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of
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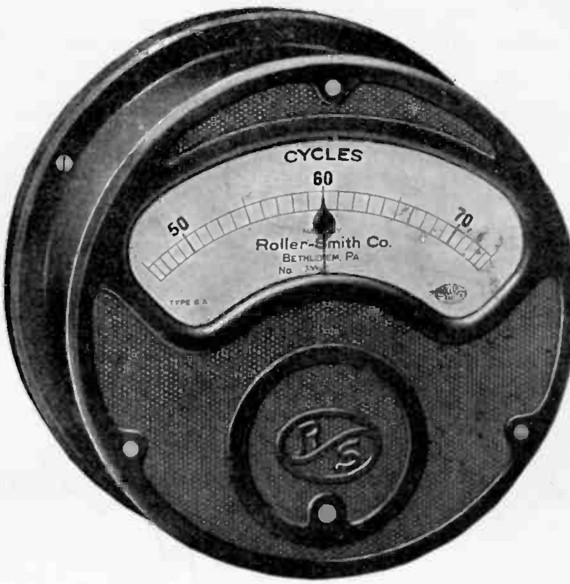

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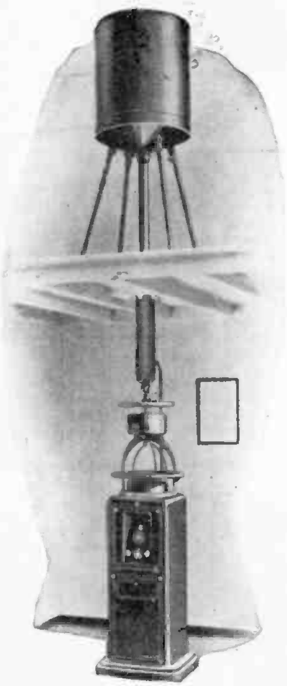

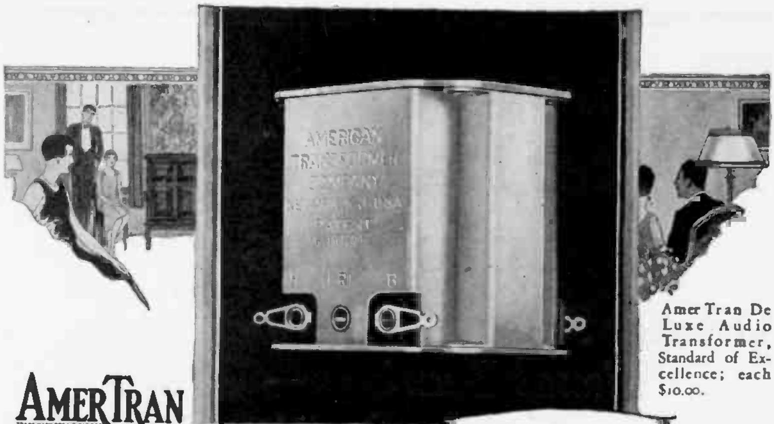

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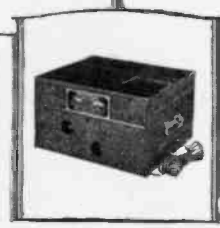

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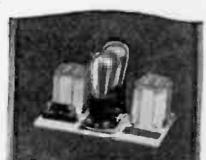

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The Institute of Radio Engineers

Volume 16 May, 1928 Number 5

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It is understood that the statements and opinions given in the PROCEEDINGS are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

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Greenleaf Whittier Pickard

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Greenleaf Whittier Pickard

SECOND PRESIDENT OF THE INSTITUTE, 1913

Greenleaf Whittier Pickard was born in Portland, Maine on February 14, 1877. He is the grandnephew of the poet, John Greenleaf Whittier. Mr. Pickard was educated at Westbrook Seminary, Westbrook, Maine; Lawrence Scientific School of Harvard University; and Massachusetts Institute of Technology.

In 1898–99 he was with the Blue Hill Observatory doing experimental radio work. For several years he was research engineer for the American Wireless Telegraph and Telephone Company. In 1902–06 he was associated with the research department of the American Telephone and Telegraph Company in radio telephony. He practiced consulting engineering in 1906–7. Since 1907 he has been a consulting engineer for and director of the Wireless Specialty Apparatus Company of Boston.

Mr. Pickard is well-known for his early inventions in connection with radio telephony, the crystal detector, loop aerials and direction-finding systems and various static mitigating devices used during the war. He has about one hundred United States and foreign patents.

In 1926 the Institute Medal of Honor was awarded to Mr. Pickard. He has been a prolific contributor to the PROCEEDINGS of the Institute. Mr. Pickard is a Fellow of the Institute.

CONTRIBUTORS TO THIS ISSUE

Ballantine, Stuart: (See PROCEEDINGS for April, 1928).

Byrnes, Irving F.: Born at Beacon, N. Y., October 15, 1898. Entered General Electric Test Department in 1918. Engaged in laboratory work on earlier types of tube transmitters, 1919–21. Developed duplex radiophone equipment used on S. S. America for ship-to-shore tests in 1922. Developed crystal control equipment now in use at stations WEAF WGY, KGO and KOA. At present engaged in development work on commercial and military high-frequency transmitters, aircraft radio equipment, crystal control, and train communication apparatus. Associate member of the Institute.

Dellinger, J. H.: Born at Cleveland, Ohio, July 3, 1886. Educated at Western Reserve, 1903–07, George Washington University (A.B. degree 1908); fellow at Princeton 1912–13 from which university received the Ph.D. degree in 1913. Instructor in Physics, Western Reserve 1906–07. U. S. delegate, Interallied Technical Conference on Radio Communication, Paris, 1921; Secretary, U. S. Government Interdepartmental Radio Advisory Committee, 1922–23; Member National Radio Conference, 1922–25; technical secretary, American Section, International Union Scientific Radiotelegraphy. Since 1907 physicist and later chief of radio section of Bureau of Standards, Washington. Vice-President of the Institute, 1924, and President in 1925. Fellow in the Institute.

Friis, H. T.: Educated at Royal Technical College in Copenhagen, 1916; Columbia University, 1919–20. In Research Department, Western Electric Company, 1920–24; Bell Telephone Laboratories, 1925 to date. Mr. Friis' work has been largely in connection with radio reception methods and measurements. He has published papers on vacuum tubes as generators, radio transmission measurements, and static interference. Member of the Institute.

Judson, E. B.: In Naval radio service 1917–1919. Laboratorian at U. S. Naval Research Laboratory, Bureau of Standards, 1919–23. 1923 to date assistant to Dr. L. W. Austin in Laboratory for Special Radio Transmission Research, Bureau of Standards. Junior in Electrical Engineering School, George Washington University. Associate member of the Institute.

Pratt, Haraden: Born July 18, 1891 at San Francisco, Calif. Graduated from College of Mech. and Elec. Engineering, University of California, 1914. Radio operator and installer United Wireless and Marconi Companies, 1910–13. Expert Radio Aide to Navy Department 1915–20. Engineer with Federal Telegraph Company in charge of research, factory and design and construction of chain of radio stations, 1922–27. At present in charge of development of radio aids to air navigation, Bureau of Standards, Washington. Member of the Institute.

Schneider, W. A.: Born at East London, South Africa, January, 1899. Received B.Sc. degree from University of South Africa, 1920; M.S. degree from University of Michigan, 1922, and Ph.D. New York University, 1927. Instructor in Physics, New York University, 1923. Assistant Professor of Physics, New York University 1927——. In charge of electrical measurements and high-frequency laboratory, Washington Square College, New York University. Member of the Institute and of the American Physical Society and Sigma Xi.

Taylor, A. Hoyt: (See PROCEEDINGS for February, 1928).

Young, L. C.: Born at Danville, Illinois, January 12, 1891. Amateur experimental work 1909–17. Telephone and Telegraph Department, Western Division of Pennsylvania Railroad 1912–17. Experimental radio work under Lt. Cmdr. A. H. Taylor at Great Lakes Naval Station, Ill., Belmar, N.J., and Hampton Roads, Virginia, 1917–1919. Aircraft Radio Section, Bureau of Standards, 1919. Since then research work at Radio Division, Naval Research Laboratory, Anacostia, D.C. Associate member of the Institute.

INSTITUTE ACTIVITIES

April Meeting of the Board of Direction

At the April meeting of the Board of Direction, held in the offices of the Institute on the fourth, the following were present: Alfred N. Goldsmith, President; L. E. Whittemore, Vice-President; Melville Eastham, Treasurer; Ralph Bown and Donald McNicol, Junior Past Presidents; Arthur Batcheller, J. H. Dellinger, A. H. Grebe, R. A. Heising, R. H. Marriott, and J. M. Clayton, Secretary.

The following were transferred or elected to the higher grades of membership in the Institute, upon favorable recommendation of the Committee on Admissions: Transferred to the Member grade: F. L. Brittin, C. L. Davis, F. P. Guthrie. Elected to the Member grade: Nathaniel Baldwin, A. L. Loomis, W. A. Schneider, Alexander Senauke, John S. Smith, H. J. Warner.

One hundred and eight Associate members and ten Junior members were elected.

The Institute's Medal of Honor for 1928 was awarded to Professor Jonathan Zenneck of the Technische Hochschule, Muenchen, Germany, for his contributions to original research on radio circuit performance and to the scientific and educational contributions to the literature of the pioneer radio art.

Letters from the Federal Radio Commission, requesting certain suggestions from the Institute regarding the allocation of Broadcast channels to Zones and States were read. It was decided that the invitation of the Commission to send representatives to an informal conference of engineers to be held in Washington on April 6th to discuss these matters should be accepted. A Committee composed of the following members of the Institute was appointed: R. H. Marriott, Chairman; J. H. Dellinger, C. W. Horn, and L. E. Whittemore. The joint report of the engineers present at the conference is printed on page 556 of this issue.

An invitation from the Washington Section of the Institute to hold the 1929 Convention of the Institute in Washington, D.C. was read. The Board voted to accept this invitation, and decided that the 1929 Institute Convention will be held in Washington.

Engineering Rise in Radio

The above is the title of a serial account of the rise and progress of radio, from the engineering and invention viewpoints, which has been written by Donald McNicol, past president of the Institute. The story begins in the June, 1928 issue of the magazine *Radio Engineering* published in New York, and will be continued in the monthly issues throughout the year.

Applications for Transfer or Election

It is very helpful if applicants for transfer or election to the higher grades of membership in the Institute (Member and Fellow) will forward a statement of their training and past experience to the persons whose names are used as references in connection with applications. Much time on the part of the Committee on Admissions in communicating with references will be saved.

In general where the Junior or Associate applicant does not know five Associates, Members or Fellows whose names can be used as references, it will be acceptable if these applicants furnish the names of five non-member engineers, or persons who are otherwise engaged in scientific work, who are personally familiar with the applicant and his radio interests.

Institute Meetings

New York Meeting

I. F. Byrnes, of the General Electric Company, presented a paper "Recent Developments in Low Power and Broadcasting Transmitters" at the New York meeting held on April 4th in the Engineering Societies Building, 33 West 39th Street. The paper is printed elsewhere in this issue.

Following the presentation of the paper the following members took part in its discussion: Messrs. F. M. Ryan, Melville Eastham, A. N. Goldsmith, J. H. Dellinger, I. F. Byrnes, E. L. Nelson, and others.

Over three hundred members of the Institute and their guests attended this meeting.

On May 2nd K. S. Van Dyke of Wesleyan University will read a paper "The Piezo-Electric Resonator and its Equivalent Network" before the New York meeting.

On June 6th two papers will be presented before a New York meeting. They are "Developments of Radio Aids to Air Navigation" by J. H. Dellinger and Haraden Pratt, of the Bureau of Standards, and "Aircraft Radio Installations" by Malcolm P. Hanson, of the Radio Division, Naval Research Laboratory.

Atlanta Section

On March 28th a meeting of the Atlanta Section was held in the Chamber of Commerce Building. Mr. Clark of the A. H. Grebe Company presented a paper "Radio-Frequency Receiving Sets."

On April 4th, in the Chamber of Commerce Building, a meeting of the Atlanta Section was addressed by M. O. Mosteller on "Shield Grid Tubes." A second paper by I. F. Byrnes on "Recent Developments in Low Power and Broadcasting Transmitters" was read by C. F. Daugherty.

Buffalo-Niagara Section

A meeting of the Buffalo-Niagara Section was held in Foster Hall, University of Buffalo, on March 14th. William E. Brindley, of the Radio Engineering Department, Westinghouse Electric and Manufacturing Company, presented a paper on "Line Power Operated Radio Sets."

The paper pointed out the public's preference for economies and conveniences of the line-power operated radio broadcast receivers as justification for the further development and production of this type of apparatus.

In order that the relative merits of the two generally accepted methods of accomplishing light-socket operation might be plainly evident, the series filament method was described first. The method, which involves the use of tubes whose filaments are heated by alternating current, was then discussed. This discussion involved the means for lighting the filaments of a-c. tubes, and for obtaining suitable plate and bias voltages; the precautions taken to prevent undesirable couplings between the various amplifier circuits of the receiver; means for locating grid returns at the electrical center of the filaments to keep hum at a minimum; input voltage regulation; line voltage accommodation and utilization of electro-dynamic d-c. excited cone speakers with line-power operated sets.

On April 11th there will be a joint meeting between the Canadian, Rochester, and Buffalo-Niagara Sections in Foster Hall, University of Buffalo.

Canadian Section

The Canadian Section held its March meeting on the fourteenth in the University of Toronto. R. A. Hitchcock, of the Radio Engineering Department, Westinghouse Electric and Manufacturing Company, presented a paper, "Quartz Radio Frequency Standards." Messrs. Soucy, D. De F. Bagley, D. Hepburn, T. R. Rosebrugh, C. A. Lowry, and J. F. Hill discussed the paper.

Seventy-four members attended the meeting.

On Wednesday, May 2nd, Mr. Clark, of the Bell Telephone Company of Montreal, will present a paper on "Carrier Current Communication," in the Electrical Building, University of Toronto.

Chicago Section

A meeting of the Chicago Section was held on March 16th in the Auditorium of the Western Society of Engineers, Monadnock Building. Walter Danley presented a paper "A High-Frequency Filament Lighting Supply System." The paper was discussed by Messrs. Miller, Marco, and Wilcox.

Forty-four members attended this meeting.

Cleveland Section

A meeting of the Cleveland Section was held on April 6th in the Case School of Applied Science. Clayton C. Russell, engineer of station WTAM, presented a paper on "Behind the Microphone of WTAM." The paper described the aerial, station, and equipment of WTAM, the first storage battery operated radio station. Pictures were projected to illustrate fully present and past equipment in use at the station.

Forty-two members attended the meeting.

Detroit Section

The Detroit Section of the Institute held a joint meeting with the Detroit-Ann Arbor section of the American Institute of Electrical Engineers on the evening of March 20th in the auditorium of the Detroit Edison Company. After viewing an interesting motion picture entitled "Voices Across the Sea," which portrayed the transatlantic telephone circuit in operation, F. H. Riddle, Chairman, presented the principal speaker of the evening.

Austin Bailey, of the American Telephone and Telegraph Company, presented "The Transatlantic Radio Telephone Circuit." He presented the problem of connecting the respective telephone systems of North America and Europe, separated by over 3,000 miles of ocean. The speaker indicated that the most feasible way of carrying out this connection, for the present at least, appeared to be by the use of radio. Some of the major difficulties involved in making such a connection were pointed out. From the fundamental radio telephone circuit which might be used for communication between two individuals on two sides of the Atlantic ocean, consisting of a radio transmitting station, a radio receiving station, a telephone transmitter, and a telephone receiver for each person, the present transatlantic radio telephone arrangement was developed. A rather detailed account of the wire circuit arrangements, the voice-operated switching device, the single side-band radio transmitter, the receiving wave antenna and the double demodulation radio receiver was given. Lantern slides of schematic circuits and of the necessarily complicated apparatus units were shown and explained.

Los Angeles Section

The Los Angeles Section of the Institute met on March 19th at the Elite Cafe, 633 S. Flower Street, Los Angeles. T. F. McDonough, in the absence of Mr. Wallace, the Section Chairman, presided. R. B. Parrish, Consulting Engineer of Los Angeles, talked on inductive radio interference and power leak hunting. Bert Fox described some interesting short wave experiments.

Twenty-two members attended the meeting.

Philadelphia Section

The Philadelphia Section held a meeting on March 23rd in the Bartol Laboratories, Philadelphia. W. E. Thompson, of the Moore School of Electrical Engineering of the University of Pennsylvania, presented a paper on "Sound." Messrs. Patterson, Wilson, and others discussed the paper.

Sixty members of the Section attended the meeting.

Pittsburgh Section

The first organization meeting of the newly formed Pittsburgh Section was held on April 3rd in the English Room of the Fort Pitt Hotel.

The following officers were elected: Chairman, W. K. Thomas; Vice-Chairman, L. A. Terven; Secretary, A. J. Buzzard, and Treasurer, Anthony Mag.

A paper entitled "Televox" was presented by R. J. Wensley, of the Westinghouse Electric and Manufacturing Company.

Forty-nine members attended this meeting.

Rochester Section

A meeting of the Rochester Section together with the Rochester Engineering Society and affiliated societies was held on March 2nd in the Rochester Chamber of Commerce Building.

Hugh M. Stoller, of the Bell Telephone Laboratories, presented a paper, "Television." Five hundred and seventy-eight persons attended the meeting.

On April 6th a meeting of the Rochester Section was held in the Hotel Sagamore. C. A. Boddie, of the Radio Research Engineering Department of the Westinghouse Electric and Manufacturing Company, presented a paper, "Carrier Current Communication and Control."

Washington Section

The following committees are announced by F. P. Guthrie, Chairman of the Washington Section: Membership Committee: Haraden Pratt, Chairman, G. D. Robinson, C. B. Mirick, Comdr. B. V. McCandlish, Eugene Sibley, J. E. Smith and C. D. Backus. Publicity Committee: R. D. Heinle, Chairman; Carl Butman, Thomas Stevenson, Bert Linz, and S. R. Winters. Meetings and Papers Committee: L. P. Wheeler, Chairman, Captain Guy Hull, and T. Parkinson.

A meeting of the Washington Section was held on April 12th in Picardi's Cafe, 1417 New York Avenue, N. W. Dr. C. B. Jolliffe (Vice-Chairman) presided.

Alfred Crossley, of the Naval Research Laboratory, presented a paper, "Modes of Vibration in Piezo-Electric Crystals." Messrs. Dellinger, Wheeler, Robinson, Jolliffe, Brewington, Hund, Herndon, Heaton, and others participated in the discussion which followed.

Fifty-seven members attended the meeting.

On May 10th two papers will be presented before the Section. The first, by M. P. Hanson of the Naval Research Laboratory, will be "Aircraft Radio Installations." The second, by J. H. Dellinger and Haraden Pratt, will be on "Radio Aids to Air Navigation."

Institute Committees

Radio Advisory Committee, Department of Commerce

Lewis M. Hull has been appointed the Institute's representative to the Radio Advisory Committee to the Department of of Commerce, to succeed Professor L. A. Hazeltine.

Subcommittee on Receiving Sets

A meeting of the Subcommittee on Receiving Sets was held at the Institute Office on March 7th. Those present were: J. H. Dellinger (Chairman), E. Austin, E. J. T. Moore, B. Olney, M. C. Batsel, C. A. Wright, J. H. Pressley, G. C. Crom, W. A. Diehl, E. T. Dickey, and V. M. Graham.

The subject of changing the value for Interference Output was brought up, and after some discussion it was decided to change this value under Definition of Terms from 0.000005 to 0.00005 watts (50 microwatts). The report of the Committee on Additional Tests was read and discussed. A number of changes were recommended, and the report was referred back to the Committee to be rewritten in final form. The report of the Committee on Test Procedure was next taken up, and it was decided that some change should be made in the output termination for receiving sets. It was decided to refer this matter to a committee of four, to consist of two members from the Subcommittee on Receiving Sets, and two members from the Subcommittee on Electro-Acoustic Devices.

Dr. Dellinger informed the Committee that he felt it would be impossible for him to continue to serve as Chairman of the Subcommittee due to his having accepted the chairmanship of the Committee on Meetings and Papers.

Mr. E. T. Dickey has been appointed Chairman of the Subcommittee on Receiving Sets.

On April 5th a meeting of the Subcommittee on Receiving Sets was held in the Institute Office. Those present were: E. T.

Dickey (Chairman), R. H. Langley, E. Austin, C. A. Wright, G. C. Crom, V. D. Landon, E. J. T. Moore, and W. A. Diehl.

I. G. Maloff was appointed representative from this Subcommittee to the Subcommittee on Bibliography.

The purpose of this meeting was to coordinate the work which had been done so far along the line of revising the Receiving Set Test Standards. The various sections of the standards were gone over in considerable detail, and recommendations made regarding their improvement. It was decided to put the final writing up of the standards in the hands of the Subcommittee, the membership of which is as follows: E. Austin (Chairman), L. M. Hull, and V. M. Graham. This committee is to review the entire standards for the Receiving Sets Subcommittee, and their report will be circulated among the membership of the Receiving Sets Subcommittee and then presented to the main Committee for further consideration.

A letter was read from the Bureau of Standards in reference to a proposed change in their standard frequency schedules. It was the opinion of the Subcommittee that it would be desirable to rearrange their schedule so that the complete broadcast band of frequencies may be covered in one evening's transmission of standard frequencies.

Subcommittee on Electro-Acoustic Devices

The final meeting of the 1927 Subcommittee on Electro-Acoustic Devices of the Standardization Committee of the Institute was held at Institute headquarters on March 7th. Final action was taken on a number of general terms and definitions that had not been the subject of written discussion. The reports of two of the Subcommittees, one covering definitions of horns and radiators and the other covering suggested symbols to be used in connection with the definitions of Electro-Acoustic Devices, were considered, but not finally acted upon. A report covering all terms and definitions that had been adopted by this Subcommittee, together with a file of unfinished matters, is being prepared for submission to the main Committee.

At the request of the Subcommittee on Receiving Sets the Chairman appointed Melville Eastham and H. A. Frederick as members of a special Subcommittee to cooperate with a similar group from the Receiving Sets Subcommittee with the object of specifying the nature of the load in the testing of radio receiving sets.

The Chairman expressed his appreciation to the members of the Subcommittee for their cooperation and work in preparing the first set of terms and definitions of electro-acoustic devices to be proposed by an Institute Committee.

Report of Radio Engineers to the Federal Radio Commission

At the request of the Federal Radio Commission, the Board of Direction of the Institute appointed a committee to attend the informal conference of engineers to consider proposed broadcasting channel allocation. The report which follows is a report of the recommendations of engineers present at the Conference, and was prepared by J. H. Dellinger, Acting Chairman of the conference held in Washington on April 6, 1928.

Resolution

It is the opinion of the engineers in attendance that from a radio engineering standpoint, under the provisions of the 1928 law requiring equality between zones, Plan A, submitted for discussion by the Commission, modified as follows, represents the maximum obtainable radio service from the available broadcasting channels in the present state of the art.

	Channels		Full Time Assignments	
	Per Zone	U. S.	Per Zone	U. S.
Class C 5,000 to 50,000 watts	10	50	10	50
Class B 300 to 1,000 watts	18	36	18	90
Class A 0 to 250 watts	4	4	40	200

Discussion

Division into Classes.—The readjustment of station allocations required by the 1928 Radio Law gives the Radio Commission an opportunity to provide the radio listeners of the United States with a grade of radio broadcasting service far superior to that furnished under the present allocation of stations. A redistribution of broadcasting stations among the states will result, if the proposed classification of services be established, in the satisfactory reception of more programs at a higher signal strength by a greater number of listeners in a larger total area than at present, and will do this with less interference than now exists.

The fundamental change required to bring about any material improvement is to provide a considerable number of channels upon which only one station operates. The reason for this is purely physical fact. Since heterodyne interference extends to many times the distance to which actual program service from a broadcasting station extends, operation of two or more stations on a channel results in an area of destructive interference much greater than the area in which program service is provided. Program service, free from interference, can be furnished at great distances from a station only when the station has exclusive use of its channel.

Since there are only 90 channels available for broadcasting in the U. S., ninety is the upper limit of the possible number of stations giving service at considerable distances.

When two or more stations operate simultaneously on a channel, program service can be furnished at short distances from each station without destructive heterodyne interference within that distance, provided the stations are located at proper distances apart corresponding to the power used. Under these conditions many stations can be operated for short-distance local service on a single channel. Outside the local service areas heterodyne interference will prevent satisfactory reception.

Sections of the country remote from centers of population can not be given service except by the stations first mentioned, which have exclusive use of their channels (Class C).

It follows that the country as a whole can be given the service it demands only by having more than one class of station, (1) long-distance stations operating on exclusive channels, (2) shorter-distance stations, operating on shared channels. Considering the broadcasting needs and development in this country, it is apparent that the second class can advantageously be subdivided into stations of moderate distance range (Class B) and small stations of very small distance range (Class A).

Number of Channels in Each Class.—The number of channels (50) indicated for Class C stations is the minimum that should be provided, in view of the far greater service, both distant and local, that will be rendered by such channels, owing to to the absence of heterodyne interference and the consequent possibility of the use of greater power. The distribution of the remaining 40 channels between Classes B and A represents the best judgment of the engineers from present information. A further study should be made of this point on the basis of service requirements of various areas of the country. It is believed that the final answer on this point will not depart widely from the figures given.

Duplication of Assignments Per Channel.—It is clear that the stations depended upon for service over large areas must that the stations depended upon for service over large areas must operate on heterodyne-free channels and that therefore there must be only one assignment to each Class C channel.

The moderate-distance (Class B) and short-distance (Class A) channels may each be used by a number of stations in simultaneous operation, since the only desideratum is good service within the local service range of each station. The power required for moderate-distance service (Class B) will not permit as much duplication of stations on one channel as will the smaller power required for short-distance service (Class A).

The amount of duplication recommended is: for each Class B channel, on the average of two and a half assignments in the U. S. (i.e., the assignment of every other channel in each zone): and for each Class C channel, 50 assignments in the U. S. (10 in each zone).

The limitation to two and a half assignments for each Class B channel is determined by the geographical circumstances of the two smallest zones (1 and 2), together with the requirement of the law of equality between zones. Points in zones 1 and 2 average less than 500 miles apart, a distance too small to permit the assignment of any one channel in both zones with recommended power.

Equality with Respect to Classes.—The provisions of the law requiring equal distribution among zones, and, according to population, among the states, of station licenses, frequencies, time, and power, must be applied separately to each of the three classes of stations mentioned. This results from the inclusion of the number of licenses as one of the elements of equal distribution.

Station Power.—In order to merit the use of a Class C channel a station must be competent to serve a large area. It follows that no Class C station should be allowed to operate with less than 5,000 watts power. The only upper limit for this class need be that fixed by the production of inter-channel interference, and, in consideration of the geographical distribution possible, may be 50,000 watts at the present time.

For the moderate-distance (Class B) channels powers of 300 to 1,000 watts will give satisfactory service, and for the short-distance (Class A) channels power should not exceed 250 watts per station because of the extensive duplication permitted.

As an exception to these general recommendations for Classes B and A, it is noted that where two or more stations operating on the same channel are all increased in power by the same factor, their heterodyne-free service ranges will be substantially unaffected and a better signal (with respect to noise interference) will be delivered within each service area. This will be at the expense of producing a stronger heterodyne whistle outside the service areas of the two stations concerned.

Time Division.—The expedient of time division does not in general lead to superior service to the listener. It is inherently uneconomic. Where several stations in an area are now dividing time, the duplication of plant and overhead necessarily results in poorer service than would result were these stations to be consolidated into a single station using all the time.

For the Class C stations praticularly, time division should not be allowed. An exclusive (Class C) channel is capable of delivering such excellent service over large areas that care should be taken to restrict the possible service from these channels by an uneconomic arrangement such as time division.

For the Class B and Class A channels there will doubtless be local conditions demanding, and perhaps justifying, time division in spite of its inherently uneconomic nature. However, the application of time division has been made difficult under the terms of the new law. Since the law requires equality of the number of hours and licenses among zones, and, according to population, among the states within each zone, if time is divided on a given channel among several stations in any one state, this division must be duplicated on some channel in every other zone and proportionally in every state.

The same difficulty will exist in any attempt to divide time between stations located in different zones, as might be sought, e.g., to take advantage of the time difference between the east and the west coasts. Time division between stations in widely separated localities is subject to the further objection of seriously complicating the maintenance of the proper frequency separation between stations in each of the localities to minimize inter-channel interference.

OBITUARY

With deep regret the Institute announces the death of

Thomas R. Bristol

Mr. Bristol served both as President and Secretary of the Atlanta Association of Radio Engineers, and the growth of that organization which permitted its incorporation into a Section of the Institute of Radio Engineers was mainly due to his untiring efforts.

As an official of the Georgia Power Company, a leader in the activities of the Atlanta Section, and as a friend, he won the respect and admiration of all with whom he came in contact. The Section and his many friends throughout the South feel the loss of this ardent worker most keenly.

STUDIES OF HIGH-FREQUENCY RADIO WAVE PROPAGATION*

By

A. Hoyt Taylor and L. C. Young

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

Summary—Studies of multiple signals of high frequency have been made upon a quantitative basis with reference not only to the round-the-world signals (sometimes called echo signals) but to nearby echoes which have a very much shorter time of arrival. A method of predicting in advance the the likelihood of round-the-world echoes occurring between any two different stations has been worked out.

Further studies of nearby echoes show a remarkable retardation on very high-frequency signals coming from the Rocky Point stations to Washington, these signals traveling an actual distance varying from 2900 kms. to over 10,000 kms., although the great circle distance is only 420 kms. The apparent violation of the skip distance law by these stations as observed in Washington has been explained. The nearby echo signals have been tentatively assumed to be due either to reflections from a heavily ionized region in the neighborhood of the magnetic poles or more likely to be due to scattered reflections thrown backwards from the first and second zones of reception, which follow the skip distance region. This throwing back of the signal thus permits under certain conditions the reception of the signal on very high frequency within what is really the skipped zone, the signal having entered this zone by a very indirect route and with a considerable time retardation as compared with the direct route.

Influence of both nearby and round-the-world echo signals upon various types of radio communication have been briefly discussed.

FOR some time the Naval Research Laboratory has been interested in the study of so-called echo signals, particularly those which travel entirely around the world. Early in the fall of 1927 it was decided to put these studies on a quantitative measurement basis in the hope of obtaining information which would be of value in the more general study of wave propagation in theory and practice. It was expected that these studies would throw additional light upon the structure of the Heaviside layer and its daily and seasonal variations. Early in these studies, however, certain phenomena manifested themselves which gave added incentive.

