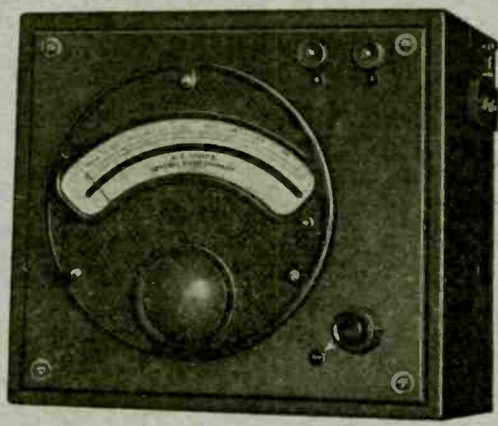
# Thermionic (Vacuum-Tube) Voltmeter



A calibrated, readily-portable vacuum-tube voltmeter has many uses in the laboratory where measurements are being made at audio and the lower radio frequencies. The Type 426-A Thermionic Voltmeter with a range of 0-3 volts weighs but 11 pounds (without batteries).

### *Details*

Meter uses the bridge circuit.

Calibrated to within 0.5% in r.m.s. volts.

Calibration good over entire audio-frequency range. Error at 20 kilocycles less than 2% of full scale, at 300 kilocycles less than 3% of full scale.

Small waveform error. A 20% third harmonic produces an error of only 0.4% in the meter reading.

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