There are, of course, many questions bearing on wave propagation that are by no means cleared up at the present time but among them are several which are of considerable theoretical

* Original Manuscript Received by the Institute, March 12, 1928.

* Presented before meeting of Washington Section of the Institute, March 8, 1928.

and practical interest and which may be mentioned at the outset of this report:

(1) Why are signals usually received during the daylight hours in Washington from the Radio Corporation's group of stations at Rocky Point, operating on frequencies so high that Washington is well inside of the skip distance zone? This point was raised in a paper by Dr. A. H. Taylor[1].

(2) Why do distant stations show what may be termed a normal time interval for round-the-world signals, whereas the Radio Corporation group as measured in Washington invariably show time intervals notably shorter than the normal time interval? These two questions are intimately related.

(3) Can any further explanation be given of the fact that high-frequency signals usually show the worst fading at moderate distances and much less fading at the extreme limits of the range?

(4) What influence will echo signals, so-called, or multiple signals, which is a better designation, have practically upon low-speed telegraphy, high-speed telegraphy, telephony, facsimile transmission and television?

(5) To what degree can directive transmitting and receiving systems be expected to suppress multiple signals?

(6) During what hours of the day and what seasons of the year are different types of multiple signals to be expected?

(7) Finally, whether there is anything in the nature of echo signals which is in contradiction with the general theoretical principles already laid down.

This paper being only in the nature of a preliminary report we do not by any means pretend to give final answers to all these questions, but it is believed that it will throw considerable light upon some of them and introduce possibly some new speculations which may at least stimulate constructive criticism, comment, and further work along similar lines in other parts of the world, which we believe to be the only means of finally settling some of these questions.

Turning to the consideration of multiple signals which are due to waves which have traveled around the world in the sense opposite to the direction from transmitter to receiver, a number of observations will be presented giving the equivalent time for the signals to pass entirely around the world, these times

[1] Proc. I.R.E., **14**, p. 539, August, 1926.

being based on the observed time differences between the direct and the rearward signal; namely, between the signal coming by the short route transmitter to receiver and the one coming by the long route in the opposite way around the world.

It should perhaps be explained at this point that records were made upon a Westinghouse multiple tower oscillograph and by the use of two superheterodyne receivers using different transfer frequencies and usually operating on antennas of different directivity. Another way to handle these two receivers is to use the same transfer frequency and the same heterodyne, thus avoiding whistling between the receivers. The fact that the higher frequencies from San Francisco failed to go around

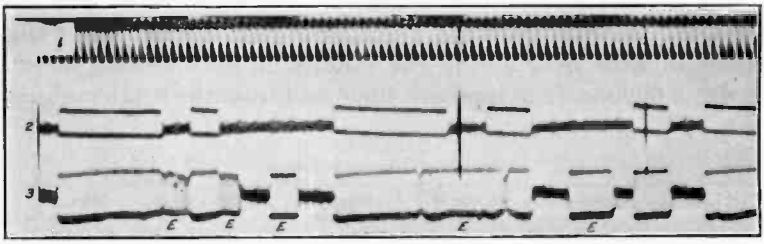

Fig. 1—Around-the-World Signals from PQW, Lisbon, 9:15 A.M., December 8, 1927. Frequency 19,180 kc.

seems to agree with the theoretical deduction that the height of the layer seldom averages low enough on the necessary great circle for 16,700 kc. and therefore would rarely, if ever, be low enough to carry around the still higher frequency.

The expression "height of the Heaviside layer" as used in this paper means the height of the equivalent reflecting layer. It does not mean the height at which the electron concentration is the maximum. In reducing path retardations to a time basis the velocity of light in free space has been used so as to put all observations upon simple comparative basis. No allowance has been made for the number of reflections which a wave might make in going from one point to another either by direct or indirect routes. Such corrections would slightly modify the time figures but not by any large amount.

Fig. 1 shows an observation taken on PQW, Lisbon, the multiple signal being marked *E*. The frequency here under observation is approximately 19,000 kc. The time of this particular observation was 9:15 A.M. Washington time. This figure shows multiple signals which are almost of the same order of intensity as the direct signals and almost equally clearcut. The observation was taken also in such a way as to indicate the direction from which the echo signal came. The line 1 on the top of the figure is the timing line from a 100-cycle tuning fork. Line 2 which shows the direct signals practically without echoes was taken on an antenna highly directive towards Lisbon, whereas line 3 which shows the echoes as well as the direct signals was taken on an antenna having strong westerly directivity. This directivity is, of course, not sharp enough to shut out the direct signal from Lisbon but is good enough to emphasize greatly the strength of the echo signal. Our general conclusion from a great many studies of this sort is that echo signals from European stations generally come in during the fall and early winter months best during the middle of the morning hours, say from 0900 to 1200 zone five time[2] and from the southwesterly

TABLE I
ECHOES ON DISTANT STATIONS

Call Letter	Location	Time of Observation	Observed Time	Around World Equivalent	Freq. kc. (approximately)
NPG	San Francisco	1310	0.1120	0.1393	16700
"	U. S. A.	1410	0.1130	0.1405	16700
"	"	1410	0.1130	0.1405	16700
"	"	1420	0.1125	0.1400	16700
"	"	1420	0.1120	0.1393	16700
"	"	1420	0.1125	0.1400	16700
AGA	Nauen	0905	0.0920	0.1382	20250
"	Germany	0908	0.0920	0.1382	20250
"	"	0915	0.0920	0.1382	20250
"	"	0915	0.0910	0.1367	20250
PQW	Lisbon Portugal	0915	0.0980	0.1374	19180
"	"	0915	0.0990	0.1386	19180
"	"	0915	0.0975	0.1352	19180
"	"	0920	0.0975	0.1352	19180
"	"	1110	0.0985	0.1380	19180
"	"	1110	0.0980	0.1374	19180
"	"	1110	0.0985	0.1380	19180
"	"	1010	0.0985	0.1380	19180
PCPP	Kootwijk Holland	0920	0.0950	0.1362	18600
"	"	0930	0.0925	0.1326	18600
"	"	0931	0.0940	0.1347	18600
"	"	0930	0.0940	0.1347	18600
"	"	0905	0.0960	0.1376	18600
"	"	0905	0.0960	0.1376	18600
"	"	0905	0.0970	0.1390	18600
"	"	0912	0.0965	0.1383	18600
"	"	0855	0.0930	0.1333	18600
"	"	0855	0.0940	0.1347	18600
"	"	0858	0.0965	0.1383	18600
PCRR	Kootwijk Holland	0926	0.0960	0.1376	14600
"	"	0928	0.0960	0.1376	14600
"	"	0928	0.0940	0.1347	14600
"	"	0928	0.0940	0.1347	14600
"	"	0940	0.0950	0.1361	14600
"	"	0940	0.0960	0.1376	14600
"	"	0940	0.0940	0.1347	14600

[2] (Editor's note: Zone five time is 75th meridian time—Eastern Standard Time.)

direction. The same is generally true of the Rocky Point group of the Radio Corporation.

On the other hand, echoes from the Naval Station NPG at San Francisco on a frequency of 16,700 kc. rarely are picked up on a collector with strong westerly directivity and when they are so picked up they indicate by their timing that they have traveled around the world in the same direction as the direct signal. Such echoes, however, are usually weaker than the reverse direction type but can be at times extremely annoying although those times are more limited in duration and do not occur as often during the year. Directivity is no defense whatever against echo signals of such a nature but it is a great defense against echoes coming in the reverse direction, as Fig. 1 plainly indicates. Table I gives a summary of measurements on various distant stations; the first column giving the call letters of the station; the second, its location; the third, time of observation; the fourth, the actual observed time interval between direct and echo signals; and the fifth, this same time interval reduced to the equivalent interval for a transit entirely around the world.

A study of this table shows variations in the time of round-the-world transit which are clearly outside of the errors of observation, but nevertheless the figures are fairly consistent and with few exceptions can be correlated with a reasonable Heaviside layer height. It is not believed that these round-the-world signals follow a curvilinear path around the world but that they encounter the layer at intervals and are turned down and reflected back up again from the earth's surface. Variations in layer height will therefore introduce small variations in the path's difference between the direct signal and the echo signal, and indeed we regard the failure of these values to show greater constancy as clear evidence of this manner of progression of the waves. From an average of round-the-world time values a figure can be set which can be called the normal time interval for round-the-world signals in the frequency band between 16,000 and 22,000 kc. Without an intimate knowledge of the exact number of jumps which the wave makes both for direct signal and echo signal, it will be impossible to say exactly what this value should be for a given height of the layer as there are a number of possible combinations. Further than this we cannot go although it is likely that there is some variation in this time interval with the frequency.

Turning for a moment to the question of the season of the year and time of day when signals of this nature should occur, it is possible to make certain theoretical predictions which, so far as our study has progressed, have been verified by practice. There is considerable evidence in favor of the assumption that the principal signal energy comes along a great circle path both for the direct and for the round-the-world signals. This is a very difficult matter to subject to experimental verification, nevertheless in the absence of information to the contrary we shall assume for the present at least that the main signal energy does so come to the receiver, our main reason in making such assumption being the action of collector systems of the Beverage type with a fair degree of directivity. This being so, it can be seen that a round-the-world signal originating in the northern hemisphere during winter time must, unless a great deal of the preceding theoretical work be wrong, get through the northern hemisphere during the light hours and do its dark hour transit in the southern hemisphere where it is summer. Otherwise, radiations starting out along great circles which would violate this simple principle would surely encounter regions where the Heaviside layer was too high for such frequencies to come down again to earth.

So far as directional observations have been taken on echo signals this simple principle has been substantiated and if one takes the globe and traces upon it the possible paths of great circles which would bring the echo signal back to the near neighborhood of the transmitter, it is quite plain that signals originating in the northern hemisphere and observed regularly close to the transmitter will show echo signals only during certain hours of the day and that these hours are by preference between 0800 and 1200 local time in the winter. It is also clear, if one lays off the possible great circles which would meet the simple condition of transversing their night path in the summer hemisphere, that the seasonal change from winter to summer will gradually push this echo period towards the afternoon, and indeed this is generally true of the observations today. We venture to say that in the mid-summer period (which we have not yet had opportunity of carefully observing) the reverse will exist and the favorite echo period will be between 1900 and midnight for the same stations.

Now, when transmitter and receiver are widely separated more complicated conditions govern the situation, but these conditions also are subject to analysis. For instance, if one considers the situation between San Francisco and Washington and remembers that here we are practically limited to one great circle and not to a choice of any one that may be possible for the signal to find its way around on, it can be seen that there are only a few periods of the day and of the year when the great circle San Francisco-Washington traced backwards could be expected to pass through a region with a sufficiently low Heaviside layer height. One of these periods is during the fall and early winter months at 1500 Washington time, and it is significant indeed that very few echoes have ever been found on NPG at any other time of the day and, so far, of the year. It is believed also that the occasions on which, even at these times, the layer is low enough to give this effect without losing the reverse signal at some point of the route, are relatively few and far between, which is also borne out by observations. Further evidence on these points is that the Radio Corporation stations on frequencies considerably higher and located not far from NPG have failed to give any echoes at all except at extremely rare and transient intervals.

Another important observation can be made here upon the performance of stations to the south of us. Strong signals are received here from the Radio Corporation station at Bogota, HJG, both in the 13,700 kc. and in the 27,400 kc. bands at certain hours of the day, but never have echo signals been observed on this station or on any of the stations in the Argentine and Brazil on similar frequencies. Theoretically, no echoes would be expected because such echoes would have to pass over both poles and one or the other is bound to be in total darkness during its winter period even in the daytime, and therefore probably has too high a layer to permit such frequencies to be carried around. Whether it will be possible during the equinoctial period to observe echoes on such southern stations is a point of considerable interest but upon which we have so far no positive information. It is barely possible that during these periods the average layer height might be low enough to get certain frequencies around. It is also quite clear that only very high frequencies, namely, above 14,000 kc., are suitable for sending frequencies entirely around the world, except at certain very limited periods, because the signal must traverse thousands of miles of daylight and only the very high frequencies have the low absorption necessary to accomplish this.

Fig. 2 shows a record on CRHB, Cape Verde Islands, on approximately 16,500 kc. Unfortunately the timing line was

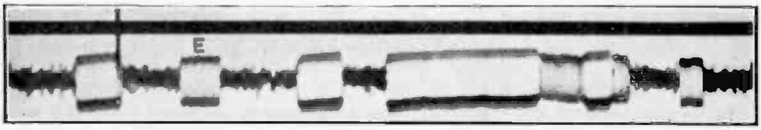

Fig. 2—Around-the-World Signals from Cape Verde Islands, 1 P.M., January 3, 1928.

omitted in this photograph accidentally so the measurement is not available, but the record shows a clear enough echo which is evidently of a reverse direction signal. The more southerly position of the Cape Verde Islands shifted the favorite echo period from the morning hours toward afternoon, this record being taken at 1300 zone five time and strong echoes being observed for at least one and a half hours later. All this in-

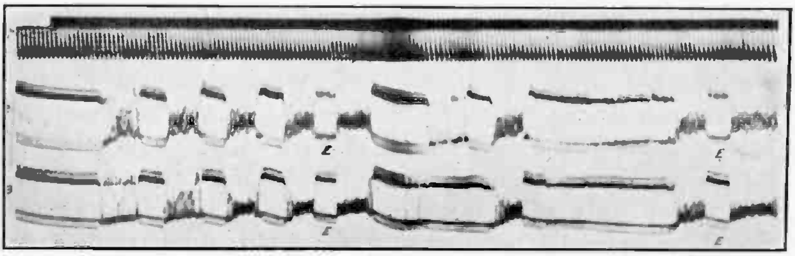

Fig. 3—Around-the-World Signals from 2XBC, 11:15 A.M., December 2, 1927. Sending ABC.

formation checks in with the general idea that echo signals must make their night transit in the summer zone and is in agreement with the general theory that the summer night layer height is notably lower than the winter night layer height except in the tropics where there is not so much difference between summer and winter. Again on this point the Naval Stations in the tropics have noted that they could continue on into the dark hours with very high frequencies over certain long distance circuits—much later into the night than can be done in the northern hemisphere except in the northern summer.

If this simple rule then is noted, it is not difficult to predict at what time of day echo signals may be expected and how that time of day varies with the time of year, and it is quite clear that when stations are geographically widely separated the times of day and times of year will be very much more limited than when the observations are taken near the transmitter. It is also clear that between certain stations there is little likelihood of echoes of this type ever being observed. Taking the figure 0.139 as the general average for round-the-world signals in the frequency band from 16,000 to 21,000 kc., a marked deviation is at once observed when we consider the observations on the Radio Corporation group.

Fig. 3 shows a typical record out of a large number taken on 2XBC at Rocky Point on a frequency of approximately 20,000 kc. The timing line 1 is made by a 100-cycle fork. Line 2 shows the signal received on a collector of directivity to the northeast, the signals marked E being those echo signals that are plainly discernible and identifiable. Line 3 shows the echoes

TABLE II

Around the World Signals—Rocky Point Group

2XBC Time of Observation	Approx. 19,900 kc. Echo Time	WLL Time of Observation	Approx. 18,000 kc. Echo Time
1010	0.1290	1035	0.1105
1145	0.1250	1035	0.1050
1145	0.1240	1035	0.1080
1145	0.1260	1035	0.1100
1225	0.1265	1145	0.1265
1225	0.1250	1154	0.1265
1250	0.1260	1155	0.1270
1255	0.1260	1230	0.1275
1255	0.1250	1235	0.1280
1255	0.1250	1248	0.1280
		1248	0.1285
		1147	0.1260
WTT	Approx. 18,500 kc.	WBU	Approx. 21,200 kc.
1115	0.1250	1025	0.1265
1120	0.1250	1037	0.1275
1034	0.1270	1055	0.1205
1050	0.1250	1012	0.1195
1320	0.1200	1130	0.1100
1005	0.1265	1025	0.1250
1040	0.1250	1125	0.1260
1048	0.1265	1000	0.1260
1120	0.1260	1240	0.1260
1025	0.1260		
WIK	Approx. 13,800 kc.		
1200	0.1230		
0920	0.1270		
0920	0.1280		
0920	0.1290		
1230	0.1110		
0937	0.1330		
0945	0.1260		

plainly discernible on a collector of pronounced westerly directivity. The fact that the echoes are stronger and more clearcut on the westerly collector indicates that the echoes are coming from a general westerly or southwesterly direction. The timing interval instead of being 0.139 seconds is 0.124 seconds.

Table II is a summary of observations taken on the Rocky Point group. An inspection of this table shows that in no case do the signals appear to take the normal time interval to go around the world. Moreover it is seen that the observed time intervals vary from 0.110 to 0.129. Not only are these time intervals decidedly too short, but they show a greater variation than several observations on distant stations. These observations are indeed of great interest. Our first thought was to explain these observations by assuming that the round-the-world signals

Fig. 4—Around-the-World Signal from NKF.

followed some course differing from the great circle route by an amount corresponding to the time interval, but we were unable to think of any physical mechanism which could produce such a path. It would be much easier to think of conditions which would make the time interval too long than to think of conditions which would make it too short. It had long been suspected that the so-called direct signals coming from the Rocky Point group on these frequencies and which apparently violated the skip distance law were not really direct signals. Means were therefore investigated to throw further light upon this matter.

This Laboratory placed one of its own high-power transmitters on 18,500 kc. and obtained the consent of the Carnegie Institution to take observations at their laboratory on the edge of Rock Creek Park some ten miles distant. Fig. 4 shows a typical echo signal on our own station NKF and with the time interval 0.1390 second. It should be explained that since we had control of the transmitter in this case we were able to arrange it to send extremely short dots of the order of duration of about one-hundredth of a second and widely spaced. This was accomplished by punching a transmitter tape with the letter *E* with ten or fifteen spaces between each letter and then running the tape through a Creed transmitter at high speed. Roughly, these dots came about three to the second.

Table III shows the results of round-the-world signals from NKF taken at the Carnegie Institution ten miles away, measurements being given both from the front end of the dot and rear end of the dot which show slight differences which seem to give slightly higher values for the front of the dot than the rear of the dot. We are not willing to lay any special weight upon this timing difference as it is quite small, but at any rate the observations show remarkably little variation and give a general average close to the general average or normal value for distant stations, differing thereby markedly from observations on the Rocky Point group. It was therefore concluded that the so-called direct signals from Rocky Point which appear to violate the skip-distance law, being received well through-

TABLE III

AROUND THE WORLD SIGNALS FROM NKF.

	Front of Dot	Rear of Dot
	0.1401	0.1382
	0.1380	0.1382
	0.1396	0.1375
	0.1406	0.1385
	0.1387	0.1376
	0.1386	0.1365
	0.1397	0.1400
Average	0.1393	0.1387

Average—front and rear, 0.139 Sec.

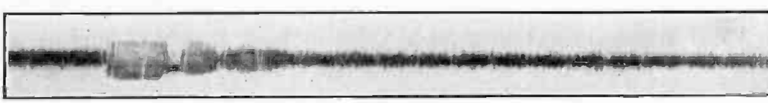

Fig. 5—Reflections from NKF.

TABLE IV

SUMMARY OF REFLECTIONS FROM NKF

0.0111	0.0207	0.0311
0.0116	0.0212	0.0312
0.0118	0.0222	0.0330
0.0119	0.0224	0.0335
0.0131	0.0226	0.0335
0.0138	0.0232	0.0335
0.0142	0.0232	0.0343
0.0149	0.0232	0.0345
0.0163	0.0233	0.0349
	0.0239	0.0355
0.0181	0.0241	0.0358
0.0184	0.0243	0.0358
0.0185	0.0243	0.0359
0.0188	0.0296	0.0360
0.0190	0.0258	0.0360

out the daylight hours but fading out in the very late afternoon and coming in again just before dawn, were not coming direct at all but were themselves echoes or multiple signals of an entirely different character from round-the-world signals. But if this were true, our own station should also show additional multiple signals or echoes very close to the reference signal or ground wave. Such indeed proved to be the case, as is shown by Fig. 5 where very short time echoes are clearly shown of the values 0.0138, 0.0235, and 0.0345 respectively.

Table IV is a summary of these nearby echoes found on NKF. We therefore concluded that the so-called direct signals from Rocky Point which appear to be violating the skip-distance law were similar echoes, but we sought for definite means of proving this point and finally hit upon means for doing so. The Rocky Point transmitters like most high-frequency transmitters having frequency multipliers, for instance, one of them transmitting on 18,000 kc. has somewhere in the preceding stages considerable energy on 9,000 kc. which is weakly coupled to the antenna system but which should be capable of giving recordable signals in Washington. Examination of this matter shows that such was indeed the case and observations were taken on 2XBC and WLL on this basis and on the following assumptions; first, the lower or half frequency could not be an echo signal because it would have to travel too far for such a frequency to give a good signal in broad daylight, our shortest echoes of this character indicating a path retardation of the order of 2,900 km. Considering the weak radiation on relatively small power put out by the transmitter on this half frequency it is hardly possible that so perfect a signal could have been received at Washington by any other than a normal sky wave route, which means for a Heaviside layer height of under 200 km., an approximate distance from New York to Washington for this signal of about 500 km. Of course, the same relay keyed both the half frequency and the high frequency and no question of relay lag was herein involved.

Fig. 6 shows a typical record on 2XBC clearly showing that the high frequency not only arrives later by 0.007 or 0.008 of a second but that the signals are strung out somewhat longer than those arriving on the lower or half frequency. The two frequencies in question were approximately 18,900 and 9,450 kc. In connection with the observations on NKF this conclusively establishes the fact that these high-frequency signals from the Rocky Point area are not violating the skip-distance law at all. Nor are they ground waves or scattered waves which could not possibly be accounted for on this timing basis, but

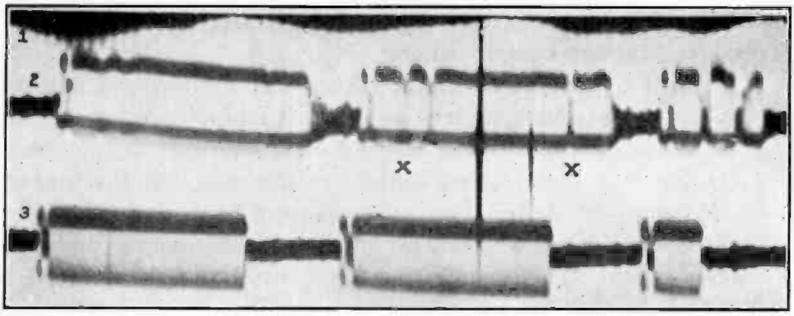

Fig. 6—2XBC, 12:50, February 29, 1928.

they are signals thrown into the skip distance area from a point or a number of points well outside of that area. If we suppose that there are several such echoes of which we have sometimes identified as many as three on NKF, it will be seen that the first echo with the shortest time interval will be the one that starts the recorded dot in the record of the higher frequency. If, therefore, we measure from the beginning of the half frequency dot to the beginning of the high frequency dot we get a time interval corresponding to the nearest echo or the shortest reflection.

Table V summarizes the values obtained on this shortest reflection or echo, which has a value between 0.007 and 0.008

TABLE V

Summary of Shortest Reflections 2XBC

0.00834	0.00866
0.00857	0.00805
0.00802	0.00853
0.00882	0.00808
0.00835	0.00700
0.00846	0.00738
0.00803	0.00750
0.00888	0.00724
0.00823	0.00776
0.00814	0.00765
0.00833	0.00755

of a second and corresponds to a signal which has traveled some 2400 km. further in coming to Washington than the half-frequency signal has. Since the half-frequency signal itself has traveled approximately 500 km. the total distance traveled by the high-frequency signal in coming from Rocky Point to Washington is about 2900 km. It is very suggestive to know that the average daylight skip distance on these frequencies is about half of this figure. This point will be considered in detail later on. There are plainly to be observed in some of these photographs on the Rocky Point stations interference patterns produced by subsequent echoes.

On Fig. 6 at the point marked *X* such an interference pattern is shown. Obviously, it will be difficult from the observations made thus on regular traffic and not on special signals to extract the values for intermediate reflection intervals, but the longest interval may be determined by measuring from the end of the half-frequency dot to the end of the corresponding high-frequency record. There is also the possibility of occasional round-the-world signals creating some confusion in these latter type of measurements. For instance, in Fig. 7 the point marked *R*

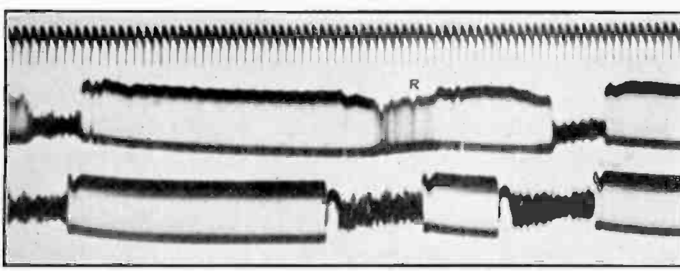

Fig. 7—Around-the-World Signal from 2XBC, 9:10 A.M. February 29, 1928.

is clearly not a nearby, but a round-the-world signal. It is preferable to take these records on nearby echoes at such times when round-the-world signals are not occurring. Apparently then, it is definitely determined that these high-frequency signals within the skip-distance band, New York to Washington, are not violating the skip-distance law but as can be seen from Table V on the nearest reflection and Table VI which gives the list of other and somewhat longer reflections, that we have yet to explain where these reflections come from, both for Rocky Point stations and for NKF. We do not propose to attempt to answer this question at the present time, but will only make a few suggestions as to possible explanations, leaving the final decision to the future when other studies with special reference to directivity and at other localities widely separated from our own may throw further light upon these points.

It may appropriately be mentioned at this time that since electrons diffuse much more readily along the lines of magnetic

TABLE VI
Long Reflections on 2XBC

0.0152	0.0214	0.0321
0.0165	0.0282	0.0311
0.0178	0.0264	0.0338
0.0141	0.0255	0.0300
0.0169	0.0254	0.0345
0.0197	0.0278	0.0325
0.0190	0.0264	0.0314
0.0126	0.0262	
0.0106	0.0226	
0.0137		
0.0173		

force than they do athwart them, there should be considerably more electronic concentration at the neighborhood of the north magnetic pole and that the distance to the north magnetic pole is about right to account for the intermediate set of echoes. The nearby set of echoes might be thought of as being due to reflections of the wave from rough portions of the earth's surface directly back on itself, so to speak, and coming from the first zone of reception; namely, from just above the edge of the first skipped distance. If we look to the southward of Rocky Point on the map we find a rough, more or less mountainous region at the correct distance to be in a position to throw such signals back into the skipped zone between Washington and New York. Equally well, if we look to the northward in Labrador we can find such a zone. It is also true that another group of reflections have a time interval suitable to be echoes from throwback signals from the rough country in the Rocky Mountain area. But the last set of reflections corresponding to time intervals of the order of 0.035 of a second and to a distance of the order of 10,000 km., is difficult indeed to account for. One would have to go south to the Andes or northeast to Switzerland in order to get a similar region adapted for throwing back such signals. We confess, however, that at the present time we are not aware of any reasonable explanation of these nearby echoes which we have found on the Radio Corporation's group and, to the same order of magnitude, upon our own station. We confess also that we have put forth the polar electron concentration idea and the backward reflection idea with no extreme faith in its probability. At the same time we believe that it is not at all impossible for these things to occur. We are naturally reluctant to entertain the idea of an additonal layer with extremely high electron concentration and of so great a height, namely 1400 km., which would be necessary to explain the path retardations on these nearby echoes by reflections and multiple reflections from such a layer. The existence of such a layer besides being utterly unaccountable on any known physical basis will be too much in contradiction with well-known and well-established facts concerning the behavior of radio waves in various parts of the spectrum. If we are forced to accept the backward reflection idea it can be seen that the nature of these reflections will frequently be such as to give the effect of bad scattering and no definite direction to such signals. Under special geographical conditions and at very high frequencies where long skip distance is obtained before the main wave can find anything that can throw it back upon itself, a certain degree of directivity on certain signals might be observed.

Turning now to the seven questions outlined in the first part of this report, it is perhaps worthwhile to see what answers or partial answers can be given to them in the light of what we have so far determined as to the nature and timing of both nearby and distant echo signals. (1) It is clear that the signals from the Rocky Point group of stations as received in Washington on very high frequencies do not violate the skip distance law nor are they signals formed by a scattering in the normal Heaviside layer. The timing intervals indicate that they come from distances between 2500 and 10,000 km. in making the transit from Rocky Point to Washington, although the straight line distance is only 420 km.

(2) The abnormal time interval on the Radio Corporation group at Rocky Point is fully explained and brought into unison with observations on our own station and in fair agreement with those of distant stations, as soon as we recognize that the signal which arrives first is itself an echo signal of variable time interval corresponding to the above mentioned path retardations.

(3) Violently fading of high-frequency signals at points only moderately distant from the transmitter may be partly due to nearby echo signals which overlap and in continually shifting phase thus contribute to this fading. At points of very much greater distances the nearby echoes would be much reduced in strength and of corresponding lesser importance in producing fading effects.

(4) All of these echo signals can produce under suitable conditions disastrous effects upon almost all known forms of radio communication. The long time echoes coming as they do around the world can usually be taken care of by directive receiving systems, but if short time echoes occur it seems likely that they will come from various directions and directive receiving systems will not be of so much advantage. Upon low speed telegraphy the short time echoes will have little or no effect, their main results being to produce a slight fuzziness of the signal. But upon telephony they will have a very disastrous effect and probably equally annoying effects for facsimile transmission and television. Fortunately, we shall usually be mainly interested in telephony, facsimile transmission, and television only over long distances. The evidence herein presented is perhaps one more argument for the reservation of such frequencies for long distance work only.

(5) Directive receiving systems can obviously be used to great advantage with certain types of echoes but can hope to do but little with others. Fortunately, in long distance work we may expect comparatively little trouble from nearby echoes on account of their lesser intensity. Directive transmission is probably capable of giving considerable assistance on all kinds of echoes, but can by no means hope to shut out completely the short time echoes referred to in this paper. In fact, this type of scattering by ground reflection may be largely responsible for the widening of the angle of the beam to greater values than would be expected from an observation of its local performance. If ground reflections of this magnitude occur at all they can throw off a great deal of radiation from a beam as well as throw it directly back upon itself.

(6) The hours of the day and the seasons of the year when round-the-world signals can be expected can be predicted for any given pair of stations by reference to the simple principle that round-the-world signal must make most of its night transit in the summer hemisphere and if the great circle between two stations is such that this is not possible, round-the-world echoes will not occur. There is entirely too little information at hand to predict in the matter of the short time echoes. It is urgently requested that observations on a quantitative basis be carried out in various parts of the world on this matter in order to demonstrate whether this is a phenomenon more or less pe-

culiar to this part of the world or is more general in its occurrence. Only by such observations can any decision be made between possible tentative explanations of the phenomena involved.

(7) There appears to be nothing in the nature of echo signals so far observed which is in contradiction with the general theoretical principles already laid down.

THE STATUS OF FREQUENCY STANDARDIZATION*

By

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Summary—*The measurement of frequency, hitherto of laboratory interest only, has become of first-rank importance in reducing radio interference. This has come about through the increasing use of all available radio channels particularly at broadcasting and higher frequencies. While an accuracy of one half per cent was satisfactory five years ago, accuracies a thousand times as good are now sought.*

The piezo oscillator is meeting the needs of this situation in large part. Much effort is being devoted to making the piezo oscillator as constant as possible. Commercially available piezo oscillators, without temperature control, are generally reliable to about 0.03 per cent, just barely enough to meet the Federal Radio Commission's requirement of one-half kilocycle. In order to reach greater accuracy, considerable work is being done on the primary standards of frequency, to insure the highest constancy and accuracy. The Bureau of Standards and other organizations are engaged on a cooperative program to attain an accuracy of 0.001 per cent. Comparisons with other nations show that the national laboratories of the larger countries are already in agreement to about 0.003 per cent.

Temperature controlled piezo oscillators will probably allow the holding of station frequencies so close that several stations can broadcast on the same frequency without heterodyne interference. Use of these or equivalent devices is vital to the maximum utilization of the very high frequencies; the separation of 0.1 per cent between high-frequency stations which is practicable in the immediate future is largely determined by frequency variations, and can be reduced as practice improves.

Introduction

RADIO manufacturers, transmitting stations, and standardization agencies have found it necessary to increase their accuracy of frequency measurement progressively during the past four or five years. This need has come about through the increasing use of the available radio channels and particularly through the development of broadcasting and of high-frequency transmission. While an accuracy of one-half per cent was satisfactory five years ago, it is now necessary to give consideration to accuracies a thousand times as good. It is not merely a question of measurement. Frequencies of transmitting stations

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must be actually held constant with very great accuracy. This is becoming more and more important as the available radio channels become saturated. The maximum number of communications can be packed into the radio spectrum only if each stays within its own channel, as any wandering due to inaccurate frequency adjustment causes interference with the communication on the adjacent channel.

Interference due to frequency variations is perhaps now the main source of interference, as far as technical (apparatus) causes of interference are concerned. Receiving sets are now so well designed that other sources of interference can be tuned out.

Piezo Oscillators

The advent of the piezo oscillator has met the needs of the situation in part. The device is a readily available standard, in terms of which frequencies may be measured to any desired precision (in the sense of fineness of adjustment). The *accuracy* with which frequencies may be thus made available is the subject to which this discussion is mainly devoted. Since piezo oscillators may be used for frequency comparison with practically unlimited precision, the question of their accuracy depends essentially on their constancy, and on the accuracy and constancy of the basic standards in terms of which they are standardized.

When the piezo oscillator was introduced, two or three years ago, it was quite commonly thought that it was an invariable standard of frequency. It has, however, been found that there are a number of factors which introduce variations in the frequency of the electromotive force produced by a vibrating quartz plate, and also in the frequency of response of a piezo resonator. These factors are the temperature, the particular method and details of the mounting of the quartz plate, the circuit constants of the associated circuits, and the methods of coupling between the circuit in which the quartz plate is inserted and the necessary auxiliary and measuring circuits. It is not true that highly accurate comparisons can be made by sending a quartz plate in the mail from one laboratory to another. The effects of the circuit constants may vary the frequency produced by a piezo oscillator several parts in 1000, and therefore a complete piezo oscillator must be sent for accurate comparisons. If it is desired to make measurements to as great an accuracy as one part in 10,000, it is necessary that the voltages used in the piezo oscillator be carefully measured and that the circuit arrangements and voltages be always the same in use as under the conditions of original calibration. This has been proved by special experimental trials of the effects of different circuit details on the frequency, by theoretical studies, and by the results of actual trial in practice. To carry the accuracy still further, to one part in 100,000, it is necessary not only to control carefully the circuit constants but also to keep the quartz plate at constant temperature.

Constancy and Accuracy of Standards

In order to secure maximum coherence of the results of frequency measurements, and minimum interference between stations adjusted thereby, it is necessary that all measurements be made in terms of the same primary standard, provided that standard has the two requisite properties, accuracy and constancy. Of these two, constancy is by far the more important, since the outstanding need is that the results of frequency measurements agree with one another, regardless of where or when made. If all should be 0.1 per cent different from the actual absolute value there would be no serious practical consequences. but if different laboratories or stations should have standards differing by 0.1 per cent there would be hopeless confusion and interference. This is not to say that absolute accuracy of the primary standard is unimportant; the highest accuracy must be sought, but this is less urgent than the maintenance of a standard of high constancy.

The official primary standard for the United States is that maintained by the Bureau of Standards. During the past four years the Bureau has steadily improved the constancy and accuracy of this standard by continuous research. In order to have a primary standard adequate to the present and the immediate future, the Bureau determined last year to establish and maintain a standard which should be constant to one part in 100,000, or 0.001 per cent. Such accuracy is difficult to attain in almost any line of physical measurement. The work is being carried on with the cooperation of other Government Departments and the various commercial organizations which have had experience in establishing frequency standards or constructing piezo oscillators of great constancy. Four organizations (the General Electric Company, Westinghouse Company, Navy

Department, and Bureau of Standards) have constructed temperature-controlled piezo oscillators which are intercompared and kept under observation at the Bureau. These are also compared against other standards of the Bureau, including quartz plates, tuning forks, and a special frequency meter. Absolute measurements of their frequencies, against time standards, are made by three organizations, the Navy Department, Bell Telephone Laboratories, and the Bureau of Standards.

The absolute measurement of frequency is a most interesting subject, but in this paper I will only be able to mention it briefly. Since frequency is the reciprocal of time, an absolute frequency measurement is a comparison against a standard of time. Ideally, this should be made as directly as possible against the primary time standard, the rotating earth. In practice, measurements are made against a standard clock, permitting frequency measurements in terms of the mean solar second. The measurements are usually made with the aid of an intermediate device (tuning fork, alternator, or oscillator) which produces an audio frequency, this being measured in terms of the clock. The comparison between the audio frequency and the radio frequency of the standard under measurement is made by a step-up process, such as the use of a harmonic amplifier[1] or cathode-ray oscillographs[2].

The measurement may be made even more directly in terms of the time standard by methods which have recently been worked out to eliminate the intermediate audio-frequency device. Such methods have been devised by the National Physical Laboratory in England, the Naval Electrotechnical Institute in Italy, and by the Bell Telephone Laboratories[3] in the U. S.

International Frequency Comparisons

Since both high- and low-frequency signals can be received over large portions of the world, it is of the greatest urgency not

[1] Frequency Measurement in Electrical Communication.—Horton, Ricker, and Marrison. *Trans.* A.I.E.E., **42**, p. 730; 1923.

A Self-Contained Standard Harmonic Wavemeter.—D. W. Dye. *Phil. Trans.*, Roy. Soc. London, **224**, p. 259; 1924.

Establishment of Radio Standards of Frequency by the Use of a Harmonic Amplifier.—Jolliffe and Hazen. Bureau of Standards Scientific Paper No. 530. 1926.

[2] Primary Radio-Frequency Standardization by Use of the Cathode-Ray Oscillograph.—Hazen and Kenyon. Bureau of Standards Scientific Paper No. 489, 1924.

[3] Precision Determination of Frequency. Horton and Marrison. Proc. I.R.E., **16**, p. 137; February, 1928.

merely that all U. S. radio be on a single frequency basis, but that this be true of the whole world. The international aspect of this is being cared for by the national standardizing laboratories of the various nations through intercomparisons of frequency standards. The Bureau of Standards has been particularly active in initiating and directing this work.

International comparisons of any physical quantity can be made by sending the standards of that quantity successively to the laboratories of the different nations. In the frequency comparisons that method has been followed with one exception. About five years ago it appeared that greater accuracy might possibly be obtained by another method, namely, the simultaneous measurement in the various laboratories of the frequencies of waves transmitted from stations of sufficient power to be received simultaneously in many nations. In 1924 such a set of comparisons was organized by the Bureau of Standards and measurements were made in the national laboratories of England, France, Italy, Germany, and the United States. The results of such comparisons extending over a number of weeks were only fairly satisfactory. The accuracy of measurement was not as good as had been hoped. The result, briefly, was to show an agreement between the various countries within about two parts in 1000. The methods used, and independent evidence of various kinds, were such that it was certain that the standards used in each of these countries were more accurate than this. The observed differences were therefore due in large part to the methods of measurement.

From the foregoing experience it was concluded that the more common method (actual transportation of standards from one laboratory to another) used in connection with other physical quantities should be considered anew. Just at that time, about four years ago, enough had been learned of the possibilities of piezo oscillators and piezo resonators to make it appear that they offered particular advantages as portable standards. Measurements upon piezo-electric devices therefore offered a method which might be superior to the scheme of measuring simultaneously the frequencies of transmitted waves. The first attempt of this kind was an informal series of measurements made in several national laboratories by W. G. Cady, Professor at Wesleyan University, Middletown, Connecticut. He took a number of piezo resonators (not oscillators) abroad; the results

TABLE I

PIEZO OSCILLATOR B. S. 33465–D WITH QUARTZ PLATE NO. 15

Laboratory	Approx. date	Temp-erature deg. C.	Frequency	Minus Mean B.S.	Frequency	Minus Mean B.S.	Frequency	Minus Mean B.S.
Bureau of Standards	Dec. 1925	—	75.30	—	106.24	—	455.40	—
National Physical Laboratory, England	Feb. 1926	17.2	75.344	+0.038%	106.273	+0.031%	455.560	+0.016%
Telegraphie Militaire, France	July 1926	(22)	75.33	+0.020%	106.1	−0.132%	455.7	+0.047%
Istituto Elettrotecnico e Radiotelegrafico, Italy	Sept. 1926	26.5	75.347	+0.042%	106.200	−0.038%	455.474	−0.002%
Physikalisch-Technische Reichsanstalt, Germany	Feb. 1927	20.5	75.331	+0.021%	106.248	+0.008%	455.525	+0.009%
Bureau of Standards	July 1927	24.8	75.33	—	106.24	—	455.57	—
Bureau of Standards	Mean B.S.	(24.8)	75.315		106.240		455.485	

TABLE II

PIEZO OSCILLATOR B. S. 33465-C WITH QUARTZ PLATE NO. 16

Laboratory	Approx. date	Temp-erature deg. C.	Frequency	Minus Mean B. S.	Frequency	Minus Mean B. S.	Frequency	Minus Mean B. S.
Bureau of Standards	May 1926	—	75.037	—	105.870	—	455.833	—
Physikalisch-Technische Reichsanstalt, Germany	Dec. 1926	20.5	75.035	−0.009%	105.879	+0.007%	455.940	+0.023%
Istituto Elettrotecnico e Radiotelegrafico, Italy	Mar. 1927	16.5	75.090	+0.064%	105.952	+0.075%	456.152	+0.069%
Telegraphie Militaire, France	June 1927	(22.)	75.004	−0.051%	—	—	455.940	+0.023%
National Physical Laboratory, England	July 1927	19.3	75.054	+0.016%	105.891	+0.018%	455.930	+0.021%
Bureau of Standards	Dec. 1927	22.6	75.048	—	105.875	—	455.840	—
Bureau of Standards	Mean B.S.	(22.6)	75.042		105.872		455.836	

of his measurements are published in his article, "An International Comparison of Radio Wavelength Standards by Means of Piezo-electric Resonators."[4]

In December, 1925, the Bureau of Standards sent a piezo oscillator to Europe, sending it first to the National Physical Laboratory of England, which was to send it in turn to the laboratory of the Telegraphie Militaire in France, to the Naval Electrotechnical Institute in Italy, to the Physikalisch-Technische Reichsanstalt in Germany, and then to be returned to the Bureau. A second piezo oscillator was sent in July, 1926, in the other direction, i.e., beginning with the Physikalisch-Technische Reichsanstalt. It is to be noted that complete piezo oscillators were sent, not merely the quartz plates.

The measurements upon these two piezo oscillators, on account of the necessary delays in getting from one laboratory to another, were only completed in December, 1927. The results are given in Tables I and II.

These results show that piezo oscillators, even without temperature control, provide a far more dependable method of making international comparisons of frequency standards than simultaneous measurements of station frequencies. The indicated differences between the various laboratories have a maximum of eight parts in 10,000; the net result is to show an agreement by this method which may be summarized as a few parts in 10,000. It was uncertain as a result of this work whether the observed differences were due to variations in the piezo oscillators used as the means of comparison or to actual differences in the basic standards of the different countries.

The same method was used, viz., the sending of piezo oscillators, to make comparisons between the frequency standards of the United States, Canada, and Japan. Early in 1927 a piezo oscillator was sent to Canada, was there measured by the Radio Service of the Department of Marine, then returned and measured again by the Bureau of Standards. The results were of the same order as those obtained in the European comparisons, and were considered by the Canadian administration as giving a comparison of standards to as great an accuracy as their measurements permitted. The Bureau of Standards sent the same piezo oscillator in March, 1927, to Japan. The average of the Japanese values differs from the Bureau of Standards

[4] Proc. I.R.E., 12, p. 805, Dec. 1924.

TABLE III

Piezo Oscillator B. S. 33465-E with Quartz Plate No. 12

Laboratory	Approx. date	Temperature deg. C.	Frequency	Minus B. S.	Frequency	Minus B. S.	Frequency	Minus B. S.
Bureau of Standards	Jan. 1927	—	75.32	—	106.26	—	455.86	—
Radio Service, Canada	Feb. 1927	22	75.27	−0.07%	106.16	−0.09%	455.93	+0.02%
Bureau of Standards	Mar. 1927	23.5	75.32	—	106.26	—	455.86	—
Ministry of Communications, Japan	July 1927	24	75.32	0.00%	106.24	−0.02%	455.85	0.00%

Note.—This piezo oscillator has not yet returned from Japan.

measurements by only one part in 10,000. The detailed results are given in Table III.

Piezo oscillators with temperature control began to be constructed in 1927, and a great increase of the possible accuracy of the comparison of standards of different laboratories was thus presented. As I was going to Europe in the summer of 1927 for the Bureau of Standards, an opportunity was afforded to use one of these instruments for comparisons with the standards of the national laboratories of Europe. It was hoped that by taking this improved instrument to the European laboratories a frequency comparison could be obtained that would surpass the previous ones in accuracy. I accordingly had the pleasure of making frequency measurements, all of which were very satisfactory, at the National Physical Laboratory in London, at the laboratory of the Telegraphie Militaire under General Ferrie in Paris, at the Italian Navy Laboratory in Livorno, Italy, and at the Physikalisch-Technische Reichsanstalt in Berlin. I wish to acknowledge the splendid cooperation given me in each of these laboratories by my collaborators, Dr. D. W. Dye at the National Physical Laboratory, Prof. R. Jouaust in Paris, Prof. G. Vallauri in Livorno, and Dr. E. Giebe at the Reichsanstalt. The measurements were made in July and August.

The frequencies of the piezo oscillator were measured at the Bureau of Standards before I left the United States and again after my return. The instrument contained two quartz plates in a thermostatically-controlled heated enclosure, the quartz plates being kept at a temperature of 46 degrees C. Instruments were provided to insure that filament and plate voltages were always the same. The frequencies of both quartz plates were approximately 200 kilocycles.

It was interesting to find that in all the laboratories the same general method is used for frequency measurements of high precision. Typically, there are three generators placed in the laboratory about ten feet apart; one is the piezo oscillator under measurement, one is the auxiliary oscillator or heterodyne, and the third is the standard instrument against which the piezo oscillator is to be measured. There is coupled to each of these a single circuit which contains a receiving set with telephone receivers connected to it. The method of measurement is in all cases some variation of the simple procedure of listening for the frequency difference between the auxiliary generator and the piezo oscillator, and by one process or another reducing this difference to zero, and then adjusting to equality with the auxiliary generator the standard in terms of which the piezo oscillator is being measured (or else determining the difference between the standard and the auxiliary generator).

TABLE IV

SPECIAL TEMPERATURE-CONTROLLED PIEZO OSCILLATOR WITH QUARTZ PLATES *Y* AND *Z*

Laboratory	Date 1927	*Y*		*Z*	
		Frequency	Minus Mean B.S.	Frequency	Minus Mean B.S.
Bureau of Standards	June 15	200.122	—	200.142	—
National Physical Laboratory, England.	July 14	200.118	0.000%	200.128	−0.006%
Telegraphie Militaire, France	Aug. 4	200.134	+0.008%	200.149	+0.004%
Istituto Elettrotecnico e Radio-telegrafico, Italy.	Aug. 16	200.119	0.000%	200.137	−0.002%
Physikalisch-Technische Reichs-anstalt, Germany.	Aug. 31	200.131	+0.006%	200.152	+0.006%
Bureau of Standards	Nov. 16	200.115	—	200.138	—
Bureau of Standards	Mean B.S.	200.118		200.140	

The results, shown in Table IV, justified every hope. The differences between the different laboratories in these measurements ranged from zero to five parts in 100,000, the average of the departures from the mean being three parts in 100,000. This agreement is indeed as good as the degree of certainty of the national standards. It is concluded that by using a portable temperature-controlled piezo oscillator in which the currents through the circuits are always adjusted to the same value, it was possible to get a 10-fold increase of accuracy over that attained with the simpler type of piezo oscillator used in the previous comparisons. This assurance as to the accuracy of the frequency standards available in the larger countries determined the action of the International Radio Conference in October, 1927, on the subject of frequency measurements, as expressed in Article 3 of the General Regulations of the International Radiotelegraph Convention.

The accuracy attained in these comparisons is not by any means the limit attainable. The instrument used in the comparisons was one upon which complete studies had not been made as to temperature equilibrium, frequency lag, and temperature coefficient of the quartz plate. No doubt as time goes on we can improve upon this. On the whole, however, I feel that it has been demonstrated that the several national laboratories are measuring frequencies with an accuracy satisfactorily in advance of the immediate requirements of radio practice. The standards of frequency of the larger countries agree sufficiently well to insure against interference provided the transmitting stations are accurately adjusted according to their national standards.

Applications in Broadcasting and High Frequencies

The developments in the accurate measurement of frequencies have their principal applications in those portions of the radio spectrum where the congestion of radio traffic is greatest, viz., broadcasting and high frequencies. The Federal Radio Commission requires every broadcasting station to operate within 0.5 kilocycle of its licensed frequency. At a frequency of 1500 kilocycles this means that the frequency must be maintained within 0.03 per cent. There were no means commercially available by which this could be done, a year ago. At the present time, using as a station frequency standard a piezo oscillator without temperature control but carefully operated, the requirement can just be met. To be certain of satisfactory operation, a piezo oscillator should be investigated over the range of temperatures at which it will operate, as sudden large changes of frequency with temperature occur in some of them.

The advent of temperature-controlled piezo oscillators opens up new possibilities. It is apparent, from the experience I have recounted, that these instruments can be relied upon, under conditions of practical use, to 0.003 per cent or better. At a frequency of 1000 kilocycles, this corresponds to a constancy of 30 cycles or better. In other words, two or more broadcasting stations using these devices could operate on the same frequency and remain synchronized so closely that there would be no audible beat note between their carrier frequencies. This is the only practical possibility at present available for eliminating heterodyne interference. Use of this plan may offer a way out of the hitherto insoluble problem of too many broadcasting stations. It is not an easily operated plan; it requires great care in operation of the piezo oscillators at all stations; but it seems to me at present the most practical of the various theoretically possible plans.

The increase in accuracy of frequency measurements has an application of at least equal importance in the use of very high fequencies. Since 0.03 per cent is about the limit of dependability of piezo oscillators without temperature control, it is not feasible at the present time to use narrower channels than 0.1 per cent. To illustrate, successive channels can be 10 000, 10 010, 10 020 kilocycles, etc. With a commercially available piezo oscillator used as a station frequency standard, the second of these channels could be reliably held within 10 007 and 10 013 kilocycles. Greater deviation than this would bring the transmission dangerously near the adjacent channels and cause interference. Thus, assuming the use of the best commercially available equipment and great care in the operation of stations, high-frequency channels cannot be spaced closer than 0.1 per cent at the present time.

More stations can be operated on the high-frequency waves almost in proportion to the increase in accuracy of the frequency control of transmitting stations. While it is true that there are other factors influencing the width of channel, e.g., selectivity of receiving sets, nevertheless for CW work it is likely that the channel width could be narrowed to something like 0.01 per cent if first-class temperature-controlled piezo oscillators, or apparatus of equivalent accuracy, were universally used in high-frequency stations. To illustrate again, at 10 000 kilocycles the channels would be 1 kilocycle apart, and the frequency of each would be maintained within 300 cycles. CW receiving sets can readily distinguish traffic with the minimum separation provided under such operation. For the whole frequency spectrum above 2000 kilocycles, this would mean that, in place of some 2000 CW station assignments possible under present conditions, about 20 000 could be accommodated.

Discussions

Henry Shore†: As Dr. Dellinger has pointed out, the second is the logical basis of our frequency measurement and standardization. Since this is so, it seems to me that any frequency standard should be directly and intimately related to the basis. Thus the frequency standard should be controlled by the clock or pendulum. A method of accomplishing this has been suggested by Dr. V. Bush of Massachusetts Institute of Technology.

The method consists of series of multivibrators interlocked and controlled by impulses from the standard time piece, the

† Research Engineer, Radio Corporation of America, New York City. Original Manuscript Received by the Institute, January 24, 1928.

first multivibrator having a fundamental period of 2 cycles per second. The second multivibrator has a period of 40 cycles per second, the third a period of 1600 cycles per second and so on up the frequency spectrum. The clock impulses, furnished say by means of photocell, simply serve to maintain the fundamental frequency constant and do not drive the multivibrator units.

For a more detailed description of the multivibrator the excellent paper of J. K. Clapp, "Universal Frequency Standardization from a Single Frequency Standard," *Journal* Optical Society of America, 15, No. 1, July, 1927, should be consulted.

G. W. Kenrick‡: Dr. Dellinger, in his interesting paper, has directed attention to the importance of the frequency standardization of broadcasting stations and suggested the use of standardized crystals at the stations to insure the constancy of the emitted frequency. I would like to direct attention to another possibility which suggests itself for holding these frequencies at such values as to insure suitable separations.

According to this plan as many stations as necessary would be established as standardization stations to transmit, on a radio channel, a standard frequency preferably equal to the desired frequency separation of the broadcasting stations or some exact sub-multiple thereof (let us say 10 kc. for example). These signals could now be received at the various broadcasting stations; and, after demodulation, passed through sufficient stages of frequency multiplication to bring them into correspondence with the given broadcasting station's assigned frequency. Such frequency multipliers utilizing accentuated harmonics in vacuum-tube circuits and resonance phenomena are, of course, quite well-known to the present stage of the art. Prime harmonics, not readily obtainable by several stages of successive multiplication alone, are readily available by the introduction of sum and difference frequencies produced by the modulation of the output of the higher multiplier stages by that of the lower stages or the fundamental.

It will be noted that this method of standardization has the advantage that the requisite frequency separations are secured independently of the precision of the 10 kc. standard which, however, is a single standard and hence readily producible with a high degree of precision and constancy at some central point,

‡ Instructor, Moore School of Electrical Engineering, University of Pennsylvania, Philadelphia, Penna. * Original Manuscript Received by the Institute, January 30, 1928.

such as the Bureau of Standards. In my opinion this method has a distinct advantage over the use of a large number of independently calibrated crystals maintained at broadcasting stations under conditions necessarily less rigorous than those to which a central standard could be subjected. It will be noted that a minute injury or disturbance in any of these secondary crystal standards will correspondingly produce interference, and not infrequent recalibrations would hence be desirable.

The production of suitable frequency multiplying sets for use in the method here described, particularly in the considerable quantity necessary for the equipment of all broadcasting stations, would seemingly be readily practicable at a per unit cost inconsequential in comparison to the total investment in even a small modern station. It will be particularly noted that, once adjusted to the proper harmonic, the standardization at each station (by dead beat methods) may be obtained without further adjustment of the apparatus and will be essentially independent of local conditions.

J. H. Dellinger: The work mentioned by Mr. Shore is an interesting addition to the work I mentioned on direct comparisons of radio frequencies with a time standard. I judge that the method is the one developed by the National Physical Laboratory. The use of multivibrators is not a good feature, as they are inferior to the harmonic amplifier.

The method Mr. Kenrick mentioned of holding broadcasting station frequencies on the licensed values is theoretically correct. However, outside of the difficulty of distributing the basic frequency to all stations, the most serious objection to the method is the requirement that every broadcasting station use a harmonic amplifier to compare its frequency with the lower frequency standard. This would introduce a complicated apparatus of laboratory type into every station; it is very unlikely that the station personnel would in all cases be competent to secure the desired results.

DETECTION BY GRID RECTIFICTION WITH THE HIGH-VACUUM TRIODE*

By

STUART BALLANTINE

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Summary—*The theory of detection of small signals by grid rectification with the high-vacuum triode of the 201A type is briefly discussed by means of the mathematical method of Carson. Special attention is given to the grid-leak, grid-condenser arrangement. The relation between the non-linear distortion and the degree of modulation and between the frequency distortion and the grid impedances is discussed. A convenient method is described for experimentally ascertaining the frequency distortion in detection and illustrated by means of the results in a typical case; this distortion is compared with that due to resonance in the r.f. amplifier circuits. A method of securing efficient grid-rectification in the super-heterodyne system is described. The detection coefficients for the 200A alkali-vapor tube are given in an appendix.*

IN an important paper recently published in the PROCEEDINGS (15, 113, 1927) Chaffee and Browning have considered in a very general way the theory of detection of small signals with the three-electrode tube. In the introduction to this paper Professor Chaffee kindly refers to some unpublished manuscript notes which I sent him in 1924 dealing with the special case of grid-circuit detection with the high-vacuum device. In these notes I had made a somewhat different mathematical approach to the subject, which appeared to me to have certain advantages of conciseness and to exhibit the results in a simple and physically fundamental way. I had also restricted myself to the detection by grid rectification because technically it was of most importance. Believing that these old notes might be found to cover some detailed aspects of the grid-detection process not specifically covered in some of the other papers I have ventured in the present paper to reproduce them in abridged form, with the omission of mathematical details.

With grid-circuit rectification the desired result of detection of a modulated carrier-wave is the production at the grid-filament terminals of the tube of a low-frequency voltage faithfully resembling the original modulation. This audio voltage is then amplified by the tube in the usual way. Due to the independence of e_p and i_g the functions of rectification and

* Original Manuscript Received by the Institute, November 11, 1927.

amplification are divorced from each other and the device may be regarded as playing the dual role of an amplifying-rectifier.[1] The theory of the amplification of the replica modulation voltage is well-known and the calculations are carried through by the customary application of the fundamental plate-circuit theorem, taking into account such impedances at the modulation frequency that may be present in the plate circuit.

In the case of plate-circuit rectification the device may also be regarded as an amplifying rectifier, but the amplification now takes place at the carrier frequency and previous to rectification in the plate circuit. The simplicity of this view is somewhat disturbed by the variability of the amplification-factor μ, which should be taken into consideration in calculating the higher order effects.

1. Summary of Assumptions.—The restricted scope of the discussion may be indicated by the following list of assumptions, which are assembled here for convenient reference:

(1) Discussion restricted to high-vacuum triode of the 201A type in the characteristic of which there are no kinks due to excitation of resonance radiation, or to ionization;

(2) The electron grid current is a function only of the grid potential and is not affected by the plate potential;

(3) The intensity of the signals is so small that terms of higher order than the second can be neglected;

(4) Specimen signal is of the type $e_0 = E_0(1 - m \sin at) \sin \omega t$.

(5) Plate rectification is negligible compared to that in the grid circuit.

Regarding the accuracy of (1) and (2) see the curves for the 201A tube shown in Fig. 4.

2. Grid-Circuit Rectification. Elements of the Mathematical Problem.—The theoretical elements of the problem are shown in Fig. 1. The impedance denoted by Z_c is commonly called the "grid-impedance" and is in series between the supply network (terminals AB) and the grid circuit of the tube. This is not restricted to the conventional form, i.e., condenser and grid-leak resistor in parallel, but may be of any linear type. The impedance denoted by Z_i (or admittance A_i) represents the input admittance of the tube in so far as it arises from the

[1] This was noticed in 1918 by L. M. Hull, to whom the expressive term *amplifying-rectifier* is due. See "Operation of an Electron Tube as an Amplifying Rectifier," *Phys. Rev.*, 15, 557, 1920.

capacity between grid-filament electrodes, and the feed-back from the plate circuit through the grid-plate capacity. The admittance due to the electron current is in parallel with the input admittance and is non-linear, the functional relationship being denoted by $i_g = f(e_g)$.

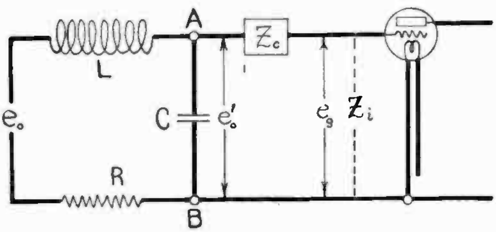

Fig. 1—Elementary Detector and Impact Circuit.

The supply circuit is arbitrarily represented as a simple resonant LC circuit, but the restriction is merely one of convenience. As I pointed out in a discussion of a paper before the Institute in 1918,[2] it is necessary in general to take the impedance of this network into consideration. The impressed voltage e_0 may be reduced to an equivalent voltage e_0 across AB, and where the impedance Z_c would enter in a discussion which ignored the supply circuit we shall find it necessary to add to Z_c the impedance of the supply circuit looking into it from the terminals AB. With these artificialities the problem is reduced to that of a non-linear circuit containing linear and non-linear impedances in series with an impressed voltage. The impressed voltage will be considered to be a modulated carrier of the form:

$$e_0 = E_0(1 - m \sin at)\sin \omega t, \tag{1}$$

where k is the coefficient of modulation. The modulation frequency a will be considered as lying below the carrier frequency ω.

Various mathematical devices are available for the solution of such non-linear problems. In particular a very fundamental

[2] Meeting of November 29, 1918; Proc. I.R.E., 7, 185, 1919. That the impedance of the supply network affects the first-order voltage passed on to the grid circuit of the tube is obvious, and trivial. What I refer to is the effect of this impedance upon the higher-order r.f. voltages, $2\omega, 3\omega, \cdots, n\omega$ which are generated by the non-linearity of the grid-current characteristic. If the supply network contains impedances which are significant at these frequencies the low-frequency detection terms may be profoundly modified. This may augment or diminish the distortion depending upon the signs and values of the higher-order parameters.

and convenient formulation in an integral equation has been devised by Carson.[3] In the steady state Carson's integral equation solution degenerates into the older power series solution which is somewhat better known and easier to handle. It is especially convenient when small amplitudes are involved and the parameters are such as to insure convergence of the series. Carson has made use of the power series method in discussing the steady state theory of the triode under van der Bijl's assumption of constant μ. I have applied this method to the present problem and the results, so far as the second-order effects are concerned, may be summarized briefly as follows.

3. Modulated Signal; $e_0 = E_0(1-m \sin at) \sin \omega t$.—It is sufficiently accurate to assume that that e_g, the voltage on the grid of the tube, is a replica of the voltage e_0 of the above form, and that the r.f. drop in Z_c can be taken care of by saying that $e_g = \theta e'_0$, θ being a complex constant. The second order effects, upon which detection is mainly due in the case of small signals, is calculated as follows: It may be shown that the "equivalent second-order" voltage is:

$$-\frac{P_2}{2A}(e_g^2) = -\frac{e_g^2}{2A}\,\frac{1}{2}\,\frac{d^2 i_g}{de_g^2}, \tag{2}$$

where A is the admittance (total) of the GF terminals of the tube for the components of the above voltage. For the modulated signal (1) this voltage is:

$$-\frac{P_2}{A}\vartheta^2 E_0^2 [1 - 2m \underset{\substack{\uparrow \\ \text{detection}}}{\sin at} + m^2 \underset{\substack{\uparrow \\ \text{distortion}}}{\sin^2 at}] \sin^2 \omega t. \tag{3}$$

The first term in the brackets represents an inaudible voltage and is of no interest; the second represents the desired voltage corresponding to detection and is proportional to $m \sin at$; the last, corresponding to the square of this quantity, represents amplitude distortion (of the second-order) which is undesirable. We may note that the distortion depends upon the coefficient of modulation, m. The relative distortion might be expressed by:

$$\frac{\text{Distortion voltage}}{\text{Detection voltage}} = \frac{m}{4} \cdot \tag{4}$$

[3] J. R. Carson, *Phys. Rev.*, 17, 116, 1921; or "Electric Circuit Theory and Operational Calculus," Ch. 10, New York, 1926.

In order to keep the distortion down to tolerable values m must be properly regulated. High-quality telephony by this method thus demands a considerable outlay of power in the carrier. I understand that it is standard practice in the better broadcasting stations to limit m to 20–30 per cent, to which corresponds a relative distortion in detection at the receiver of about 5 per cent. The coefficient m is not, however, a very useful conception when the modulation undergoes the wide fluctuation of practice.

Of the equivalent second-order voltage (3) the second term is the useful demodulation effect. It is of main interest, and the other terms need not be further considered. Retaining only low-frequency components, the e_1 component of the voltage across Z_c and Z_{AB} (to which the voltage across the grid is obviously equal), is:

$$e_g = \frac{1}{2}\frac{d^2 i_g}{de_g^2}\frac{Z_c'}{1+Z_c'A}\vartheta^2 m E_0^2 \sin at \qquad (5)$$

Here the impedances or admittances are functions of the frequency a.

4. Detection Coefficient for Second-Order Grid Rectification.—The a-frequency voltage acting upon the grid as a result of the rectification is

$$e(\text{audio}) = \frac{1}{2}\frac{d^2 i_s}{de_g^2}\left| Z \right| mE_0^2 \sin (at+\phi), \qquad (6)$$

$$E(\text{audio}) = D_g m E_0^2; \qquad (7)$$

where

$$Z = \frac{Z_c(a)}{1+Z_c(a)A(a)}.$$

D_g is the *detection factor for second-order grid-rectification* and when multiplied by the square of the amplitude of carrier voltage and the modulation coefficient gives the amplitude of the audio voltage. If r.m.s. values are employed:

$$E(\text{r.m.s.}) = \sqrt{2} D_g m E_0(\text{r.m.s.})^2 \qquad (8)$$

The detection factor consists of two parts: the first, $1/2\, d^2 i_g/de_g^2$, is a tube parameter and equivalent to an expression which I proposed in 1919[4] to represent the detecting action of the tube;

[4] Proc. I.R.E., 7, 139, 1919.

the second, which may be called the *grid-impedance factor,* represents the effect of the grid apparatus (Z_c) cooperating with the tube. The general requirement for efficient detection is that Z_c shall be large for the modulation frequency and small for the carrier frequency. For high-quality telephony the modulation frequency extends over a considerable range, from about 50 to 10,000 cycles per second, and in order to prevent frequency distortion in the process of detection we have the further requirement that Z_c shall remain as nearly constant as possible over this range. As the audio impedance of Z_c increases without limit and the input admittance A_i vanishes the detection approaches its ultimate value:

$$D_g = \frac{1}{2} \frac{d^2 i_g}{de_g^2} \frac{1}{g_g}. \tag{9}$$

This quantity was proposed by L. A. Hazeltine[5] as a detection factor for grid-rectification, expressing the merit of the tube as a detector. While it is appropriate only in somewhat ideal circumstances, as I urged in this 1919 discussion, it is nevertheless of value as indicating the ultimate possibilities of the tube when and if Z_c can be so selected as to take advantage of them. Hazeltine's factor might be termed the *ultimate detection coefficient* or the *optimal detection coefficient.*

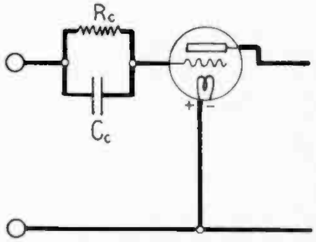

Fig. 2—Grid Leak and Condenser Arrangement for Grid-Circuit Detection.

5. **Grid-Condenser and Grid-Leak Arrangement.**—With further reference to radio telephony by means of a r.f. carrier it may be of interest to consider briefly the action of the venerable grid-condenser, grid-leak form of Z_c. (Fig. 2) So far as the audio-frequency action is concerned it is a matter of indifference whether R_c is shunted across C_c, as shown in Fig. 2, or connected

[5] L. A. Hazeltine: Proc. I.R.E., 7, 173, 1919.

directly between grid and the positive terminal of the grid-biasing battery E_c, because the audio impedance of the r.f. apparatus LC is negligible. The function of R_c is to provide the high audio impedance necessary for efficient detection, while C_c by-passes the r.f. currents and prevents a significant r.f. drop across R_c. It is interesting to compare this with the older theories in some of the textbooks. In these explanations detection is intimately connected with the charging of C_c, and R_c simply serves in the case of the high-vacuum tube as a leak for this charge, whereas from our present viewpoint R_c is the essential element, and so far as the process of detection is concerned C_c is not only superfluous but harmful as a potential source of frequency distortion.

If ω is large enough the r.f. spectrum of the modulated signal will cover a small range about ω, so that if there be no r.f. impedance in the plate circuit of the detector tube, ϑ is constant. If there is significant carrier-frequency impedance in the plate circuit of the detector, as for example in the case of a resistance-coupled audio amplifier (where the by-pass condenser must be limited in order to preserve reproduction of the high audio frequencies), or in the still more unfavorable case of an R-coupled amplifier used with a superheterodyne receiver with intermediate frequency of the order of 10^5 cycles, the component of input impedance due to feed-back through the grid-plate capacity must be considered and the determination of ϑ can perhaps be made more easily by experiment than by computation.

So far as audio response is concerned the quantity of direct interest is ϑ^2. Fig. 3 illustrates the variation of this quantity in a typical broadcast receiver as the capacity of the grid-condenser C_c is varied. The ordinates are derived from the output audio voltage (with constant modulated r.f. signal in the antenna) which is proportional to ϑ^2. The circuit conditions immediately antecedent to the detector were typical: $L=200$ microhenrys, $C=0.0004$ μfds; 201A tube ($E_b=67$ v., E_c return to positive filament terminal). It will be seen from this curve that the value of C_c could be reduced to about one-half the conventional value (0.00025 μfds.) without much sacrifice of grid voltage.

The grid impedance factor Z in (6) depends upon the grid-electron conductivity (g_g), the admittance of Z_c, and input admittance of the tube (A_i), all at the frequency of modulation. Thus:

$$Z = \frac{1}{g_o + A_i(a) + A_c(a)}. \tag{10}$$

The tube factor g_o may be determined experimentally as a function of the grid-operating voltage. The parameter, dg_o/de_o may then be derived from this data by taking the slope of the conductivity curve for several values of e_o. The admittance of Z_c is easily computed, but the input admittance A_i is somewhat more complicated.

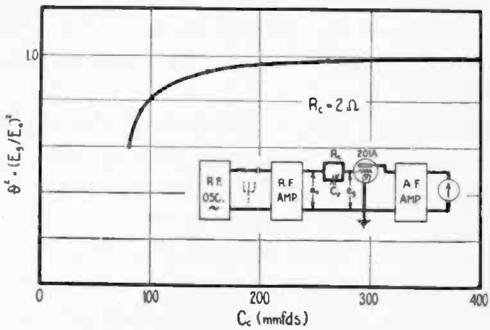

Fig. 3—Variation in $\vartheta^2 = (E_0/Eg)^2$ in a Typical Case as Affected by Grid-Condenser Capacity.

6. Continuation. Special Case; Zero Input Admittance.—To get an idea of the relative effects of these several elements we may temporarily ignore the input admittance, and consider the cooperation of g_o and Z_c. In these circumstances the amplitude of Z is:

$$|Z| = 1/\sqrt{(g_c + g_o)^2 + a^2 c_c^2}. \tag{11}$$

The variation of Z with the modulation frequency a represents a frequency-distortion in the process of detection which is worth noticing in the case of telephone reproduction.

Experimental values of the parameters of a UV-201A type tube which are of interest in the calculation of the detection factor are shown in Fig. 4. This tube was an old one in which the emission had fallen somewhat and is thought to be a better specimen of tubes in use than a new one would have been. The full-line curves represent grid conductance (di_g/de_g) and the dotted curve the grid current i_g for a plate voltage of 45. The actual potential assumed by the grid when using a grid-leak resistance R_c returned to positive filament ($E_c = 5$) are determined graphically as follows:

$$\begin{aligned} i_g &= f(e_g) && \text{(a)} \\ i_g &= \frac{E_c - E_g}{R_c} && \text{(b)} \end{aligned} \qquad (12)$$

Curve *a* is the grid-current, grid-voltage curve of the tube; curve *b* is a straight line intersecting the E_g axis at E_c and the i_g

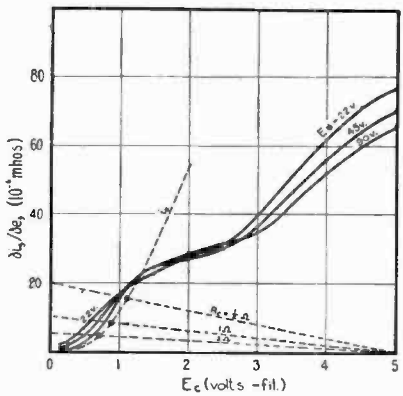

Fig. 4—Experimental Values of Grid Electron Conductance g_g and Grid Current i_g for UV-201A Type Tube Showing Operating Points for Various Values of Grid-Leak Resistance.

axis at E_c/R_c amperes. The intersection of these two curves gives the actual grid potential. The intersections for R_c's of 2, 1, and 1/2 megohms are shown in the figure, amounting to 0.7, 0.9 and 1.1 volts respectively. The values of D_g for various values of R_c as a function of the modulation frequency have been computed from the formula:

$$D_g = \frac{1}{2}\,\frac{dg_g}{de_g}\,\frac{1}{\sqrt{(g_g+g_c)^2+a^2c_c^2}} \qquad (13)$$

These are shown in Fig. 5.

For low modulation frequencies the detection factor increases with the grid-leak resistance and is approximately equal to unity for 2 megohms. The frequency distortion due to the shunting effect of the grid condenser ($C_c = 0.00025$ μfd.) at the higher frequencies also increases with R_c; for $R_c = 2$ megohms the amplitude at 5000 cycles has fallen to 62 per cent of its normal value. If the higher frequencies are to be preserved it appears desirable to avoid this distortion by employing a low R_c. This involves a double sacrifice in amplitude, double because not only the detection factor is reduced, but the losses introduced into the r.f. LC circuit by the increased electron conductivity further reduce the r.f. amplitudes. From the latter viewpoint it is somewhat preferable to keep the grid-electron conductance low and to obtain the desired high value of $g_g = g_c$ by making g_c high. The

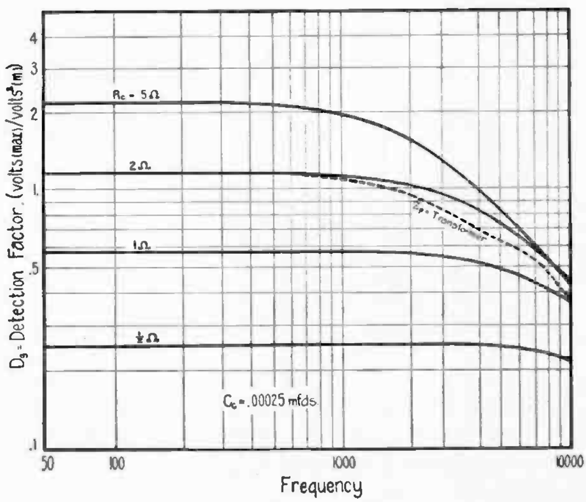

Fig. 5—Detection Coefficient of Second-Order Grid Rectification for UV-201A Tube for Various Grid Leaks as Affected by Audio-Modulation Frequency. Dotted Curve Showing Effect of Audio Input Impedance (trans. plate load).

proper bias for this may be obtained by disconnecting the return from the positive filament and using a battery E_c of less than 5 volts. This will minimize the r.f. losses due to this adjustment, but there still remains the decreased detection factor. The makers of the UV-201A tube recommend a grid-bias of from 5 to 8 megohms. Under these conditions the sensitivity will be good but the frequency distortion will be rather severe.

The above recommendation has been defended by W. B. Roberts of the Radio Corporation Test Department,[6] who calculates that with a 201A tube the use of a 5-megohm leak will

[6] Proc. I.R.E., 15, 793, 1927.

result in a decrease of but 10 per cent at 4500 cycles. The grid resistance at the resulting operating point is stated to be 65,000 ohms. This conclusion is in startling disagreement with the conclusions of this paper (as well as the data of Chaffee and Browning) which is to be attributed to Mr. Roberts' error in choosing the grid resistance. This is actually more nearly 250,000 ohms, and 65,000 ohms corresponds to a grid-leak of 0.5 megohms, not 5 megohms. In these circumstances the frequency distortion would be serious, as Fig. 5 shows. This is confirmed experimentally when the plate rectification is relatively small (as is usually the case), and the impressed voltages lie within the bounds contemplated by the "small signal theory" (i.e. below about 0.3 volt r.m.s.). Both plate rectification and higher impressed voltages tend to offset the frequency distortion (*vide* Sec. 8) and the experimental results under these conditions may be deceptive.

7. Continuation. Effect of the Input Admittance, A_i.—In the preceding section the input admittance was assumed to be zero in order to exhibit the action of the grid-condenser and grid-leak in the simplest possible way. We may now take this into consideration and briefly indicate its effect.

The input admittance in question is that presented at the modulation frequency a. As occasioned by the grid-plate capacity of the detector tube it will depend among other things upon the audio impedance in the plate circuit. Two types of plate load are of practical interest: (1) an audio interstage coupling transformer, and (2) a coupling resistor; both will usually be shunted by a small by-pass condenser to reduce the r.f. input admittance. If the precise nature of these impedances is known over the audio range the input admittance may be computed from formulas previously published;[6] but this is likely to prove a vexatious process and the required values are perhaps more easily arrived at by direct measurements. The results of such measurement of the components g_i (input conductance) and C_i (input capacity) for the UV-201A tube are reproduced in Fig. 6a for the two types of plate load.

In the first case, the transformer (R.F.L. Model 3A) was of average characteristics as follows: $L_1=40$ h., $L_2=430$ h., $\alpha L_1=0.4$ h., $C_2=0.00016\mu$fd., ratio 3.3/1. The tube constants were as follows: $E_b=45$ v., $E_c=1$ v., $\mu=8$, C_m (grid-plate) $=8.5$

[6] J. M. Miller, "Scientific Papers of the Bureau of Standards," No 351, 1919. Stuart Ballantine: *Phys. Rev.*, 15, 409, 1920.

$\mu\mu$fds., C_1 (grid-filament) $= 4$ $\mu\mu$fds. The referred secondary capacity antiresonates with L_1 at about 700 cycles, marked n_0 on the curve. Below this the transformer reactance is inductive and g_i is negative. Above n_0 and up to frequency n_1, near which the referred secondary capacity resonates with the leakage reactance, the reactance is negative and g_i is positive. Above n_i the leakage reactance prevails for an interval in which g_i again becomes negative. The input capacity, C_i, varies from about 112 $\mu\mu$fds. to a minimum of 33 $\mu\mu$fds. near n_1.

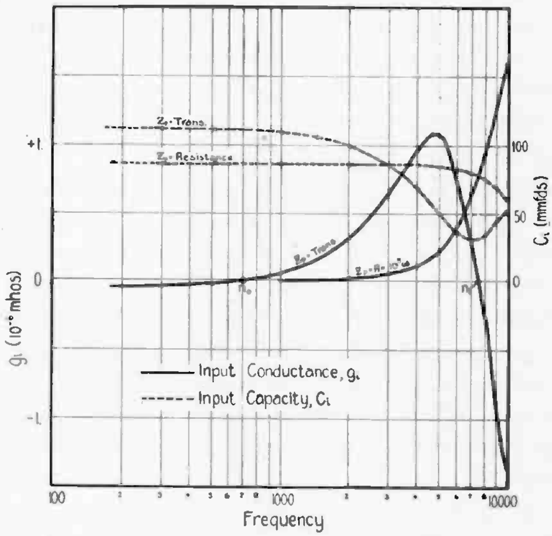

Fig. 6a—Input Conductance, g_i, and Input Capacity, C_i, of UV-201A Tube as a Function of Audio-Frequency for Two Types of Plate Load, (1) Transformer and (2) 100,000-ohm Coupling Resistor.

In the case of the R-coupling arrangement, $E_b = 90$ v., and the coupling resistor was 100,000 ohms with a by-pass condenser of 0.0005 μfd. Here g_i rises and C_i falls continuously with increasing frequency.

The effect of these input admittance variations upon the "impedance factor" Z and the detection factor D_y may be computed from (10). The results are represented by the dotted curve in Fig. 5 for the case of a 2-megohm grid-leak resistor and an audio-transformer plate load. The effect of A_i is not particularly striking. The chief effect is that due to the increased total capacity, which has been increased by C_i about 50 per cent.

The curves for the transformer and resistor will therefore be very much alike. In the absence of A_i the amplitude had decreased to about 62 per cent at 5000 cycles; with A_i it is decreased to about 50 per cent of its low-frequency value.

By arranging a proper audio-frequency feed-back I have found it possible to compensate the falling off of the detection factor at high audio frequencies, and even to give it the rising characteristic which is useful in compensating the frequency distortion due to the selectivity of tuned circuits, audio-amplifier and loudspeaker characteristics, etc.

8. Effect of Plate Rectification upon Frequency Distortion.—For small signals the rectification in the plate circuit may be represented by an equivalent voltage, E, acting as usual through the plate resistance and external impedance, where:

$$E = D_p E_0^2 m \vartheta_p^2 \ ; \ D_p = -\frac{1}{2}\frac{\delta^2 ip}{\delta e_g^2}\frac{1}{g_p}$$

and $\vartheta_p = Z_p(\omega)/Z_p(\omega) + R_p$. The quantity ϑ_p depends upon the degree of by-passing of the external impedance in the plate circuit for the r.f. components and is analogous to the corresponding quantity for the grid circuit. Considering the grid-condenser, grid-leak arrangement and adding the effects of plate rectification to those due to the grid, we get for the total voltage effective in the plate circuit:

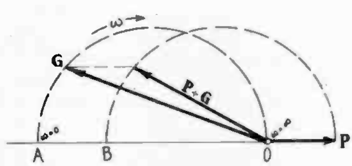

Fig. 6b—Vector Addition of Grid and Plate Rectification; Grid-Leak and Grid-Condenser Arrangement.

$$E = E_0^2 m \left[\underbrace{D_p \vartheta_p^2}_{\text{plate rectification}} - \underbrace{\frac{1}{2}\frac{\delta^2 i_g}{\delta e_g^2}\frac{1}{g_c + g_g + A(a) + A_c(a)}\mu}_{\text{grid rectification}} \right]. \tag{14}$$

The combination of these two rectification effects is illustrated vectorially in Fig. 6b. The vector G represents the grid detection; as the frequency varies from 0 to infinity its endpoint describes the semicircle AO. The plate detection is represented by the vector P which is constant with respect to frequency. The vector sum of these revolves about the point O and its end point describes the semicircle BP. It is immediately clear that the effect of plate detection is to reduce both the total detection and its variation with frequency. In particular when $P=1/2\ G$ (zero frequency), or:

$$D_p\delta_p^2=\frac{\mu}{4}\ \frac{\delta^2 i_g}{\delta e_g^2}\ \frac{1}{g_c+r_g},$$

the frequency distortion vanishes and the detection is halved. When $P>G(O)$ the detection increases with the frequency instead of diminishing. The experimental curves shown in Fig. 6c

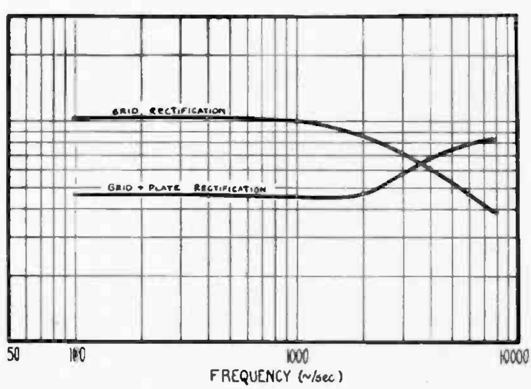

Fig. 6c—Effect of Plate Rectification on Frequency Distortion; Nominal Grid Detection with Grid-Leak and Grid-Condenser; 201A Tube, 5,000 meters.

illustrate the two types of variation. For conventional values of the constants grid rectification is so much more efficient than plate rectification that the latter affects the distortion to a negligible extent.

This furnishes another method of adjusting the distortion; like that suggested in Section 6 (i.e., reducing $C_c\ /g_c+g_o$) it involves a sacrifice in efficiency.

9. Experimental Method for Determining Frequency Distortion.—The frequency distortion in a grid-circuit detector caused by the variation of the grid impedance factor may also be investigated directly by experimental methods. Fig. 7 illustrates a method[7] which I have used successfully for several years and as applied to the usual grid-leak, grid-condenser arrangement have found simple and convenient when a calibrated modulated r.f. carrier is not at hand. The constant voltage furnished by an adjustable audio oscillator is introduced in series with the grid-leak R_c as shown. If not normally so connected the grid-leak is connected between grid and filament during these measurements to permit grounding the a.f. source. The audio voltage is kept small enough so that first-order effects alone are concerned; it is then not necessary to filter the output before leading it to

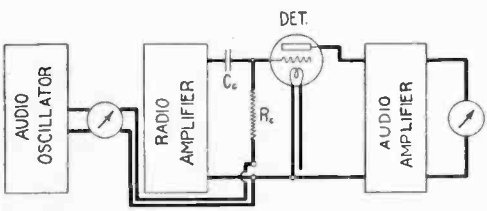

Fig. 7—Experimental Method of Studying Frequency Distortion in Grid Detection (Grid Leak and Grid Condenser) using Audio-Frequency Oscillator.

the output meter. The "amplifier" should preferably have a gain at least equal to that of the audio amplifier of the average radio broadcast receiver. If the frequency-response curve for the amplifier (including the amplifying performance of the detector tube) is not known it may be found at the same time by making $R_c = 0$ and plotting output against frequency. Absolute values are of no interest. The ratio of the two curves found with $R_c = 0$ and $R_c = R_c$, corrected so that it approaches unity at low frequencies, varies with frequency in precisely the same way that the grid impedance factor varies with frequency. For if e represents the impressed audio voltage, then the voltage e_g across the grid-filament terminals will be

$$\frac{e_g}{e} = \frac{g_c}{g_c + A + i\omega c_c} = g_c \times \text{grid } z \text{ factor.} \qquad (15)$$

[7] This scheme was devised independently by H. A. Wheeler; (Discussion at I.R.E. Convention, January, 1927.)

The convenience of the method depends upon the grid-leak impedance being a pure resistance; in the general case other methods must be resorted to.

It should be pointed out that this method measures only the variation of grid impedance and will not give a true picture of the frequency distortion when there is appreciable plate rectification. If plate rectification is suspected it is preferable to use for the measurements a calibrated r.f. carrier, modulated at various audio frequencies.

10. Relation of Detector Distortion to other Sources of Frequency Distortion in a Typical Receiver.—A question of prac-

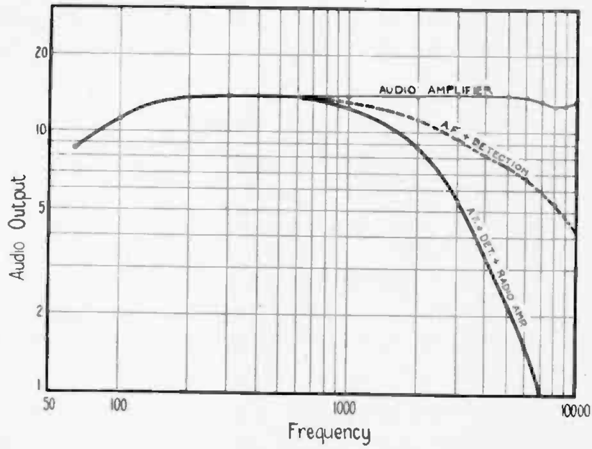

Fig. 8—Illustrating Frequency Distortion in the Process of Grid Detection to Other Sources of Distortion in a Typical Broadcast Receiver.

tical interest is the relation of the frequency distortion in the detector to other sources of frequency distortion in the receiver. I have tried to indicate an answer in Fig. 8 for the case of a typical five-tube broadcast receiver. This receiver employed two stages of r.f. amplification and three tuned circuits, the circuits being arranged in the form of a Wheatstone a-c. bridge to render each stage monodic so that true cascade selectivity would be obtained. The top curve, labeled *Audio Amplifier*, represents the distortion in the two-stage audio amplifier, the amplification being measured as the ratio of voltage at the grid of the power tube to that at the grid of the detector tube (as described in the last paragraph, $R_c=0$). The power tube contained its normal electrophone load but so filtered as to prevent coupling through the internal impedance of the common B battery. The transformers (R.F.L., Model 5A) were two which I had designed for another purpose and happened to be at hand. In addition some artificial feed-back was introduced between the stages in order to iron out residual irregularities in the response curve. The resulting response curve is fairly uniform and suitable for this comparison.

The effect of the detector distortion is added to the audio amplifier in the dotted curve, which was taken by the method of the last section. Conditions were typical: 201A tube, $R_c = 2$ megohms, $C_c = 0.00025$ μfds.

The final heavy curve represents the distortion in the entire receiver and was obtained by introducing into the antenna a constant carrier modulated at various audio frequencies by a constant amount (20 per cent). The frequency of the carrier was 750 kc. (400 m.). The distortion due to the selectivity of the r.f. amplifier is rather pronounced at this frequency; at 1300 kc. (230 m.) it is scarcely noticeable up to 5000 cycles. The distortion in the process of detection thus appears to be important in comparison with that due to selectivity in the r.f. amplifier even at a frequency where this latter is most prominent. At 1300 kc. the detector distortion is considerably more important, and tells the whole story if the audio system is good.

11. Application to the Super-Heterodyne.—The superheterodyne utilizes two detectors: the first converts two frequencies of the order of 10^6 into a difference frequency of the order of 10^5; the second converts this difference frequency into audio frequencies ranging from 0 to 10^4. Thus the frequencies in each detector differ by one order of magnitude. In the ordinary receiver they differ by at least two orders of magnitude (carrier 10^6, audio response 10^4). It has already been shown that in the ordinary receiver the use of a grid-condenser, grid-leak form of Z_c is attended with difficulties; in the superheterodyne these difficulties are considerably magnified. In the second detector it is necessary to filter the plate circuit carefully in order to keep ϑ high, particularly when a resistance-coupled audio amplifier is employed. The problem becomes really acute, however, in the first (frequency-changing) detector.

A theory of detection which considers only the second-order effects will not, of course, apply to the process in the first detector of the superheterodyne. If this were the case the signal amplitude would rise continuously with the heterodyne voltage. Actually, as Armstrong showed experimentally, it reaches a maximum and an "optimum heterodyne" exists. Appleton and Taylor have given a rough mathematical explanation of this in terms of the higher order parameters of the tube, of which the fourth seems to be of most importance. However, according to the series analysis of this problem given in Sec. 2, each higher order effect is derived from that of next lower order, and it may be inferred from the second-order terms that in the usual arrangement of the first detector in the superheterodyne the detection takes place by plate-circuit rectification and not by grid-circuit rectification as the frequent connection of a grid-leak and

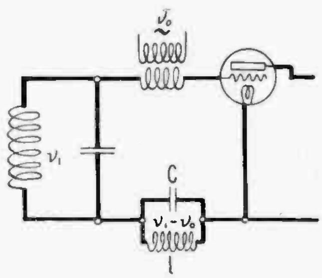

Fig. 9—Arrangement for Increasing the Efficiency of Grid-Rectification in the First Superheterodyne Detector. Anti-resonant Circuit LC is Tuned to Difference (intermediate) Frequency.

condenser in the grid circuit by many persons would seem to suggest. Consider the efficiency of the grid-condenser, grid-leak arrangement in this case.

For $C_c = 0.00025\ \mu$fd. and $R_c = 2$ megohms the detection factor at a frequency of 10^4 according to Fig. 4 has fallen to 40 per cent of its d-c. value; at an "intermediate frequency" of 10^5 it will have fallen to 4 per cent of its d-c. value on account of the low impedance of C_c for this frequency. In these circumstances the contribution of the grid-circuit rectification is very doubtful. In the plate circuit, on the other hand, the coupling transformer or filter has a high impedance at the intermediate frequency and efficient detection probably takes place here.

In order to see if the efficiency of detection in the grid-circuit under conditions of optimum heterodyne might not be better than that of the plate circuit under similar conditions I investigated, several years ago, the scheme shown in Fig. 9. Here the circuit *LC*, anti-resonant at the intermediate frequency, is placed in series with the grid and replaces the grid-condenser and leak. The constants can be so chosen that the impedance is low at the carrier frequency and maximum at the intermediate frequency. The efficiency of detection in the grid-circuit is thus increased from 4 to about 50 per cent. In order to avoid complications due to feedback from the plate into *LC* through the grid-plate capacity I used a neutralizing arrangement. Among other things a very noticeable increase in selectivity in the i.f. tuning is to be

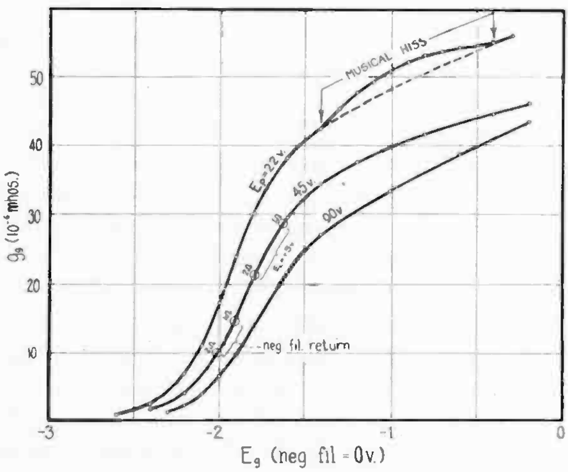

Fig. 10—Electron Grid Conductance of 200A Type Detector Tube for Various Plate Voltages. Small Circles Indicate Operating Points with 1 and 2 Megohm Grid Leaks. Returned to Positive or Negative Filament Terminals.

observed immediately with this arrangement. The same thing can be done in an ordinary detector where sharp audio discrimination is desired, as in the case of c.w. telegraphic work to eliminate noise. In this case *LC* are tuned to perhaps 1000 cycles. The question as to the relative merits of grid and plate-rectification for frequency changing in the heterodyne is not relevant to the present paper and will be considered in detail in a later publication. Fig. 8 is included merely to indicate how grid rectification may be obtained, if desired.

Addendum

Note on the Detection Characteristics of the 200A Type Tube.—Since this paper was written the 200A type detector tube has been placed upon the market. This tube appears to contain alkali vapor, derived from a capsule contained in a small hemispherical boss welded to the plate. So far as I know, very little technical information has been published relating to the theory of operation of this alkali vapor device or to its detection characteristic. It may therefore be of some interest to include curves of grid conductance for a specimen tube selected at random from stock, and a calculation of the detection factor for small signals.

From the viewpoint of detection the main thing of interest is the variation of grid conductance with the grid potential. This is shown in Fig. 10. The grid is of fine mesh and the amplification factor is about 20; this shifts the region of operation to negative values of E_g. The correct negative operating potential may be obtained with the usual values of grid-leak by changing the grid return from the positive to the negative terminal of the filament. The actual operating points for grid-leaks of 1 and 2 megohms for both positive and negative returns are marked on the curve for $E_p = 45$ v. It is noticeable that in this tube the plate has more influence upon the grid conductance than was the case with the 201A type tube, hence our separation of the amplifying and detecting functions is not strictly correct. The operating point giving the greatest range of linearity between g_g and E_g is found at $E_g = -1.85$ v., which may be approximated by the use of a 2-megohm leak with positive filament return or a 1-megohm leak with negative filament return. The range of linearity is about 0.1 volt, which in view of the high amplification factor will be adequate to take care of the amplitude of the carrier voltage.

The detection factors for low frequencies at various operating points are given in the following table:

TABLE I

LOW FREQUENCY DETECTION-FACTOR (GRID-RECTIFICATION) FOR 200A TUBE ($E_p = 45$ v.) FOR VARIOUS GRID-BIASES

R_c	E_c	E_{g0}	g_g	D_g
1	5 v.	1.62 v.	2.85×10^5	0.567
2	5	1.8	2.1	1.4
1	0 v.	1.91	1.5	1.97
2	0	2.0	1.0	2.06

A comparison with the factors for the 201A tube (Fig. 5) will indicate that there is not much difference between D_g for the two types for the same grid conductance (same r.f. loss); the difference, however, favors the new tube. The increase in signal strength which is observed when this tube is substituted for the 201A is therefore probably to be accounted for by its increased efficiency as an amplifier which results from the much higher amplification factor. The plate resistance at the operating point ($E_g = -1.85$) is about 35,000 ohms. In view of this an audio coupling-transformer designed to operate with the output resistance of the 201A tube will not be satisfactory with the new tube, necessitating redesign with probably a lower turns-ratio. When this is attended to and the same frequency-response characteristic is attained it may be found that the over-all performance has been reduced to about that of the 201A tube. For resistance-coupling the tube may have some advantage, provided the plate circuit is carefully filtered to keep down r.f. input impedance.

It is a pleasure to acknowledge the experimental assistance rendered by Mr. Raymond Asserson.

List of Symbols

$A_g = g_g = 1/R_g$ = Admittance of grid-filament terminals of tube due to electron current.

A_i = Input admittance exclusive of electron current.

$A = A_i + A_g$ = Total admittance of GF terminals of tube.

A_c = Admittance of apparatus in series with grid circuit of tube.

g_i = Conductance component of input admittance.

C_i = Capacity component of input admittance.

C_c = Capacity of grid-condenser.

$g_c = 1/R_c$ = Admittance of grid-leak.

i_g = Electron grid current.

E_0 = Amplitude of carrier voltage.

e_0 = Modulated signal $= E_0(1 - kF(t))$ sin ωt.

e = Audio voltage across GF due to detection.

E = Amplitude of above.

m = Coefficient of modulation.

$P_1, P_2, \cdots, P_n$. Differential grid-current parameters of tube.

D_g = Detection factor for grid-circuit rectification.

Z = Grid-impedance factor.

e_0' = Equivalent voltage across AB (Fig. 1) due to e_0.

RECENT DEVELOPMENTS IN LOW POWER AND BROADCASTING TRANSMITTERS

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Summary—*Various types of radio transmitting equipments are described, ranging in output from 200 to 2000 watts. The application of master-oscillator power-amplifier circuits for low- and medium-frequency transmitters is explained, and the uses of quartz crystal control for high-frequency and broadcast transmitters are described. A brief explanation is also given of the equi-signal system of radio beacon transmission, which promises to become an important aid in the navigation of aircraft.*

THE purpose of this paper is to describe the more important commercial developments which have taken place in low-power transmitting equipment during the past two or three years. The term "low power" as used in this paper refers to equipment with an output of less than 5 kw. This is a more or less natural division of radio transmitting apparatus since outputs of less than 5 kw. are generally obtained with air-cooled vacuum tubes using motor generator sets as a source of power supply, while transmitters having outputs of more than 5 kw. utilize water-cooled tubes with high voltage rectifiers as the usual source of plate supply.

A definition of the method of rating vacuum-tube equipment is essential in comparing various classes of apparatus or in discussing overall efficiency, arrangement of tubes, and general performance. The transmitters covered in this paper have their ratings based on the power delivered to the antenna, exclusive of all losses in loading inductors or antenna series capacitors included within the transmitter proper or mounted externally. This method of rating is of considerable importance in determining the design of a transmitter since unfavorable antenna conditions and other factors often result in high losses in the antenna loading system which are not included as part of the output from the transmitter.

Vacuum-tube transmitter development during the ten years from 1917 to 1927 might be divided roughly into three periods. From 1917 to about 1920 we may say that the fundamental

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oscillator circuits were fairly well-determined and limited military and commercial applications of tube transmitters were made. The problem of designing reliable apparatus required considerable attention during this period, while larger size vacuum tubes were developed to meet the demand for higher outputs.

In the period from 1921 to 1924, we have seen a considerable revision in the type of circuits used in the various transmitters.

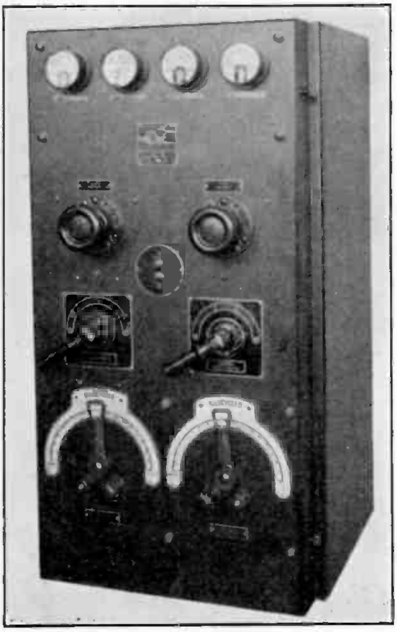

Fig. 1—Front View of Transmitter, Model T-4.

Master-oscillator circuits, providing continuously variable frequency control with a high degree of stability, supplanted the former antenna oscillator circuits. Much progress was also made in securing simplified controls. In the older transmitters, it was necessary to make critical adjustment of tapped coils or coupling devices and transmission was generally limited to a definite number of frequencies. The newer designs permit all adjustments to be made from the front of the panel and the loading on the vacuum tubes is not dependent upon the skill of the operator.

Work done during the past three years or so has consisted largely of commerical development of transmitters suitable for high-frequency operation, together with refinement in circuit and mechanical design of low- and medium-frequency transmitters. The exacting requirements for constant frequency in the case of the very high frequency equipment have been met through the application of quartz crystal control. The use of crystal control brought about the development of cascade radio-

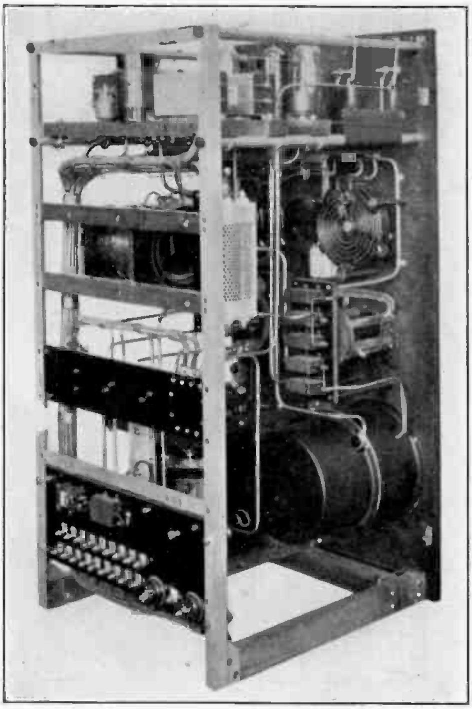

Fig. 2—Rear View of Transmitter, Model T-4.

frequency amplifier circuits so that the comparatively small output obtained from the crystal-controlled tube could be amplified to the desired level. In order to secure high frequencies from comparatively thick crystals, frequency multipliers were also utilized by taking advantage of the harmonics produced in the plate circuit of a tube when the grid is properly biased and supplied with a high exciting voltage. Crystal control has also been applied in the broadcast field so that a very high degree of frequency constancy may be attained by a station. Equipment of this type is described in detail further in this paper.

200-watt Transmitters

Transmitting equipment, having an output of 200 watts, was developed for the U. S. Coast Guard for service on many of their smaller vessels. A front view of the transmitter, which is known as model *T-4*, is shown in Fig. 1 and a rear view in Fig. 2. Particular attention was directed in the design of this transmitter to reduce the number of controls to a minimum and at

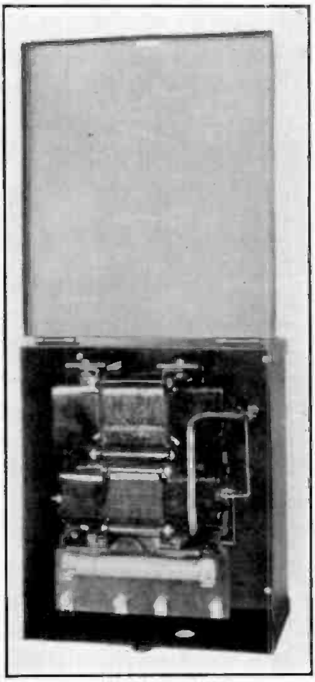

Fig. 3—ICW Telegraph Attachment for Model T-4 Transmitter.

the same time provide for setting the frequency and maintaining it to a high degree of accuracy.

The transmitter utilizes four CG-1984 (UV-211) vacuum tubes, one functioning as the master oscillator and the other three as radio power amplifiers. When used on the average small ship antenna, whose capacitance generally lies within the values of 0.0006 to 0.001 μfd., the transmitter covers a continuous frequency range from 250 to 500 kilocycles. CW and ICW telegraphy are obtained by placing the signal switch on the panel in the proper position. The two large pointers near the bottom of the panel control the master oscillator variometer and the antenna variometer. The desired transmitting frequency is set by means of the master oscillator variometer and the antenna circuit is then resonated for maximum current by means of the antenna variometer. In addition, the antenna inductance switch is provided in order to select any one of four taps which are provided on the antenna loading inductor.

The four vacuum tubes are mounted in a cushioned cradle near the top of the transmitter in order to permit adequate ventilation and provide for easy replacement. Four instruments are also mounted near the top of the panel and indicate antenna

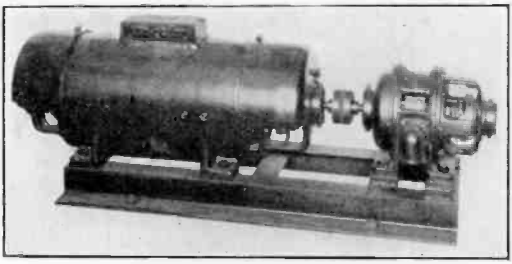

Fig. 4—Three-Unit, Four-Bearing Motor-Generator Set.

current, filament voltage, total plate current, and plate voltage. Rheostats are supplied to permit convenient control of the filament and plate voltages. A momentary contact start-stop push button is mounted in the center of the panel for starting and stopping the motor generator set. A similar switch is also supplied for external mounting on the operator's table so that the equipment may be controlled from either location.

The rear view shown in Fig. 2 illustrates the arrangement of the various component units in the transmitter. The metal container in the lower right section shields the master-oscillator variometer. The capacitors in the master-oscillator circuit are mounted directly above the variometer. All high-frequency wiring in the transmitter is made with copper tubing while low-frequency and control circuits are run in lead-covered wire.

In order to provide ICW telegraphy with this equipment, a separate attachment is supplied as shown in Fig. 3. This unit, whose operation will be described more in detail later, is designed for installation in any convenient place in the radio room and contains no moving parts and requires no adjustment.

A 3-unit, 4-bearing motor-generator set is supplied to furnish filament and plate power and power for the ICW attachment. This machine is shown in Fig. 4, and the automatic starter for controlling it, in Fig. 5. The motor operates from a line supply of 110 to 125 volts direct current and is also built for operation from a 32-volt d-c. system. Slip rings are provided on the motor

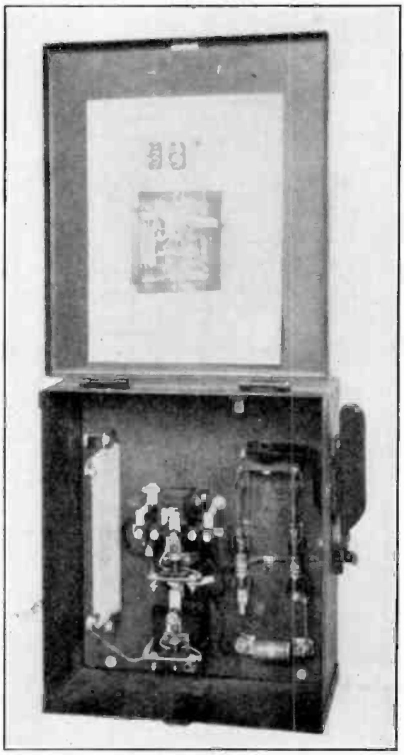

Fig. 5—Automatic Starter.

winding in order to furnish alternating current for heating the filaments of the vacuum tubes. The plate generator is rated 0.8 kw. at 1000 volts direct current. The third unit of the M.G. set is known as the tone alternator and delivers 0.25 KVA at 110 volts and 500 cycles. Ball bearings are provided in this motor generator set.

The theory of operation of this 200-watt transmitter may be understood by referring to the schematic circuit diagram in Fig. 6. The master-oscillator tube, consisting of one CG-1984 tube, has its frequency controlled by the variometer L-4 which operates in a capacity-coupled circuit. This variometer is shunted by three capacitors connected in series marked *C*-1, *C*-2 and *C*-4. Capacitor *C*-3 is the usual plate-blocking capacitor and serves to keep the d-c. plate voltage off the oscillating circuit and at the same time provides a low reactance path for the radio-frequency energy. The d-c. plate supply for the master-oscillator tube is obtained from the 1000-volt generator through the radio

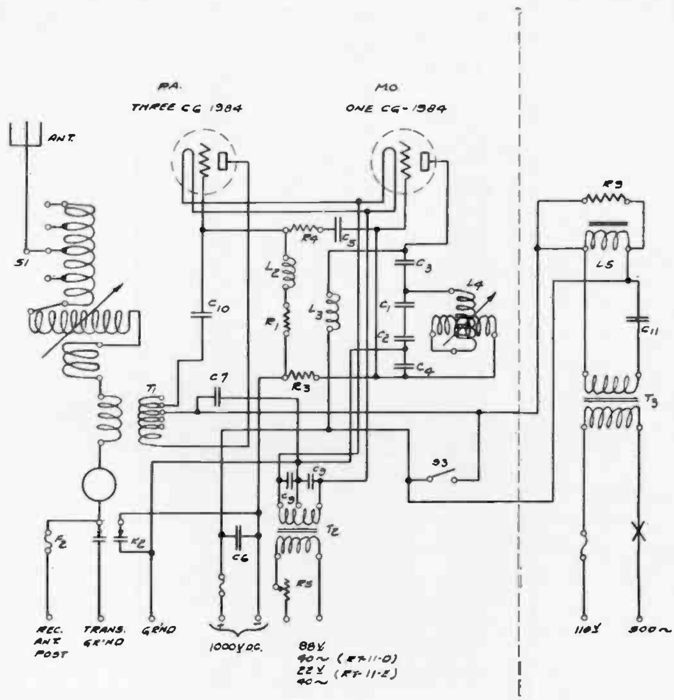

Fig. 6—Schematic Circuit Diagram of Model T-4 Transmitter.

choke *L*-3. Grid excitation to the three CG-1984 power amplifier tubes is obtained through capacitor *C*-5 and resistor *R*-4. The grid-leak circuit of the radio-amplifier tubes is made up of inductor *L*-2 which acts as a radio-frequency choke, and resistor *R*-1. The grid leak on the master-oscillator tube is resistor *R*-3.

Capacitor *C*-10 is used to stabilize the radio amplifiers, while capacitor *C*-7 is the plate by-pass unit and provides a low reactance path for the high-frequency energy in the power-amplifier plate circuit.

The power output from the radio-amplifier tubes is delivered to the antenna through the antenna transformer *T*-1. Flexible leads are provided to taps on the primary of this transformer to make adjustments for unusual antenna conditions. In the ordinary case, these adjustments are made at the factory and it is not necessary to readjust them in the actual installation.

The antenna circuit is adjusted for resonance to the frequency of the master oscillator by means of the antenna loading inductor

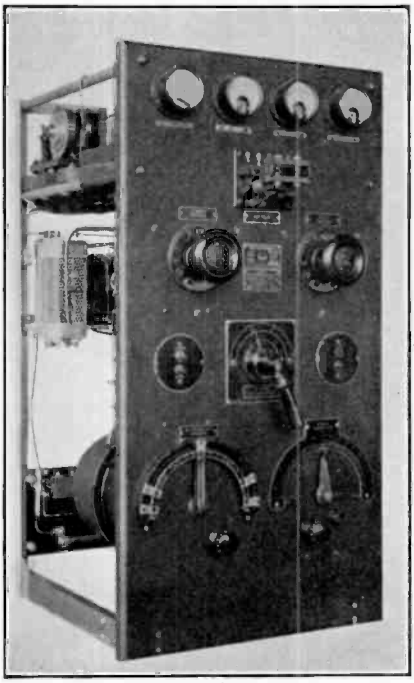

Fig. 7—Front View of Model ET-3627-A Transmitter.

L-1 which, as stated before, is provided with four taps and a variometer.

Since modern radio traffic conditions require rapid change-over from send to receive, a magnetically operated break-in relay is supplied in the transmitter. This relay is designated as *K*-2 in Fig. 6. It is equivalent to a double-pole, single-throw relay, with the parts designed to operate at keying speeds up to 40 words per minute. One pair of contacts are in series with the low side of the antenna circuit and serve to short circuit the input to the radio receiver during the transmitting condition. The second pair of contacts key the transmitter and are so timed that they close slightly after and open slightly before the contacts in the antenna circuit. This arrangement prevents sparking at the antenna contacts and reduces the disturbance from clicks in the radio receiver.

The fundamental keying circuit may be understood by referring to the schematic diagram. The negative lead from the

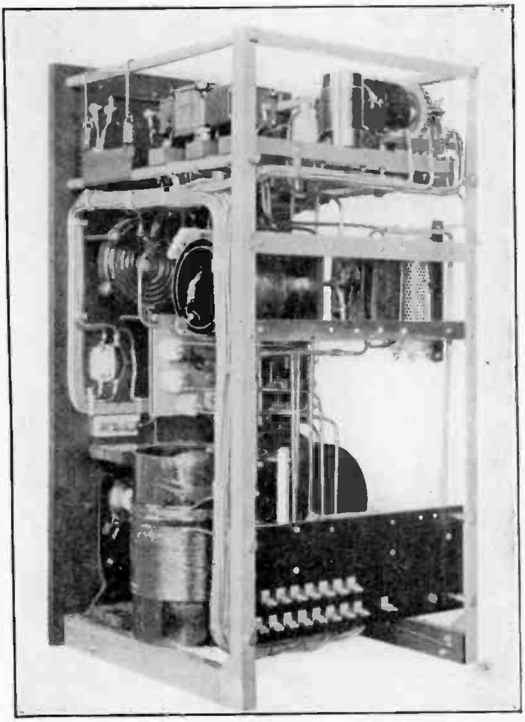

Fig. 8—Rear View of Model ET-3627-A Transmitter; Motor-Driven Chopper in Upper Right Section of Frame.

1000-volt generator connects to one of the key contacts on the break-in relay. After passing through these contacts, the negative plate circuit connects to the mid-point of the filament transformer *R*-2. In addition, the grid leaks *R*-1 and *R*-3 of the radio amplifier and master oscillator respectively are returned to the negative side of the plate circuit. This form of keying circuit therefore breaks both the negative plate circuit and the grid current with the result that a negative potential is impressed upon the grids of the tubes whenever the contacts open. Comparatively large amounts of power can be keyed in this manner with but slight sparking at the relay contacts.

The method of obtaining ICW telegraphy in this transmitter is of interest as it provides the equivalent of positive plate modulation without the use of additional vacuum tubes. Five-hundred cycle power from the tone alternator on the motor-generator set is supplied to the primary of transformer *T*-3

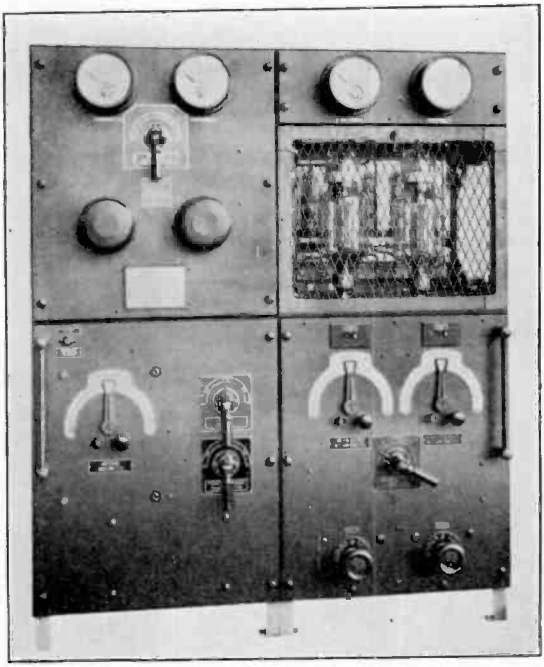

Fig. 9—Front View of 500-watt Coast Guard Transmitter.

shown on the diagram in Fig. 6. This transformer steps up the voltage to a suitable value for introducing directly into the plate circuit of the main power-amplifier tubes. The reactor *L*-5 provides an appropriate path for the d-c. plate current normally required by the power-amplifier tubes while capacitor *C*-11 provides a path for the 500-cycle power. The resistor *R*-9 shunted around reactor *L*-5 is used to prevent transients or surges set up while keying. The output current of the amplifier tubes is proportional to the plate voltage impressed upon them and the arrangement shown permits the 500-cycle voltage either to add to or subtract from the normal d-c. plate voltage. A pleasing note having constant characteristics is obtained with this modulating system and it has the additional advantage that it may be heterodyned at the receiving station if desired.

200-WATT R.C.A. TRANSMITTER

Fig. 7 shows a front view of the model ET-3627-A transmitter, developed for the Radio Corporation of America, which has been

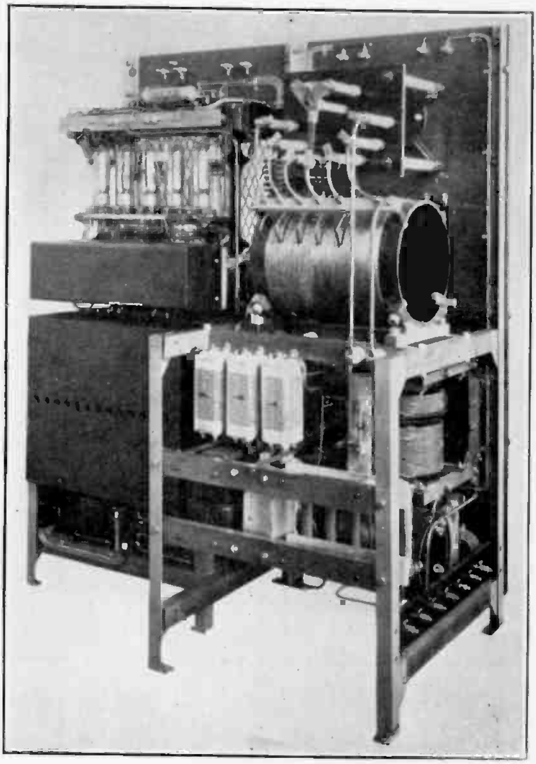

Fig. 10—Rear View of 500-watt Coast Guard Transmitter.

extensively applied for marine installations. The fundamental circuits in this transmitter are quite similar to those in the Coast Guard 200-watt equipments but some changes have been made to meet the requirements of commercial service. An adjustable positioning device for the master-oscillator variometer is of particular interest and is shown in the lower left section of the panel in Fig. 7. This device permits any five frequencies within the 312- to 500-kilocycle range to be selected and a permanent adjustment maintained. Such an arrangement is of considerable help to an operator in changing from his calling to his working frequency as it makes it unnecessary to set the master-oscillator pointer carefully at an exact position on the dial.

ICW telegraph is carried out in the ET-3627-A transmitter

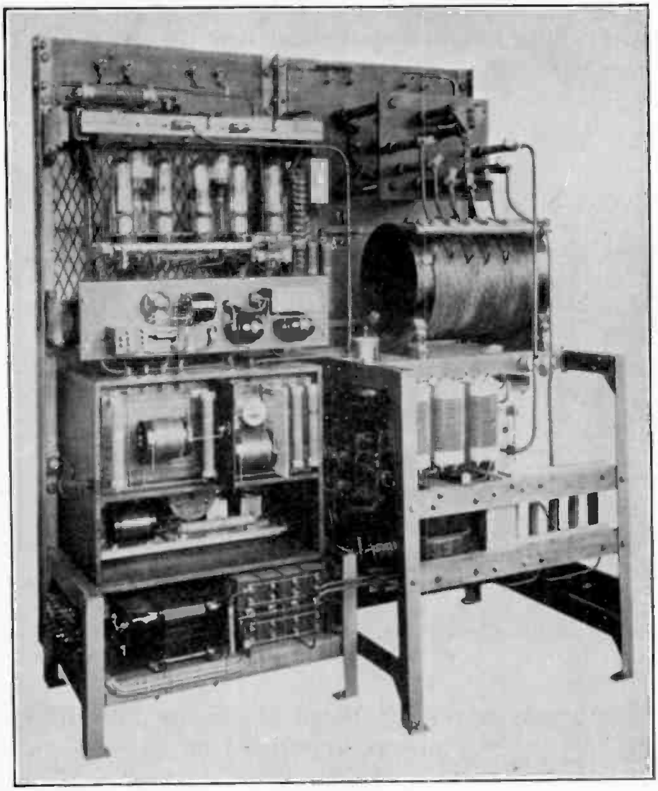

Fig. 11—Rear View of 500-watt Coast Guard Transmitter with Shielded Compartment Removed.

by means of a motor-driven chopper. Referring to Fig. 8, this chopper may be seen in the upper right section of the frame.

Extensive applications have been made of the ET-3627-A transmitter for coastwise vessels or for other ships which require a compact transmitter capable of giving a reasonable communication range. The daylight range under normal conditions from this transmitter when transmitting on CW is from 400 to 600 miles, while night ranges of 1500 miles have been obtained. These ranges are for transmission over water.

500-watt Coast Guard Transmitter

In order to meet the need for higher power equipment than provided for in the sets already described, a 500-watt transmitter was developed for the U. S. Coast Guard. A front view of this transmitter is shown in Fig. 9. Fig. 10 shows a rear view of the transmitter with the shielded compartment in position over the master-oscillator and audio-amplifier circuits, while Fig. 11 is a rear view with the shielded compartment removed.

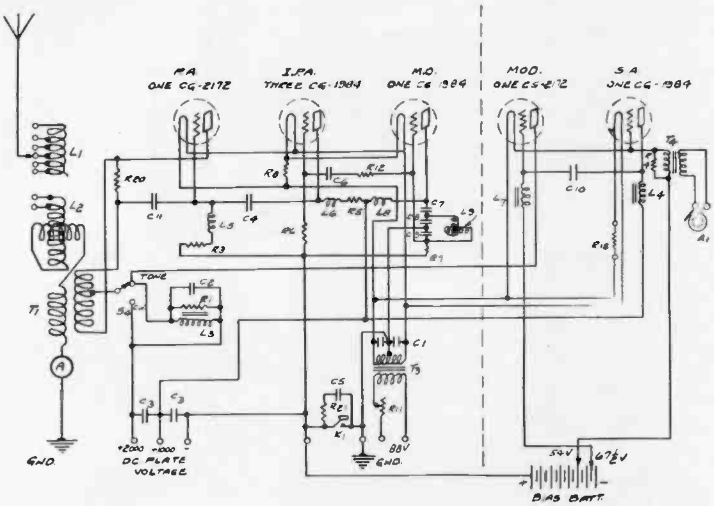

Fig. 12—Schematic Circuit Diagram Showing Fundamental Arrangement in 500-watt Transmitter.

A continuous frequency range of 125 to 500 kilocycles is provided by this equipment when used on an antenna whose capacitance falls within the limits of 0.00085 to 0.001 μfd. Since a transmitter of this power rating is ordinarily used on ships where fair-sized antennas may be erected, it is not designed to work into as low a value of capacitance as the smaller set. In addition, much lower transmission frequencies are possible. Signalling may be carried out by CW or ICW telegraphy, and the audio circuits in the transmitter are so designed that telephony may be carried on with slight modifications in the wiring.

The transmitter uses a total of seven vacuum tubes as follows:

1 CG-1984 (UV-211) as master oscillator.
3 CG-1984 (UV-211) as intermediate amplifiers.
1 CG-2172 (UV-851) as main radio amplifier.

1 CG-2172 (UV-851) as modulator.
1 CG-1984 (UV-211) as audio amplifier.

The functioning of these tubes will be described later with reference to the circuit diagram.

The CG-2172 tube is normally rated at 1 kw. output and operates on a d-c. plate voltage of 2000. The filament requires

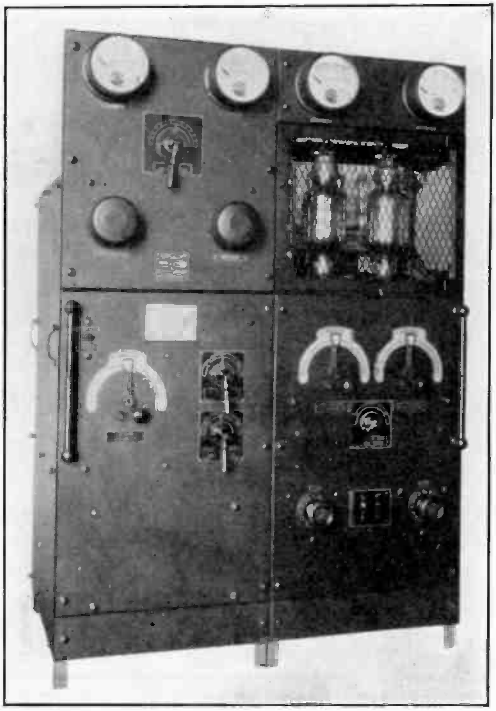

Fig. 13—View of 2-kw. Transmitter.

15.5 amperes at 11 volts and is heated from alternating current. The use of a 1 kw. tube in this transmitter to secure a nominal output of 500 watts was desirable for two reasons. In order to operate the antenna at the lower frequencies, a considerable amount of loading inductance is required with its corresponding losses. In order to provide ICW telegraphy, and at the same time permit telephony to be used later if desired, the CG-2172 tube was selected as a modulator. Actual tests on the completed transmitter showed that outputs of from 500 to 750 watts could easily be obtained even under unfavorable antenna conditions.

One of the chief electrical requirements for this transmitter was that it should permit any frequency within the specified band to be selected in a short period of time and that it should maintain this frequency constant to within 350 cycles despite normal changes in antenna characteristics or variations in line-supply voltage. Experiençe has shown that a high degree of frequency stability in a transmitter of this power can be

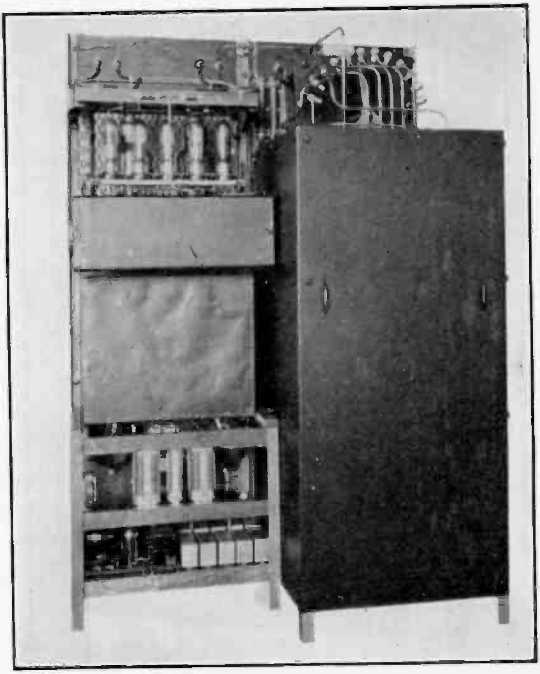

Fig. 14—View of 2-kw. Transmitter.

obtained through the use of an intermediate amplifier between the master oscillator and the main radio amplifier. This arrangement enables the master-oscillator or frequency-determining circuit to be built with relatively small well-shielded units, while the intermediate amplifier acted as a buffer to prevent reaction from the antenna circuit from disturbing the load on the master oscillator.

A schematic circuit diagram showing the fundamental arrangement in the 500-watt transmitter is shown in Fig. 12. The master-oscillator circuit is the capacitively-coupled type with inductance variation provided for changing the frequency. In the transmitter proper two such variometers are utilized in order to spread out the frequency scale.

Referring to Fig. 12, the three intermediate power-amplifier tubes, which are connected in parallel, have in their plate circuits an inductor L-6 and a resistor R-5. The values of these two

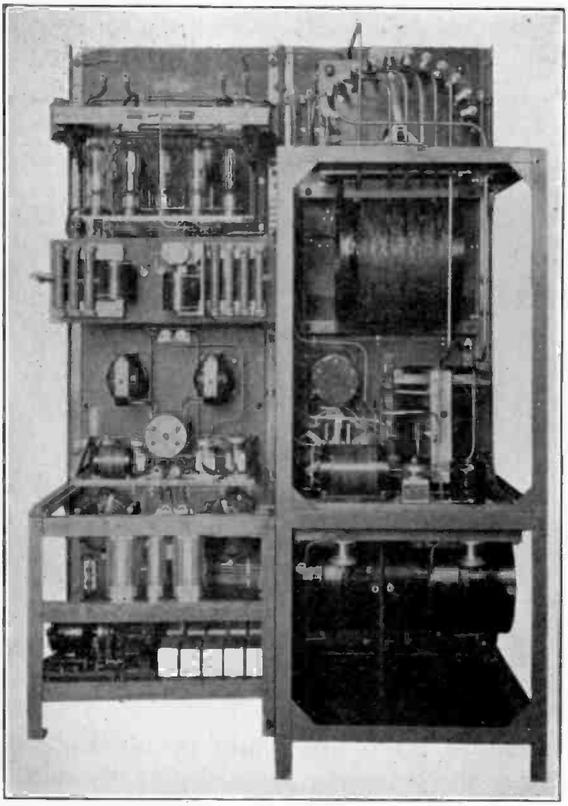

Fig. 15—View of 2-kw. Transmitter.

units are so selected that fairly uniform amplification is obtained over the entire frequency range of the transmitter. For this reason, no adjustments of any nature are required in the intermediate amplifier circuit. The voltage built up across L-6 and R-5 is used to excite the grids of the CG-2172 radio-amplifier tube, through the coupling capacitor C-4. A grid leak choke L-5 and a grid leak R-3 are provided in the grid circuit of the radio-amplifier tube. The plate circuit of the CG-2172 amplifier is coupled to the antenna circuit through the output transformer

T-1. In the actual transmitter, two of these transformers are supplied with an appropriate band change switch to place either transformer in circuit, depending upon the frequency desired. The characteristics of output transformers such as used in these transmitters are similar in some respects to standard power transformers. The primary or plate winding is designed with sufficient reactance so that the input to the power-amplifier tubes is limited until the antenna circuit is in resonance to the frequency being supplied to the grid of the amplifier. This provides simplified tuning for the radio operator as the power-amplifier tube does not draw its full load until the antenna circuit has been correctly

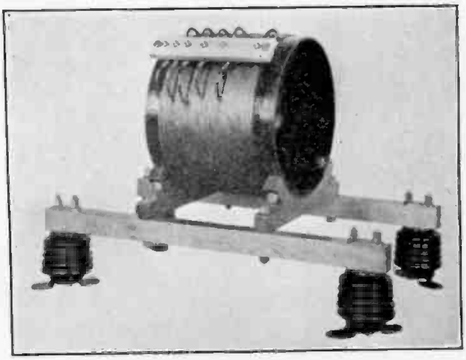

Fig. 16—External Loading Coil.

resonated. Loading of the antenna circuit is accomplished in the usual manner with a tapped inductor and a variometer for fine adjustment.

ICW telegraphy is accomplished by the familiar plate modulation system common to many broadcasting transmitters. The iron core reactor L-5, in Fig. 12, is common to the plate circuit of the radio-amplifier tubes and the modulator tubes. Audio frequency for modulating is obtained from a small tone alternator A-1 in the schematic diagram. The output from this machine passes through a step-up transformer T-4 where it is impressed upon the grid-filament circuit of the audio-amplifier tube. The audio-amplifier is of the reactance-capacitively-coupled type and delivers this output through capacitor C-10 to the modulator grid. In order to carry on telephony with this transmitter, it is merely necessary to substitute a microphone and battery for the tone alternator.

Referring again to Figs. 10 and 11, the general mechanical design of the 500-watt equipment may be observed. The master-oscillator, intermediate-amplifier, and audio-amplifier circuits are mounted in the left rear section of the transmitter. Complete shielding of these units is provided. The vacuum tubes are mounted above the audio-amplifier unit in a cradle which is cushioned with springs and sponge rubber. A door on the front

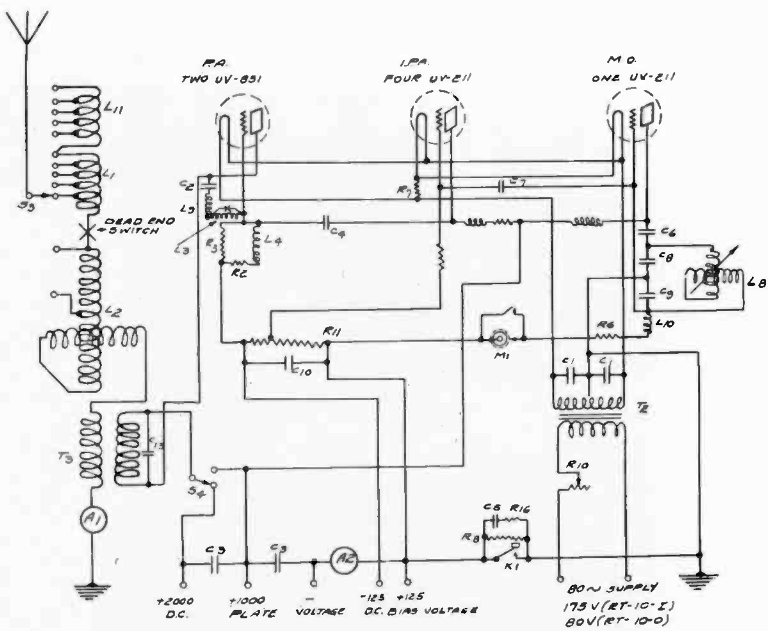

Fig. 17—Schematic Diagram of ET-3638 Transmitter.

of the panel provides for easy replacement of these tubes. The output transformers and the antenna-loading inductor with the antenna switch are mounted in the right rear section. Extensive use is made of Mycalex insulation on the antenna inductance switch. The band change switch which selects the appropriate output transformer is also insulated with Mycalex. As it is necessary to carry transmitters through narrow doors on shipboard, the design is such that easy disassembly of the transmitter into two or more sections can be accomplished. A small terminal board is built on one of the panels to provide for interconnection between units.

2-kw. R.C.A. Model ET-3638 Transmitter

For large vessels handling a considerable amount of traffic at long distances, a 2 kw. radio transmitter provides a logical rating. It is also suitable for shore installations, where comparatively long distance transmission is required. Views of a 2-kw. transmitter developed for the Radio Corporation are shown in Figs. 13, 14, and 15.

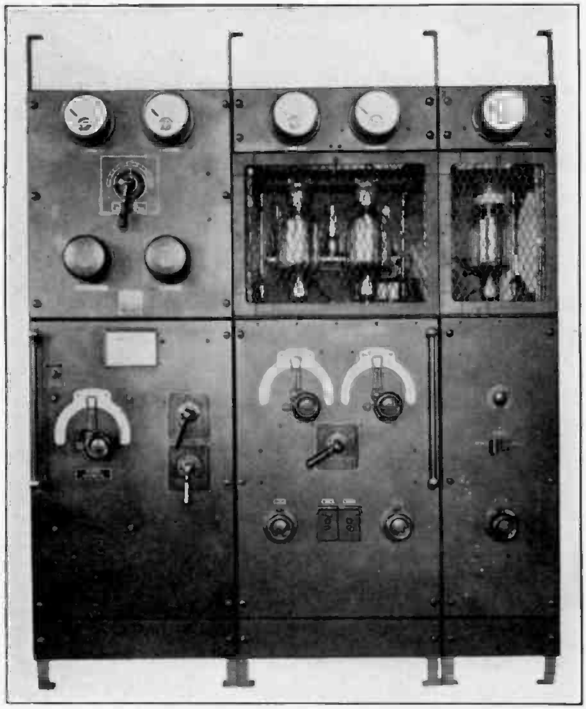

Fig. 18—Front View of 2-kw. Transmitter with Telephone Attachment.

The ET-3638 transmitter uses a total of seven vacuum tubes. Five of these tubes are type UV-211 and the remaining two are type UV-851. One of the UV-211 tubes operates as a master oscillator, four UV-211 function as intermediate amplifiers, and the two UV-851 tubes are connected in parallel as the main radio power amplifiers. A continuous frequency range of 125 to 500 kilocycles is covered by the transmitter when used on the average ship antenna. An antenna current of about 25 amperes is the usual value obtained. Continuous-wave and interrupted continuous-wave telegraphy are provided, the latter being obtained by means of a motor-driven chopper.

Power supply for the transmitter is obtained from a 3-unit motor-generator set consisting of a motor with slip rings for filament heating, a 2000-volt 4.6 kw. plate generator, and a small bias generator for holding grid bias on the various tubes.

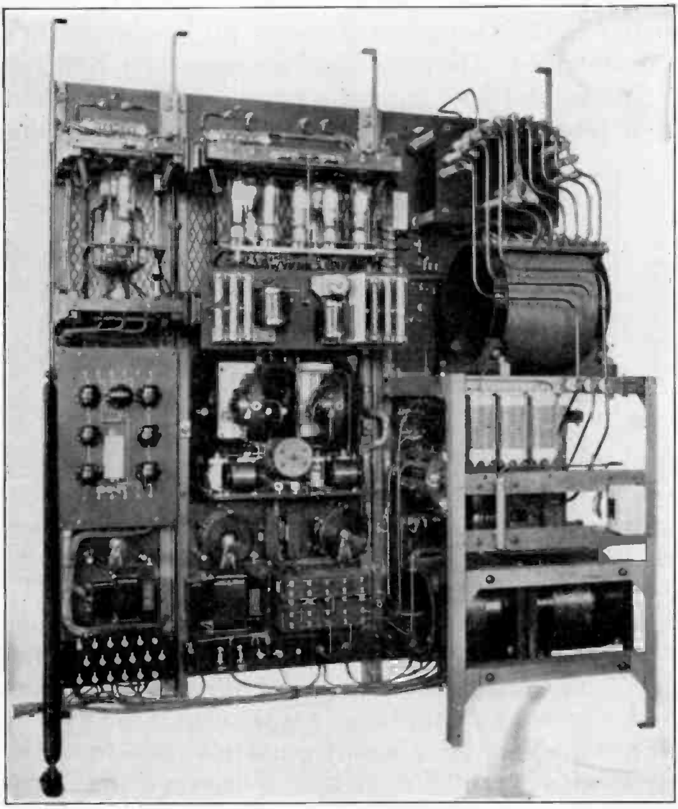

Fig. 19—Rear View of 2-kw. Transmitter with Telephone Attachment.

In order to permit operation at the lower radio frequencies on antennas whose capacitance is somewhat lower than the average, an external loading coil is supplied such as shown in Fig. 16. When operating into an 0.001 antenna at 125 kilocycles, the potential on the antenna end of the loading inductor reaches values as high as 32,000 volts. For this reason, ample insulation is provided on the loading inductors and on the antenna switch which changes the taps.

Extensive shielding has been employed in this 2 kw. transmitter not only to permit a high degree of frequency stability to be maintained, but also to enable the transmitter to be installed close to metal bulkheads without causing high losses. The various shields are easily removed for inspection or repair of the transmitter.

A schematic circuit diagram of the ET-3638 transmitter is shown in Fig. 17. This circuit is in most respects similar to those already described. The motor-driven chopper, for ICW, is used to break the grid leak current on the master oscillator tube. A cut-off bias obtained from the 125-volt bias generator is main-

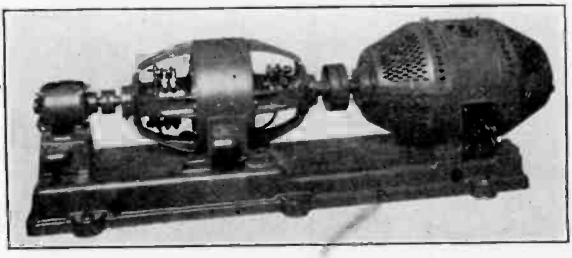

Fig. 20—Three-Unit Motor Generator Set.

tained on the grids of the four intermediate amplifiers and the two main amplifiers, so that the plate current of these tubes falls to zero whenever the excitation from the master-oscillator tube is interrupted by the chopper.

A considerable amount of work has been done to minimize harmonic radiation from transmitters of this type. Suitable design of the output transformer and the antenna loading inductors, together with shielding, has resulted in very low radiation of harmonic energy. Measurements taken on a transmitter of this type show that the fundamental energy is approximately 30,000 times as great as the second harmonic and about 60,000 times as great as the third harmonic component. Referring to Fig. 17, the capacitor *C-13* in shunt to the primary of the output transformer *T-3* is used to by-pass the very high frequency harmonics.

U. S. Coast Guard Model T-2-A 2 kw. Transmitter

A 2-kw. transmitter with a telephone attachment was developed for service on some of the larger vessels of the U. S. Coast Guard. Front and rear view of this equipment are shown in Figs. 18 and 19 respectively. The general arrangement of tubes in the radio transmitter proper is similar to that employed in the 500-watt Coast Guard equipment, with the difference that more tubes are used. The transmitter proper has one CG-1984 (UV-211) as a master oscillator, four similar tubes in parallel as intermediate amplifiers, and two CG-2172 (UV-851) tubes as the main radio amplifiers. In order to carry on telephony or ICW

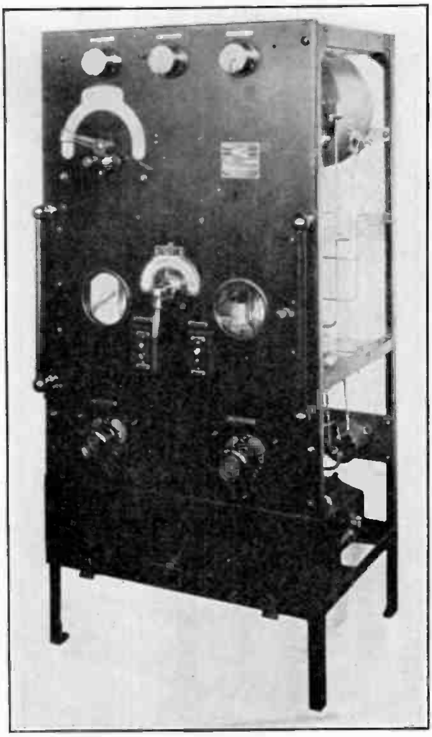

Fig. 21—400-watt Transmitter

telegraphy, a separate telephone attachment which may be mounted alongside the transmitter, is furnished. This attachment utilizes one CG-1984 as the speech amplifier and one CG-2172 tube as the modulator. When the signal switch on the transmitter is placed in the tone or ICW position, the plate voltage on all the tubes is reduced in order to permit the modulator tube to control properly the output of the radio amplifiers. The transmitter covers the same frequency range as the 500-watt Coast Guard set, namely, 125 to 500 kilocycles.

The type of 3-unit motor-generator set supplied with equipments of this nature is shown in Fig. 20. This machine is designed to carry its load when operating in high ambient temperatures such as are encountered in engine rooms.

Aircraft Radio Beacon Equipment

An interesting development being carried out at the present time consists of a system for guiding aircraft. It is known as the

Fig. 22—Experimental Form of Goniometer.

double beam equi-signal method of transmission and permits the use of standard receiving apparatus in the aircraft. An additional feature is that the pilot or operator need not possess an extensive knowledge of the telegraphic code.

Two large loops are used for transmission instead of the conventional type of antenna. These loops are installed at right angles to one another and each produces, if separately energized, a well-known figure eight pattern of radiated energy. A goniometer, similar to the well-known Bellini-Tosi type, is utilized with necessary modifications to adapt it best for this beacon system. The goniometer couples the radio transmitter to the transmitting loops and by variations of the rotor of the goniometer, the combined pattern of the loop may be rotated. In other words, the goniometer permits the combined pattern to be set for a desired course, with convenience from the transmitting station, without physically changing the position of the large transmitting loops. The rotor, or primary, of the goniometer consists of two coils which are alternately connected to the radio transmitter by means of an automatic relay. By suitable adjustment of the angle between the

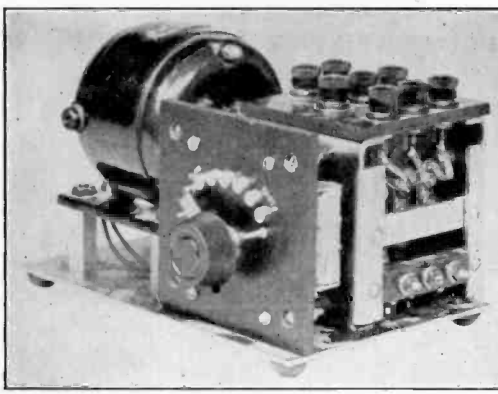

Fig. 23—Automatic Signalling Device.

two rotor coils, the patterns of the two loops are made to overlap, and in this overlapping zone what is known as an equi-signal area is maintained.

In order to produce interlocking signals, the automatic relay may be arranged to send for example, the letter *N* on one rotor coil and the letter *A* on the other coil. By suitable timing, the dot of the *A* is made to begin as the dash of the *N* terminates, with the result that the receiving operator hears a series of dashes, as long as he is flying in the equi-signal zone. Tests have shown that the width of this equi-signal zone is to the order of 2 to 3 miles at distances of about 100 miles from the transmitting station and this width can be varied by suitable adjustment at the goniometer.

Fig. 21 shows a 400-watt transmitter which is being used for some of the experimental work with the aircraft beacon. This transmitter utilizes two UV-204-A tubes in a self-rectified circuit with 500 cycles plate supply and is adjusted to operate on a frequency to the order of 290 kilocycles. An experimental form of the goniometer is shown in Fig. 22. The two inside or rotor coils may be clearly seen, while the secondary or outer coils which consist of several turns are wound at right angles to one another and connect to each of the transmitting loops. The automatic signalling device shown in Fig. 23 is provided with cams for

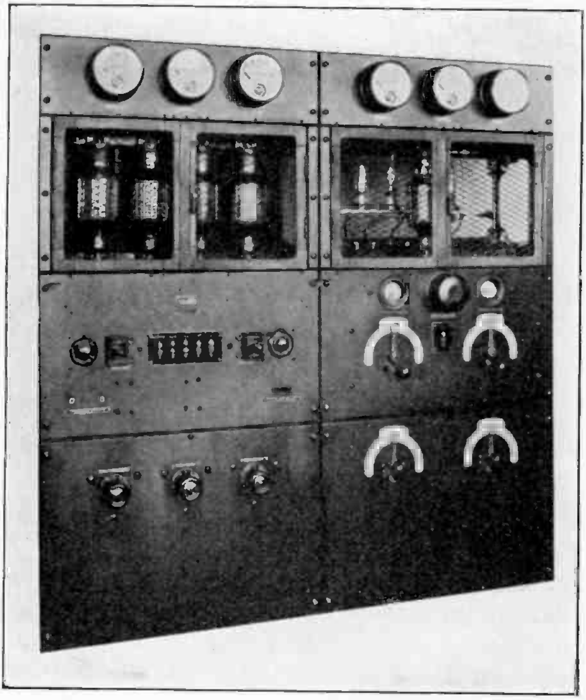

Fig. 24—View of 1-kw. Broadcast Transmitter.

sending the appropriate letters to secure the interlocking signal. A small rheostat is provided to vary the speed of the motor which drives this signalling device.

An installation of the radio beacon equipment has been made at Hadley Flying Field, New Brunswick, N. J., and with the aid of this equipment, practical operating data and the general characteristics of the beacon system are being obtained. This work is being carried on in cooperation with the Department of Commerce and active steps are being taken to work out a practical system that may be used throughout the country.

1-kw. Broadcasting Equipment

A broadcasting transmitter that meets the requirements for present-day high-quality service should possess at least three important characteristics. The design should permit the carrier wave to be conveniently adjusted and maintained to within at least 500 cycles of the assigned frequency. It is also important

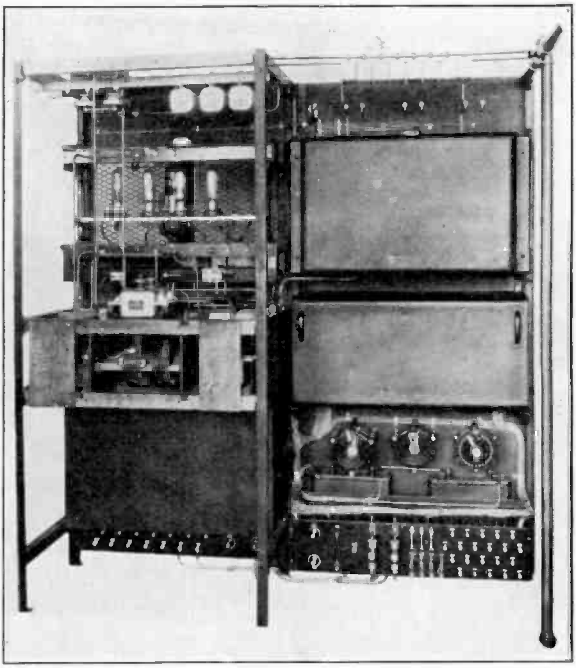

Fig. 25—View of 1-kw. Broadcast Transmitter.

that the carrier frequency should not fluctuate while modulation is taking place. The second requirement which the equipment should possess is to provide a high degree of fidelity so that the modulated output of the transmitter conforms as faithfully as possible to the input to the microphone. The third requirement concerns overload capacity and the various circuits should be so designed and the tubes chosen to prevent distortion from overloading on high modulation peaks. Unless such overload capacity is provided for, it is necessary for the supervising operator to smooth off the peaks excessively with consequent impairment of the quality.

Various views of the 1-kw. broadcast transmitter are shown in Figs. 24, 25, and 26. The condenser microphone with its self-contained amplifier is shown in Fig. 27.

The transmitter as normally designed covers a frequency range from 666 to 1200 kilocycles, although it may be easily

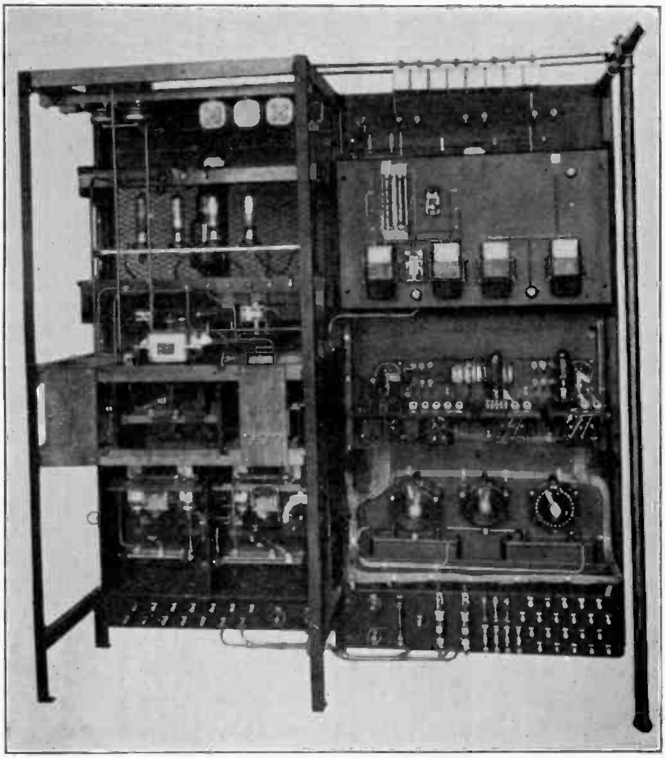

Fig. 26—View of 1-kw. Broadcast Transmitter.

modified for any frequency within the broadcast band. The complete equipment utilizes the following vacuum tubes:

2 UX-201-A as audio amplifier.
1 UX-210 as audio amplifier.
2 UV-211 as audio amplifiers.
4 UX-851 as modulators.
1 UV-211 as master oscillator.
2 UV-211 as intermediate radio amplifiers.
1 UV-851 as the main radio amplifier.
1 UV-211 as oscilloscope rectifier.

All of the above tubes are contained within the transmitter proper with the exception of one of the UX-201-A tubes which is mounted with the condenser microphone.

It will be observed that four modulator tubes are used and one main radio-amplifier tube. This ratio permits maximum modulation to be obtained without overshooting the modulator tubes. Due to the use of such a low-impedance bank of modulator tubes,

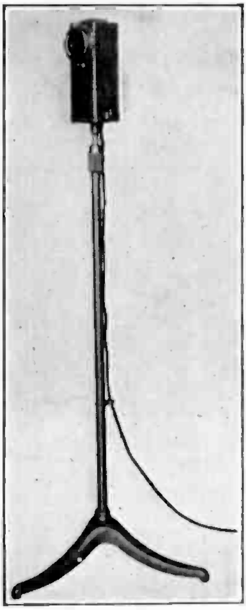

Fig. 27—Condenser Microphone with Self-Contained Amplifier.

combined with a large modulation reactor, the low audio frequencies are well maintained.

A schematic circuit diagram is shown in Fig. 29. All the vacuum tubes to the left of the antenna circuit in this diagram are in the audio-frequency circuit, while the tubes to the right are in the radio-frequency circuit. The condenser microphone works into the first UX-201-A tube, this tube being mounted with its associated output transformer, in the microphone housing. The secondary winding on the output transformer is of low impedance so that the microphone cable may be run for a considerable distance without picking up interfering current. The first three stages of audio amplification in the transmitter proper are the resistance type, and the fourth stage utilizes an iron core reactor in its plate circuit. Volume-control potentiometers are provided on the input to the third and fifth stages of amplification. Provision is also made for ready connection to incoming lines for outside pick-up service.

Referring to the radio-frequency tubes in the schematic diagram, the master oscillator has its frequency controlled by means of a variable capacitor for fine adjustment and by variation of taps on the inductor for coarse adjustment. This tube supplies grid excitation to 2 UV-211 tubes which are provided with a tuned tank circuit and function as intermediate amplifiers. The main radio-amplifier tube, a UV-851, also has its plate circuit tuned and is in turn inductively coupled to the antenna

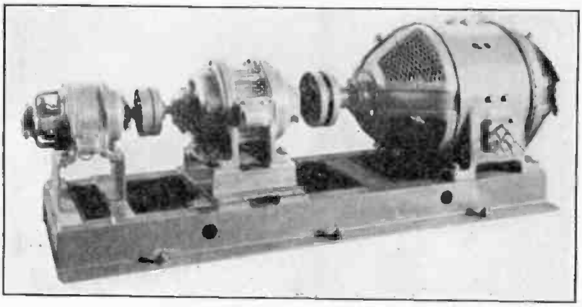

Fig. 28—Three-Unit Plate Motor Generator Set.

circuit. Complete shielding is employed to provide maximum frequency stability and the various coupled circuits minimize harmonic radiation.

One of the problems in the successful operation of a broadcast transmitter consists of reducing all hum or background of noise in the carrier wave to an extremely low value. In the ET-3633 equipment, this is accomplished by the use of suitable filter for the plate circuit of the vacuum tubes and by the use of a separate direct-current filament generator for all the larger tubes. The audio amplifiers have their filaments heated from a storage battery. Fig. 28 shows the three-unit plate motor generator set and Fig. 31 the filament motor generator set.

The oscilloscope supplied with the equipment for checking the percentage modulation is of interest. This unit is shown in Fig. 30 and is equivalent to the familiar oscillograph with the exception that it contains but one vibrator and is designed to use an incandescent lamp as a light source. The UV-211 tube which is con-

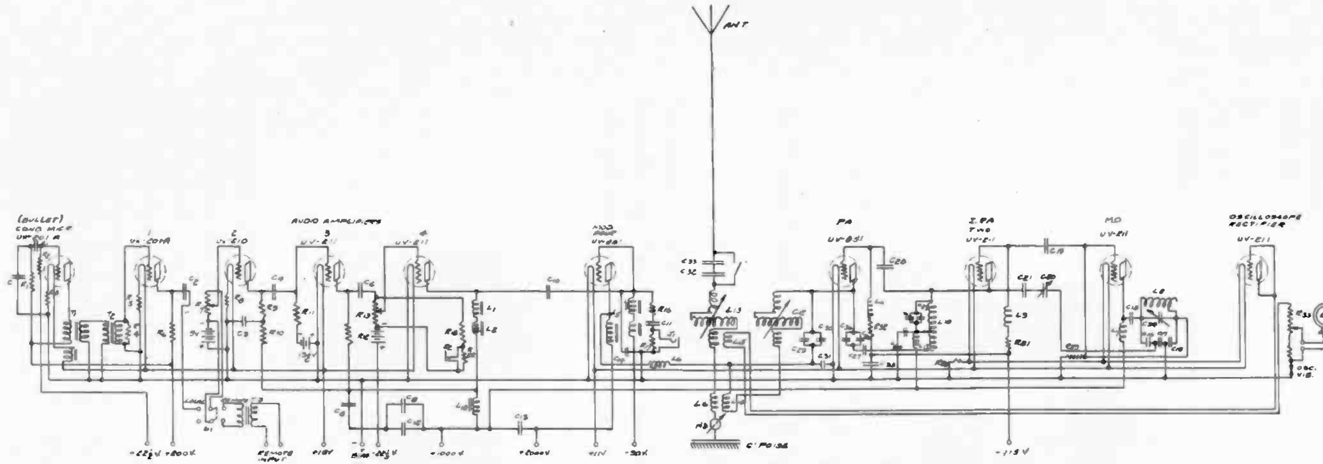

Fig. 29—Schematic Circuit Diagram of 1-kw. Broadcast Transmitter.

A_3 Ant. Ammeter
C Cond. Microphone
C_1 Grid Cond.
C_2 Coupling Cond.
C_3 By-Pass Cond.
C_4 Coupling Cond.
C_6 Coupling Cond.
C_8 Filter Cond.
C_{10} Coupling Cond.
C_{11} Blocking Cond.
C_{12} Filter Cond.
C_{13} Filter Cond.
C_{14} By-Pass Cond.
C_{15} M.O. Plate Blocking Cond.
C_{16} M.O. Plate Cond.
C_{17} M.O. Plate Cond.
C_{18} M.O. Grid Cond.
C_{19} I. P. A. Coupling Cond.
C_{20} Neutralizing Cond.
C_{21} Neutralizing Blocking Cond.
C_{22} I.P.A. Var. Tank Cond.
C_{23} I.P.A. Tank Cond.
C_{24} I.P.A. Plate By-Pass Cond.
C_{25} P.A. Coupling Cond.
C_{26} P.A. Neut. Cond.
C_{27} P.A. Neut. Blocking Cond.
C_{29} P.A. Tank Cond.
C_{30} P.A. Tank Cond.
C_{31} P.A. Plate By-Pass Cond.
C_{32} Ant. Series Cond.
C_{33} Ant. Series Cond.
C_{34} M.O. Var. Tank Cond.
C_{35} Bias Filter Cond.
C_{36} P.A. Neut. Cond.
L_1 Plate Reactor
L_2 Plate Reactor
L_3 Mod. Grid Reactor
L_4 Mod. Grid Reactor
L_5 Modulation Reactor
L_6 P.A. Plate Choke
L_7 M.O. Plate Choke
L_8 M.O. Tank Induct.
L_9 I.P.A. Grid Choke
L_{10} I.P.A. Tank Induct.
L_{11} P.A. Grid Choke
L_{12} P.A. Tank Var.
L_{13} Ant. Variometer
L_{14} P.A. Coupling Induct.
L_{15} Oscill. Pick-Up Induct.
L_{16} Ant. Coupling Induct.
L_{17} I.P.A. Plate Choke
R_1 Polarizing Res.
R_2 Grid Res.
R_3 Fil. Res.
R_4 Transformer Loading Res.
R_5 Fil. Res.
R_6 Coupling Res.
R_7 Volume Control Res.
R_8 Fil. Res.
R_9 Plate Res.
R_{10} Plate Series Res.
R_{11} Grid Res.
R_{12} Plate Res.
R_{13} Volume Control Res.
R_{16} Listening Res.
R_{17} Listening Res.
R_{18} Listening Res.
R_{19} Parasitic Res.
R_{20} Parasitic Res.
R_{21} Parasitic Res.
R_{22} Listening Res.
R_{23} Parasitic Res.
R_{24} Parasitic Res.
R_{25} Parasitic Res.
R_{27} Parasitic Res.
R_{28} Filament Res.
R_{29} M.O. Grid Leak Res.
R_{31} I.P.A. Grid Leak Res.
R_{32} P.A. Grid Leak Res.
R_{33} Oscill. Resis.
S_1 Microph. Switch
T_1 Bullet Output Transformer
T_2 Input Transformer
T_3 Input Transformer
J_1 Listening Jack
J_2 Listening Jack
L.S. Loud Speaker.

nected as a rectifier in the transmitter is coupled to the antenna circuit and is utilized to supply the audio frequency to the oscilloscope.

The first transmitter of the ET-3633 type is in service at station CYJ in Mexico City. Similar transmitting equipment

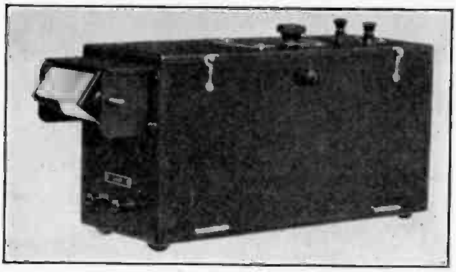

Fig. 30—Oscilloscope Supplied with Equipment for Checking Percentage Modulation.

has been built for Cornell University and St. Lawrence University.

Crystal-Controlled Broadcast Amplifier

A 1-kw. crystal-controlled amplifier which is used in some of the General Electric broadcast stations is shown in Figs. 32 and 33. This unit supplies grid excitation to the water-cooled high-

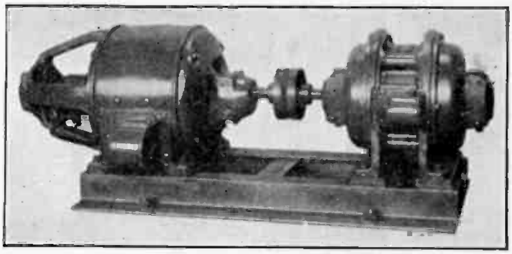

Fig. 31—Filament Motor Generator Set.

power radio-frequency amplifiers. A schematic diagram is shown in Fig. 34 and illustrates the various circuits which are employed in the crystal-controlled unit. The crystal-controlled tube, type UX-210, operates with the crystal connected between its grid and filament circuits. The plate circuit of the tube is tuned by means of a variable condenser which is designed to cover the broadcast-frequency band. The crystals themselves are mounted in a temperature-controlled compartment and a thermostat is supplied in order to maintain the temperature constant at 45 deg. C. Provision is made for mounting four crystals, any one of which may readily be selected by means of a switch on the panel.

A second UX-210 tube is used to amplify the output from the crystal-controlled tube and this in turn is followed by a UV-211, 50-watt tube. Two additional UV-211 tubes connected in

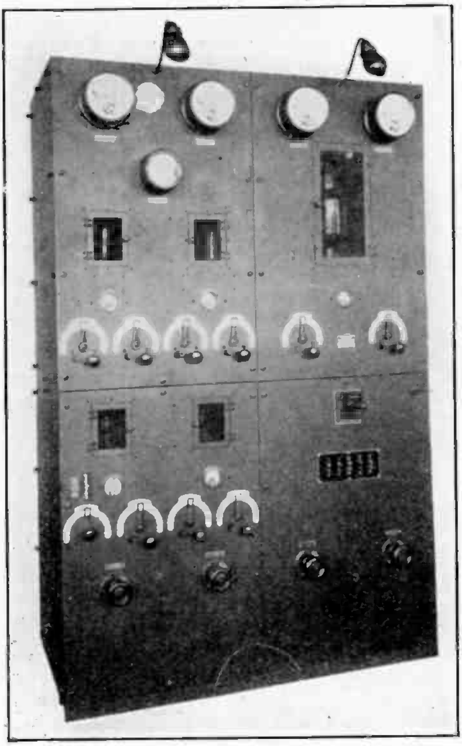

Fig. 32—Front View of 1-kw. Crystal-Controlled Amplifier.

parallel amplify the output from the first UV-211 tube and these are followed by a 1 kw. tube type UV-851. Straight amplification is employed throughout this unit, the crystal being ground for the final output frequency that is desired. Sufficient energy is available from the UV-851 stage to excite 1 or 2 water-cooled radio-amplifier tubes.

1-kw. High-Frequency Transmitter

In order to investigate the transmission characteristics of some of the higher frequencies, a 1 kw. transmitter was developed to cover a continuous frequency range from 3748 to 14990 kilocycles (80 to 20 meters). This transmitter was designed so that crystal control could be employed for any desired frequency within the range, and in addition master-oscillator control was supplied so that gradual and continuous variation of frequency was possible. A number of plug-in coils were utilized so that efficient operation throughout the band could be maintained.

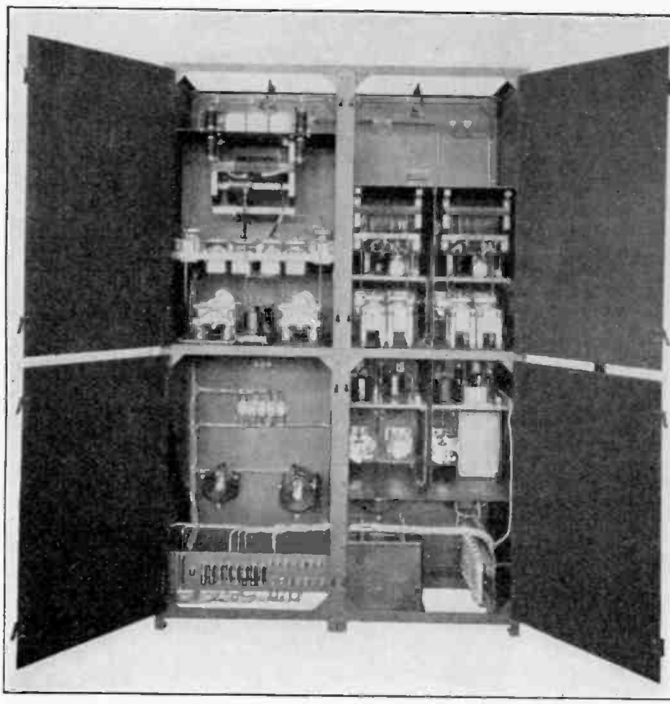

Fig. 33—Rear View of 1-kw. Crystal-Controlled Amplifier.

A front view of the 1 kw. transmitter is shown in Fig. 35. The view in Fig. 36 is taken with the shielding door open, which provides access to all the removable coils and also the vacuum tubes. Each amplifier stage is enclosed in its own shielded compartment in order to secure satisfactory stability.

The various circuits in this high-frequency transmitter are covered in schematic form in Fig. 37. A total of six vacuum tubes are used. The first or crystal-controlled tube is known as type SA-14 and is similar to the standard UX-210 except that it has a higher amplification constant and higher plate impedance.

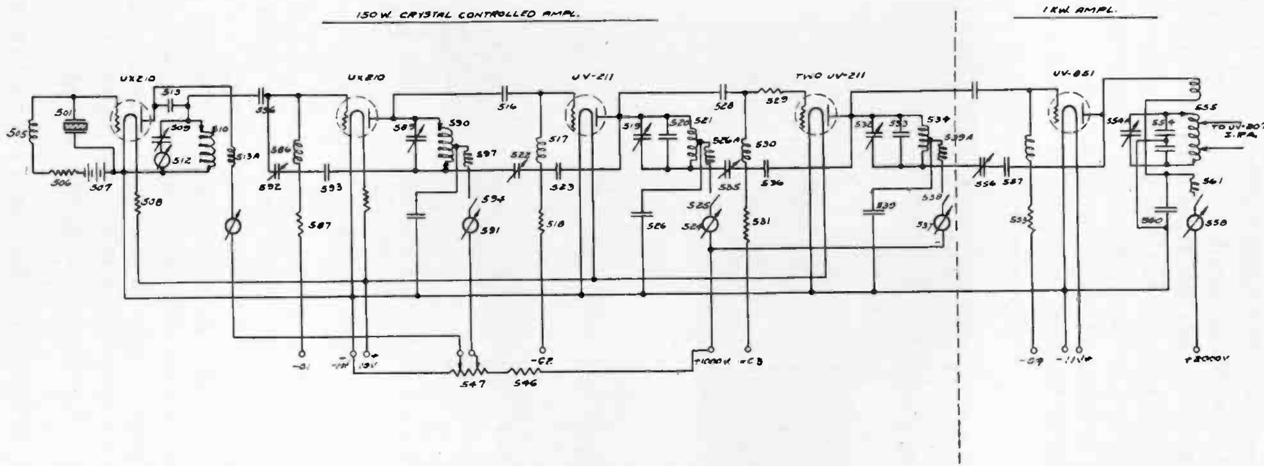

Fig. 34—Schematic Diagram Illustrating Various Circuits Employed in Crystal-Controlled Unit.

The crystal-control tube excites a second SA-14 tube, the plate circuit of this tube being tuned to some multiple of the crystal frequency. In some cases the third harmonic of the crystal frequency is utilized while for the higher frequencies the fifth harmonic is selected. The third tube in the transmitter is a standard UX-210, and is designed either to amplify the output from the preceding stage in the case of crystal control or to act as a self-

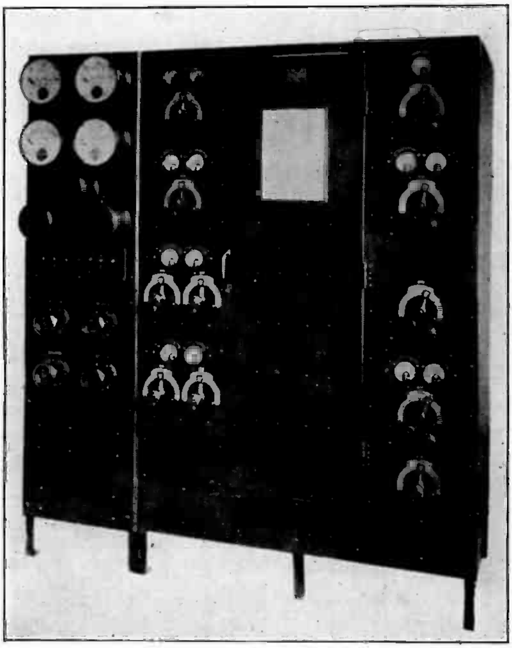

Fig. 35—Front view of 1-kw. Transmitter.

excited master oscillator when crystal control is not desired. A double-pole, double-throw switch provides for quick changeover from crystal to master operation or vice versa.

The remaining three stages consist of a UV-211, a UV-204A, and a UV-851 tube respectively. Each of these stages is designed with a tuned plate circuit inductively coupled to the following grid circuit. Variable condensers are provided so that the various stages may be balanced to prevent self-oscillation.

Factors Influencing the Type of Circuit

In any discussion of the various types of transmitting equipment, such as described in this paper, the question may be asked what factors chiefly influence the selection of one type of output circuit as compared to another, when intermediate stages of amplification are necessary, etc. It has been our experience that for commercial equipment which is required to cover a fairly wide frequency band with a minimum number of controls, an antenna transformer, such as shown in Fig. 6 in the circuit diagram, is preferable. With a properly-designed antenna trans-

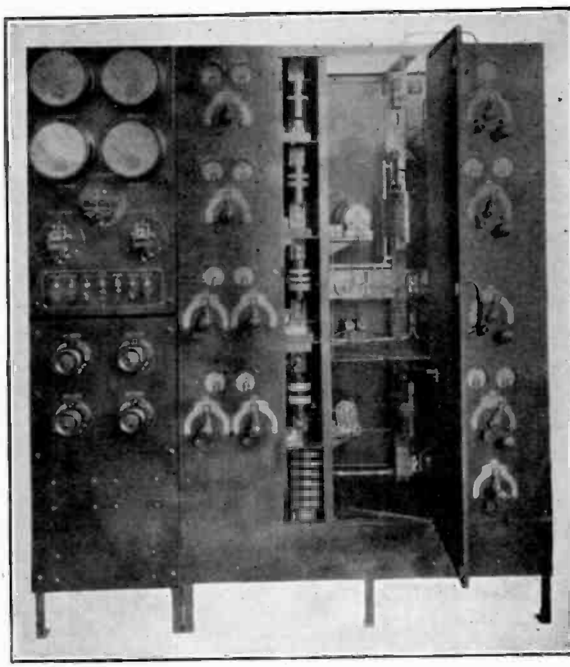

Fig. 36—View of 1-kw. Transmitter with Shielding Door Open.

former, the tubes are better protected against overload in case the circuits are not correctly resonated and frequency ranges having a ratio of approximately 2 to 1 may be covered without any adjustments whatever being made on the antenna transformer.

In the case of very high frequency transmitters where distributed capacitance of the circuit becomes increasingly important, it seems desirable to tune definitely the plate circuit of the final amplifier tube in order to secure best operation. We then have a so-called *tank* output circuit instead of the untuned antenna transformer arrangement.

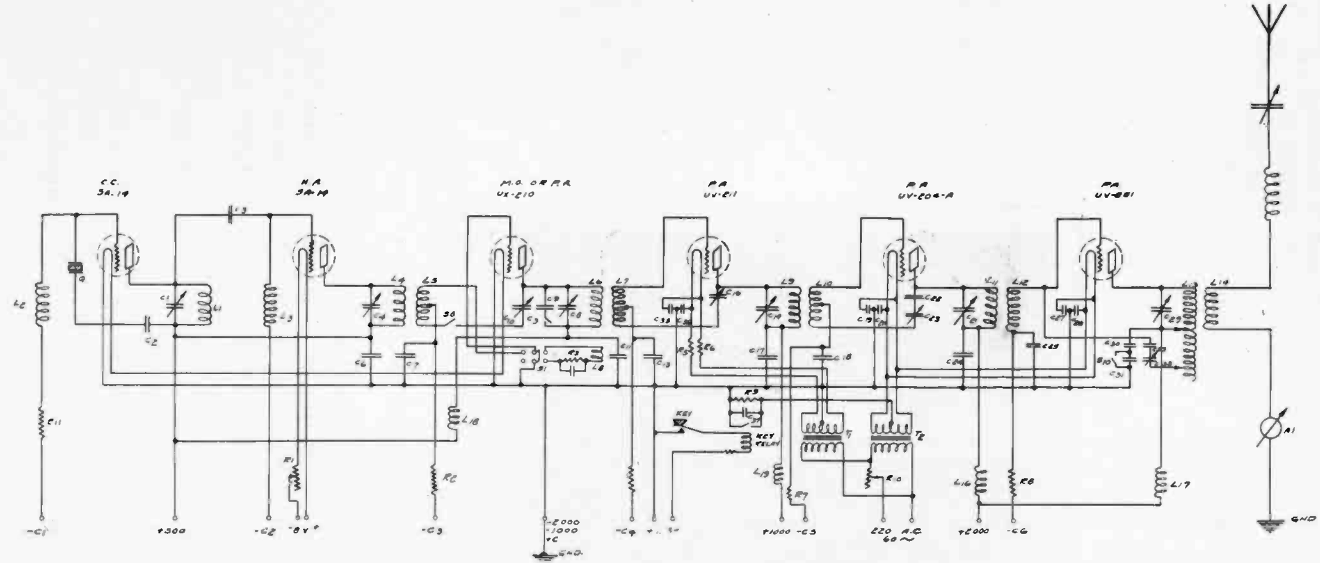

Fig. 37—Various Circuits of 1-kw. High Frequency Transmitter.

A_1 Ant. Ammeter
C_1 Var. Tank Cond.
C_2 By-Pass Cond.
C_3 Coupling Cond.
C_4 Var. Tank Cond.
C_6 By-Pass Cond.
C_7 By-Pass Cond.
C_8 Var. Tank Cond.
C_9 Tank Cond.
C_{10} Neutralizing Cond.
C_{11} By-Pass Cond.
C_{12} M. O. Grid. Cond.
C_{13} By-Pass Cond.
C_{14} Var. Tank Cond.
C_{16} Var. Neutralizing Cond.
C_{17} By-Pass Cond.
C_{18} By-Pass Cond.
C_{19} Fil. By-Pass Cond.
C_{20} Fil. By-Pass Cond.
C_{21} Var. Tank Cond.
C_{22} Blocking Cond.
C_{23} Var. Neutralizing Cond.
C_{24} By-Pass Cond.
C_{25} By-Pass Cond.
C_{27} Fil. By-Pass Cond.
C_{28} Fil. By-Pass Cond.
C_{29} Var. Tank Cond.
C_{30} By-Pass Cond.
C_{31} By-Pass Cond.
C_{32} Var. Neutralizing Cond.
C_{33} Blocking Cond.
C_{34} Ant. Series Cond.
C_{35} Fil. By-Pass Cond.
C_{36} Fil. By-Pass Cond.
C_{37} Key Cond.
L_1 Tank Induct.
L_2 Grid Choke—C.C.
L_3 Grid Choke—H.A.
L_4 Tank Induct.
L_5 Grid Induct.
L_6 Tank Induct.
L_7 Grid Induct.
L_8 M. O. Grid Induct.
L_9 Tank Induct.
L_{10} Grid Induct.
L_{11} Tank Induct.
L_{12} Grid Induct.
L_{13} Tank Induct.
L_{14} Ant. Coupling Induct.
L_{15} Ant. Loading Induct.
L_{16} Plate Choke
L_{17} Plate Choke
L_{18} Plate Choke
L_{19} Plate Choke
Q Mounted Quartz Crystal
R_1 Fil. Resistance
R_2 Grid Leak Res.
R_3 Grid Leak Res.
R_4 Grid Leak Res.
R_5 Fil. Resistance
R_6 Fil. Resistance
R_7 Grid Leak Resis.
R_8 Grid Leak Resis.
R_9 Key Resistance
R_{10} Fil. Control Res.
T_1 Fil. Transformer
T_2 Fil. Transformer

The power rating of a transmitter determines to a large extent whether or not intermediate stages of amplification are required. In order to secure a high degree of frequency stability in a master-oscillator, power-amplifier type of set, it is essential that considerable circulating energy be maintained in the master circuit. In addition, it is desirable to make the capacitance and inductance elements in the master circuit so that they maintain their values over long periods and so that they may be easily shielded. This ordinarily results in a fairly small master-oscillator assembly with a 50-watt tube as the usual type. If a 50-watt tube is too small to provide sufficient excitation for the main power amplifier in a transmitter, it is then desirable to introduce an intermediate stage of amplification or perhaps several stages. In the 2 kw. type of transmitter such as previously described, the intermediate amplifier is so designed that it functions without adjustment over the complete frequency range of the transmitter.

In the case of crystal-controlled transmitters, cascade-amplifier circuits are necessary due to the low level obtained from the crystal-controlled tubes. For high-frequency transmitters where, of course, crystals are chiefly used, developments are now under way with transmitters which will be equipped with special high-frequency tubes. Such tubes similar to the new UV-852 tubes will be designed to have low inter-electrode capacities which make them more suitable for operation at the higher frequencies than the present standard tubes.

The problem of measuring the output of high-frequency transmitters by means of a dummy load has been given considerable thought. If an attempt is made to use the conventional dummy antenna resistors, it is found that their inductance has an appreciable effect on the load circuit, and accurate measurements are difficult. One method which has been successfully used to measure high-frequency power consists of a bank of incandescent tungsten lamps which are used to load the transmitter. These lamps are mounted in a compartment with a photo-electric cell and their brilliancy controls the internal resistance of the cell. Such a device may be calibrated on direct current or low-frequency alternating current and tests have shown that accurate measurements can be made with such a system. In other words, the brilliancy of the lamp when heated by high frequency is the same as when heated by an equivalent power at low frequency or by direct current.

APPARENT NIGHT VARIATIONS WITH CROSSED-COIL RADIO BEACONS*

By

Haraden Pratt

(Radio Engineer, Bureau of Standards, Washington, D. C.)

Summary—*The combined effects of apparent wave direction shifts and fading, of signals from a crossed coil type of radio beacon as received on airplanes in flight at night, are described. A brief explanation of the operation of such a beacon is given. The results of observations of similar signals at night received on an automobile, together with some general conclusions, are mentioned.*

IT early became apparent that the employment of coil antennas on airplanes for determining the directions or bearings of radio stations was beset with difficulties. The coils were necessarily limited in size and considerable amplification was needed to secure a signal of suitable strength. Airplane engine ignition interferences in the radio receiving system prevented the use of very much amplification and so the distance range was limited. The high level of noise present on aircraft prevented a close observation of the minimum signal sector during rotation of the coil, thereby impairing the accuracy of that method as applied to aeronautical navigation; not to mention many other disqualifying practical and operational difficulties.

While the complicated system of taking several bearings on airplane radio signals from ground stations and communicating a position back to the airplane has found successful application in Europe, various means for the taking of radio station bearings from airplanes were attempted without reaching a practical solution of this problem. It was not, however, until the crossed coil radio beacon was proposed that those interested in the art became encouraged to expect the realization of a simple and workable system to guide aircraft.

The crossed coil beacon idea was investigated by the Bureau of Standards several years ago, and further work on it carried forward by the Signal Corps, since which time its development has been rapid, and there are now several operating beacons installed in the eastern part of the United States.

* Original Manuscript Received by the Institute, March 24, 1928. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

Essentially, this beacon comprises two coil antennas disposed in two vertical planes fixed at an angle to each other. In a simple form of the beacon, this two-coil system is free to be rotated about a vertical axis. When the coils are similarly excited with radio-frequency currents modulated at an audio rate, signals of equal intensity from each will be heard on a receiving set when situated along any one of the two vertical planes bisecting the angles between the planes of the coils. At other points the signal intensities from each coil will be different. This marking off in space of vertical equisignal planes constitutes the directive feature of the crossed coil type of beacon, and these equisignal zones are frequently referred to as the courses set down by it. Ordinarily, only one of these courses is used.

In its practical application and for convenience in construction the beacon used in this country employs a radiating system of two large fixed single-turn loops disposed at right angles to each other. It is possible to rotate the radio field about these antennas without rotating the antennas. A suitable goniometer interposed between these loops and the power source permits, by the turning of its rotor, the rotation in space of the equisignal zones. A mechanical device automatically transmits the letter *A* on one coil and the letter *N* on the other. These are so interlocked that a continuous buzz or dash is heard along the equisignal zone. The width of this zone where the perfect continuous dash only is heard depends largely upon the acuteness of the observer's attention, and may vary between limits, for example, of from $1\frac{1}{2}$ to 3 degrees. To the right or left of this zone either the letter *A* or *N* predominates distinctly.

For the guidance of aircraft the crossed coil beacon possesses several obvious advantages:

(1) There is no zone of minimum or maximum signal strength to be observed.

(2) Location of the course or beam is secured by an automatic comparison of two signals.

(3) Regardless of the position of the aircraft within a wide angle when off the course this beacon furnishes a definite signal enabling the craft to locate and return to its proper course. This characteristic permits temporary detours to be made during flight around stormy areas or obstructions, a very important and valuable feature.

(4) The aircraft uses an ordinary receiving set with the usual

trailing wire antenna permitting signals to be received under the most favorable conditions as regards minimum sensitivity of airplane receiving set to local noise and disturbances.

(5) An aircraft may be guided along a set and invariable airway without reckoning wind drift.

These advantages had much to do with the selection of this type of beacon for application to our national airway systems particularly those over which schedule mail airplanes operate.

To secure information of a practical nature, receiving equipment was installed in the summer of 1927 on a mail airplane operating between the airports of Cleveland and New York over an airway approximately 380 miles long. Two directive radio beacons were available, one at the New York terminal and the other at a point 170 miles west near Bellefonte, Pa. The radio frequency used was 290 kc. The audio modulation was at the rate of 500 cycles per second. The radiating loops were of a triangular shape 300 feet long and 80 feet high at the apex. The current in each loop was 8 amperes. This route crosses the Allegheny mountain ranges which occupy nearly all of that region and is a particularly favorable one for this experimental flying both because of the rough topography and the prevalent foggy and cloudy weather.

The accuracy of the directive beacon as a guide had been established as of a high order, through considerable use in the past, but upon examination of the situation it was learned that all previous experience with it had been confined to daylight flying. Its operation at night had been untried and it was not known to what extent the well-known night shift phenomenon previously observed with direction-finding systems might affect it. Night flights over the airway mentioned were therefore undertaken in August, 1927, and the writer immediately observed results inconsistent with those secured by day. During the first flight it seemed impossible to keep the airplane on a course corresponding to the interlocking dash signal. No sooner was this signal received when it would change to the letter *A* or letter *N*. No amount of manipulation of the airplane would improve the situation. The dash signal would come and go at intervals of a few minutes. It soon became apparent that at the distance involved, which was about ninety miles, no accurate fixed course existed, but that the equisignal zone was rapidly moving about in an indefinite way.

This disconcerting effect indicated that some further study of the phenomenon must be made, and several night flights up to distances of 175 miles from the beacon were undertaken.

In every case the shifting of the equisignal zone or course was noticed. The general results secured from five flights made at an average altitude of 2000 feet may be stated as follows:

(1) Within 25 miles of the beacon the shifting was not of a very serious nature.

(2) At 50 miles the shifting became pronounced but due to the zone appearing to be stationary in its proper position for possibly 75 per cent of the time, the beacon could still be depended upon when used with judgment.

(3) At a distance of 100 miles the shifting became very pronounced and persisted for more than 50 percent of the time, giving the beacon a questionable value.

(4) At 125 miles the beacon was of no further use as a guide.

(5) The shifting of the zone was gradual so that at first one would be inclined to think it due to the movement of the airplane.

(6) It appeared that the topography of the country between the beacon and the airplane exerted a considerable influence on the extent of the variation.

(7) Exceptional variations in shift over an arc as great as 100 degrees in azimuth were noted, but in general the change was confined to within possibly 25 degrees.

(8) Beyond 15 miles the fading of the general level of signal received was very severe during flight over mountains. Several variables being involved, no conclusions have been reached as to the relative contribution of each factor.

A few observations of the Bellefonte beacon at night have been made on the ground at Washington, a distance of 134 miles. While present, the shifting phenomenon was less pronounced than that observed in the air. On a night flight from Harrisburg to Washington no shifting of the zone was noticed, using signals from a beacon at College Park, Md. As there are no marked mountain ranges near College Park, these observations would indicate that topographical features have an important bearing on the matter of these variations.

To shed further light on the question, two sets of night-time measurements on the Bellefonte beacon were made in October 1927 by an automobile party, one at a point 22 miles and another

32 miles distant, both locations being in mountainous territory. Records obtained with a graphic field intensity recorder were made of signals transmitted by one Bellefonte loop, using both a vertical antenna and a coil antenna placed in a vertical place extending towards the beacon. Ratios of the extent of the variability over a period of several minutes, to the average field intensity were observed to be:

at 22 miles with coil antenna 0.25
with vertical antenna zero
at 32 miles with coil antenna 0.44
with vertical antenna 0.07

Ratios of the variability to the maximum field intensity were observed to be:

at 22 miles with coil antenna 0.43
with vertical antenna 0.05
at 32 miles with coil antenna 0.56
with vertical antenna 0.1

Rotating the coil antenna around its vertical axis so as to receive minimum signal showed a variation in the direction of the arriving field as large as 30 deg. over a ten-minute interval.

Observing Location	Miles from Bellefonte	Date	Time	Receiving Antenna	Maximum Fluctuation in per cent	Average Fluctuation in per cent	Direction Shift in degrees
Newville, Pa.	53	Oct. 28	10:15 P.M.	Vertical	38	13	—
" "	53	"	10:35 P.M.	Coil	140	116	62
Andersonburg, Pa.	40.5	"	1:59 A.M.	Vertical	3	3	—
" "	40.5	"	2:19 A.M.	Coil	35	32	30
Lewistown, Pa.	22.7	Oct. 29	6:22 P.M.	Vertical	2	0.5	no observation
" "	22.7	"	6:02 P.M.	Coil	3	0.75	
Sunbury, Pa.	48.5	Oct. 30	4:32 A.M.	Vertical	0	0	no observation
" "	48.5	"	6:22 A.M.	Coil	93	68	
Woodward, Pa.	18.7	Oct. 30	11:59 P.M.	Coil	22	16	8
Hartleton, Pa.	27	Oct. 31	2:12 A.M.	Vertical	18.5	9	—
" "	27	"	1:52 A.M.	Coil	65	57	56
Sunbury, Pa.	48.5	"	6:20 A.M.	Vertical	0	0	—
" "	48.5	"	4:15 A.M.	Coil	21	13.8	15
Hartleton, Pa.	27	"	11:54 P.M.	Vertical	0	0	—
" "	27	"	11:39 P.M.	Coil	12.5	7	12
Woodward, Pa.	18.7	Nov. 1	12:52 A.M.	Vertical	0	0	—
" "	18.7	"	1:07 A.M.	Coil	7	3	2
Sunbury, Pa.	48.5	Oct. 31	9:13 P.M.	Vertical	3	9	—
" "	48.5	"	8:55 P.M.	Coil	38	38	12
Lewistown, Pa.	22.7	Nov. 1	6:10 P.M.	Vertical	8	1.4	—
" "	22.7	"	6:10 P.M.	Coil	30.5	18	—

The coil and vertical antennas were used so that a crude idea might be secured as to the relative extent of apparent shifts in the direction of propagation of the wave, and fading or variation of the received signal strength. The observed shifts of the equisignal zone of the crossed coil beacon signals could be due to either or both effects. The results seem to indicate that fading plays a minor part in the phenomenon.

Observations using an automobile were made again, about November 1, 1927. The results are tabulated as follows, signals from one Bellefonte antenna loop being observed:

The values tabulated in the last column are those maximum shifts observed by following the minimum received signal on a coil antenna through rotation of the coil over a period of several minutes. These data were all taken in mountainous sections of Pennsylvania. They agree in general with the results secured by the first automobile party.

It is hoped that this brief outline of these preliminary observations made by the staff of the Bureau of Standards will serve to focus attention on the performance of this type of radio beacon so that its limitations as a guide for flights at night may be studied and practical information secured whereby these performance characteristics and the conditions influencing them may become better understood.

The data on field intensities given in this paper were secured through the courtesy of Mr. T. Parkinson, Research Associate at the Bureau of Standards, who undertook the automobile trips and made the ground observations.

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OSCILLOGRAPHIC OBSERVATIONS ON THE DIRECTION OF PROPAGATION AND FADING OF SHORT WAVES*

By

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Summary—*The short-wave transmission path is generally but not always located in the vertical plane through the transmission and receiving points.*

Direction finding depends upon determining the direction of the wave at the receiving point; it does not give accurate results when the twilight zone is in the way of the wave path.

The angle between the earth and the direction of short-wave propagation varies continuously and the changes in this angle are much larger than the changes in angle of propagation in the horizontal plane.

The observations are consistent with the view that the fading is mainly caused by wave interference.

Introduction

THIS paper is intended to be a description of a method for determining the absolute direction of propagation of short waves. The experimental results presented were obtained on 16-meter transatlantic signals. The experiments also give some valuable information on fading.

The method depends upon the beating effects of two received signals, one from the distant and one from a local source when applied to two spaced receivers, the local signal being common to the two. The local signal does not vary or suffer from fading; therefore the beat notes produced in the two sets will represent the signal from the distant station both in relative phase and amplitude, providing the amplitude does not change at a greater rate than can be represented by the beat frequency and this condition is not ordinarily observed. The fading period of the signal[1] was in general five seconds and the beat frequency was held at 500 cycles per second.

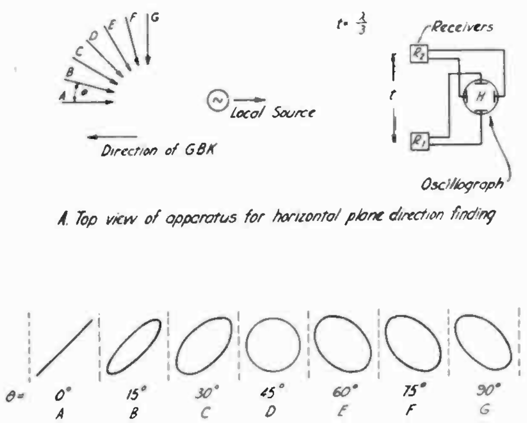
The beat note outputs of two receivers are connected to the deflection electrodes of a fiament type of "Braun" or cathode-ray tube and the resulting figure shows the phase difference and the amplitude of the signal waves at the two receiving points. The figure may be a straight line, an ellipse or a circle and it

* Original Manuscript Received by the Institute, March 21, 1928.

[1] Signals from GBK (British beam station) 16m. were generally used.

will change according to the instantaneous value of the amplitude of the field of the signal wave at the two antenna locations.

For a small separation (a fraction of a wavelength) the figure maintained a constant shape and varied only in size. For several wavelengths separation the figure varied continuously in both size and shape indicating random fading and phase relations. Using different antennas, horizontal on one set and vertical on the other, it was found that the phase and amplitude relations between the vertical and horizontal fields generally



A. Top view of apparatus for horizontal plane direction finding

B. Oscillograph figures corresponding to waves with directions A-B-C····G

Fig. 1

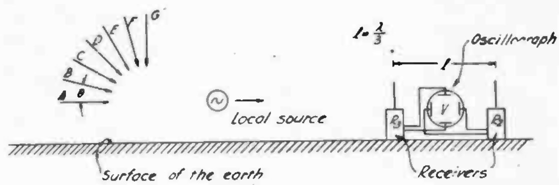
varied at random even when the receivers were close together. In the following description of the experiments the sets were always separated by one-third of a wavelength and only vertical antennas were used. Other distances of separations, for instance one-half wavelength, would have produced similar results.

Direction-Finding in the Horizontal Plane

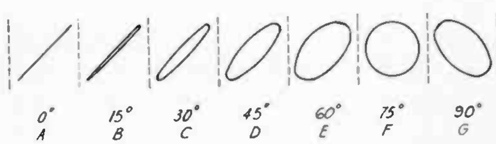
A top view of the experimental apparatus is shown schematically in Fig. 1-A. The two receivers[2] R_1 and R_2 are located so that the line connecting them is at right angles to the great

[2] Double detection receivers as shown in Fig. 9 of a paper by H. T. Friis and E. Bruce, "A Radio Field-Strength Measuring System," Proc. I.R.E., 14, pp. 507–519, Aug. 1926. The rod antennas were only two feet long in order to prevent distortion of field. The low frequency parts of the sets were made exactly alike so that the oscillograph figure did not change when the beat note was varied. Type 224-A oscillograph made by the Western Electric Co. was used.

circle direction of the transmitting station GBK and the local source oscillator is located in the direction of the transmitting station. Fig. 1-B shows calculated oscillograph figures for different directions, A, B, etc. of propagation of a signal wave. For the direction A there will be no phase difference of the fields at R_1 and R_2 and the oscillograph figure will be a straight line. Direction B will cause a phase difference $(2\pi l \sin\theta)/\lambda = (2\pi \sin\theta)/3$, where l is the separation of the sets and the ellipse B, Fig. 1-B, will be the resulting figure. The figures have been experimentally



A. Side view of apparatus for vertical plane direction finding



B. Oscillograph figures corresponding to waves with directions A, B, C, ---- G.

Fig. 2

checked by means of a second local source oscillator located in directions A, B, etc. in place of a distant signal. The transatlantic signal waves from GBK produce the figures A to C as shown in Fig. 1-B. The size of the observed figures change continuously and they often decrease to zero but there are no appreciable variations in their shape. A straight line or thin ellipse changing in length is the characteristic figure for daylight conditions over the entire transmission path of the signal waves, indicating that the wave path is very nearly located in the *vertical plane of the transmitter and receiver points.* With the local source oscillator located in a fixed position in relation to the two receivers, the whole system has been used successfully as a direction-finder by rotating it until a straight line figure is obtained.

The passing of the "shadow wall" or twilight zone through the wave path of the signal causes large changes in the figure. At times its shape will change continuously from a line to an ellipse, such as C in Fig. 1-B; again it will remain an ellipse for a long period, indicating deviation in the direction of propagation in the horizontal plane. A deviation of as much as 30 deg. from the true direction has been observed. The figure will usually change in amplitude but it is only the largest figures that should be considered in this horizontal direction-finding system. It has unfortunately not been possible to reproduce the actual figures, like a moving picture, but later calculated figures will be shown which may give an idea of the changing oscillograph figures.

Direction-Finding in the Vertical Plane

Fig. 2-A shows the apparatus used. Two receivers R_2 and R_3 and the local source oscillator are now located in the direction of the transmitter. Fig. 2-B shows calculated oscillograph figures for waves A, B, etc. arriving at different angles θ with the earth. A wave A coming along the earth will cause beat notes at R_3 and R_2 with no phase difference, i.e., the figure will be a straight line since both signal A and the local signal travel along the same path. Direction B will cause a phase angle $2\pi l(1-\cos\theta)/\lambda$ and the ellipse B, Fig. 2-B, is the resulting figure. These figures were again checked by means of a second local source oscillator in place of the distant signal. However, this local oscillator was moved around in the horizontal plane and not in the vertical plane as this is much simpler and there should be no difference between a wave propagated horizontally at an angle θ with the direction R_2-R_3 and a wave propagated in the vertical plane of R_2-R_3 and with the angle θ with the earth. For down-coming waves the field at R_2 and R_3 will be the resultant of two waves, a direct wave and one reflected from the ground. The ground being the same at R_2 and R_3 and the sets being at the same height over the ground, the ground reflected waves have no effect on the relative phase of the low-frequency beat notes.

Fig. 2-B shows that small angles cannot be determined as there is too little difference between the ellipse and the straight line. This might be overcome by arranging the sets R_2 and R_3 over each other but complicated effects caused by the reflected waves from the ground are then introduced.

Signals from GBK gave figures *A* to *E* shown on Fig. 2-B. During more than a month's observations the figure would be a straight line during the morning hours, indicating small angle propagation. Towards noon the figure changed continuously from a line to an ellipse, being elliptical most of the time. In the afternoon it changed more rapidly from lines to ellipses. Figures corresponding to angles as large as 60 deg. have been

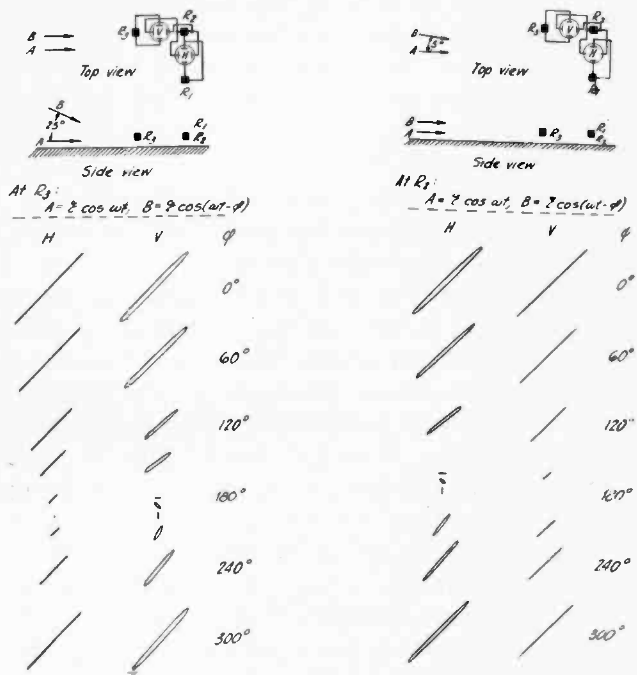


Fig. 3—Wave-Interference Figures. Fig. 4—Wave-Interference Figures.

observed. Later it was found that large angle propagation occurred in the morning also, i.e., the phenomena are very irregular and many further observations are required before definite conditions as to systematic variations can be drawn. So far the results indicate that the changes in angle of propagation in the vertical plane are much larger than the changes in angle of propagation in the horizontal plane. The figures change in size just as in the horizontal direction experiments and here also it is only the largest figures that are to be considered.

The ellipse *B*, Fig. 2-B, tells us that the wave is propagated at an angle θ with the line passing through $R_2 - R_3$, but it does not identify any particular line in the conical surface satisfying this condition. It is therefore necessary to have both a horizontal plane system and a vertical plane system going at the same time so that figures for both can be observed simultaneously, in which case it is easy to determine the movement of the wave. This was done, one receiving set R_2 being common to the two systems and the two oscillographs being mounted close together.

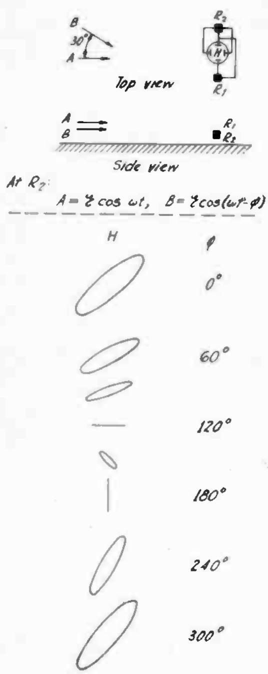


Fig. 5—Wave-Interference Figures.

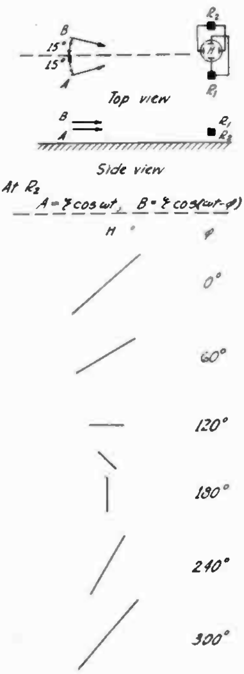


Fig. 6—Wave-Interference Figures.

The results already mentioned are based on the use of this double system.

Fading

The oscillograph pictures mentioned above would continuously increase and decrease in magnitude with an average fading period of five seconds. The small pictures in the fading valleys seemed, at first, to be very irregular, but careful observation disclosed that they practically always consisted of a small line or ellipse rotating quickly one way or the other but practically never exceeding a rotation of more than 180 deg. These characteristic rotating figures, and also the fact that the direction of propagation changes all the time, suggests that fading is caused by wave interference. In Figs. 3, 4, 5, 6, 7 are shown calculated oscillograph figures which would result from a signal composed of two waves A and B of the same amplitude[3] propagated in different directions as shown in the top of the figures. It is assumed that the relative phase ϕ between the waves changes

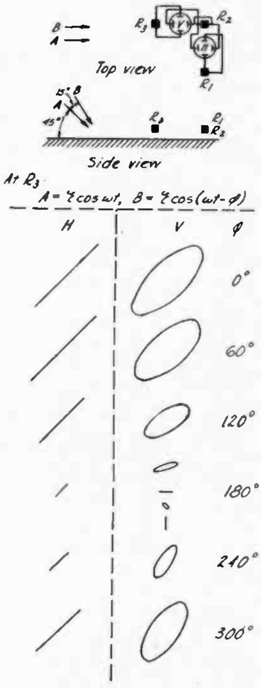


Fig. 7—Wave-Interference Figures.

continuously and the figures correspond to different phase angles. Now these figures have a striking resemblance to the actual figures observed on signals from GBK. The signal figures are sometimes much more complicated but this may be caused by interference between more than two waves. Also the amplitudes of the two waves may not be alike in which case the signal will not decrease to zero during a fading period, as is often found to be the case. The figures shown in Figs. 3 and 4 illustrate the rotating

[3] It is assumed that each of the two waves induce the same e.m.f. in the receiving antenna.

feature of the actual figures. The ellipse figure in Fig. 3 and the line figure in Fig. 4 rotate clockwise with increasing phase angle ϕ. It would have been counter-clockwise in case the angle ϕ had decreased. Note that the speed of rotation is fastest when the figure is small which is in agreement with actual observations. As many as four consecutive fading periods have had the same rotation direction, which means that the relative length of the two wave paths has changed four wavelengths.

In Figs. 3 and 4 the two waves A and B are located in the horizontal plane and the plotted figures correspond to a horizontal plane direction-finding system. In Figs. 5, 6, 7 are plotted the figures that would be observed simultaneously in a horizontal plane direction-finding system, H, and in a vertical plane direction-finding system V. These figures are typical of actual observations.

The total length of each wave path is of the order of 300,000 wavelengths, so it is not remarkable if one path changes a few wavelengths in relation to the other, and thereby causes a continuously changing phase shift of the two waves.

In addition to wave-interference fading there may also be absorption fading, by which is meant quick changes in absorption of a single wave. It is also possible that a single ray may fade due to path changes analogous to what would be produced in light reflection by a rippling reflecting surface. It is believed however that wave interference is by far the most common cause of short-wave fading.

AN AUTOMATIC RECORDER FOR MEASURING THE STRENGTH OF RADIO SIGNALS AND ATMOSPHERIC DISTURBANCES*

By

E. B. Judson

Laboratory for Special Radio Transmission Research, Bureau of Standards, Washington, D.C.)

Summary—*A description is given of apparatus for automatically recording the field strength of low-frequency stations and atmospheric disturbances. The receiver, amplifiers, rectifier, and recorder are switched on by relays controlled by a clock and arranged so that for different 5-minute periods during the hour the strength of several stations may be recorded. The sensitivity of the system remains constant over long periods, provided the filament and plate currents do not change. Calibration can be made at any time from either a radio-frequency or audio-frequency source. Typical curves of the variations in signals and atmospheric disturbances are shown.*

THE recording system described was designed for the purpose of obtaining knowledge of the behavior of radio signals over considerable periods without the presence of an observer. With the apparatus used it is possible to obtain hourly observations of the field strength of several stations and atmospheric disturbances throughout the twenty-four hours.

The entire apparatus is controlled by a clock, which, at different five-minute periods during the hour, actuates a series of relays automatically turning on the receiving set and amplifiers and tuning to the desired stations.

Fig. 1 shows the schematic diagram of the circuit and Fig. 2 shows the arrangement of the apparatus.

The receiving set is of the conventional autodyne type with two tuned circuits having a tuning range from 60 kc. (5000 m.) to 12.0 kc. (25,000 m.). Two antennas are used, one having an effective height of 16 meters for reception of transatlantic stations and atmospheric disturbances, while the other having an effective height of 1.5 meters is used for nearby American stations.

In order to insure greater constancy of sensitivity, only audio-frequency amplification is used. This consists of two

* Original Manuscript Received by the Institute, January 5, 1928. Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce. Read at the meeting of the International Union of Scientific Radiotelegraphy at Washington, Oct. 13, 1927.

stages of transformer coupling followed by four stages of resistance-capacity coupling. With this arrangement, as long as all the filament currents remain constant and the plate voltages do not change the system retains its calibration with sufficient accuracy (within 10 per cent) over periods of several months.

The last audio-frequency amplifier is coupled to a rectifier circuit, containing the recording galvanometer, through an air-core audio-frequency transformer. A three-electrode tube having the plate and grid connected is used for rectification.

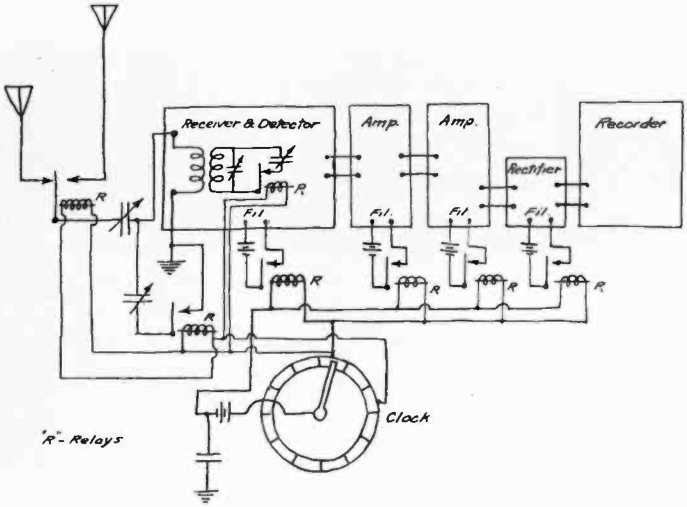


Fig. 1—Automatic Recorder. (Laboratory for Special Radio Transmission Research—Bureau of Standards.)

Generally, tubes used in this manner give a slight galvanometer deflection, when no signal is present, due to the initial velocity of the electrons. This current, however, can be balanced out by a reversed e.m.f. across the galvanometer if it is comparable to the current received from signals.

Records of the variation of signals and atmospheries are made with a Cambridge-Paul Thread Recorder.

This instrument is essentially a sensitive recording galvanometer having a moving coil arranged to give a series of instantaneous records of the galvanometer deflections. The moving coil of the galvanometer has attached to it a pointer which overhangs the drum carrying the paper, while between the pointer and the drum an inked thread is stretched parallel to the axis of the drum at a short distance above its surface. A presser bar is situated above the galvanometer pointer which is normally held free of the pointer by a cam and its follower. At regular intervals the cam makes a half revolution, first allowing the presser bar to fall upon the pointer and immediately raising it to its normal position. As the presser bar falls it depresses the pointer on the drum nipping the inked thread between the pointer and the paper producing a dot on the paper, which makes a visible record of the deflection of the galvanometer at the moment. The drum of the recorder is arranged for two

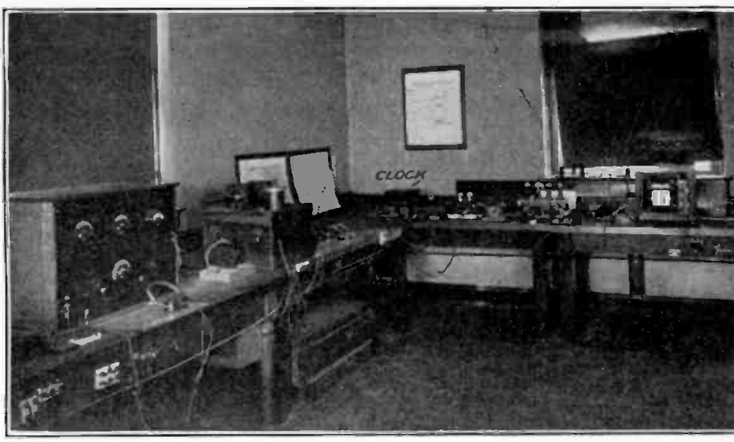


Fig. 2.

speeds, one giving a complete revolution in twenty-four hours and one giving a revolution every two hours for short time records. For the present purpose the twenty-four hour revolution is used.

The clock controlling the entire system has its face plate equipped with twelve brass segments arranged in a circle, each segment representing five minutes. A spring on the end of the minute-hand makes an electrical connection with each segment as it passes over.

The cam allows the presser bar to depress once every 30 seconds, making ten dots on the paper for one five-minute segment.

For the present purpose, the first five-minute segment in the hour is connected so that when the minute-hand contact passes over it, a relay closes, turning on the receiving set, tuned to the station having the highest frequency of those to be measured. The amplifiers, the rectifier tube, and the presser bar control are switched on simultaneously by means of other relays.

The following segments operate the same relays as the first, but are arranged to close other relays which connect parallel variable capacities across the primary and secondary tuning ca-

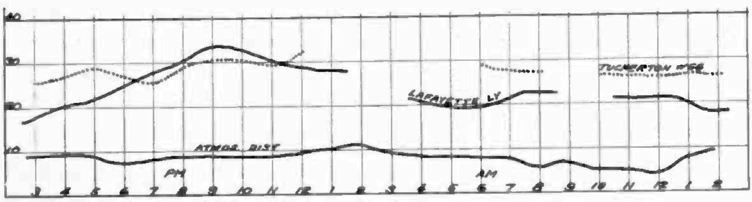


Fig. 3—LY, WGG and Atmospheric Disturbances, March 11–12, 1927.

pacities of the receiving set. This allows the receiver to be tuned to other frequencies effective only for a certain clock segment.

The entire system is slightly sensitive to change of tone. The pitch of the signals being recorded is therefore set to 1000 cycles by comparison with an electrically-driven 1000-cycle tuning fork. A 30-ohm damping resistance across the galvanometer coil slows its period so that it is little affected by change of speed in transmission. Absolute calibration of the receiving

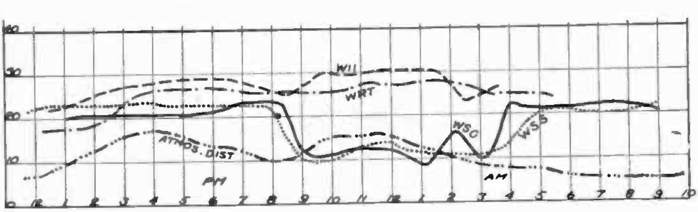


Fig. 4—WSS, WRT, WII, WSO and Atmospheric Disturbances, July 12–13, 1927.

set is obtained from a radio-frequency oscillator feeding into the antenna circuit, while the amplifiers and rectifier may be checked at any time by connecting them to the output of the telephone comparator.[1]

The deflection-current curve of the galvanometer is nearly straight over the usual range of observations. As a protection

[1] Proc. I.R.E., 12, p. 521, 1924.

against heavy atmospherics the deflection is limited just below full scale by limiting the output of the last amplifier tube.

Continuous records of several stations and atmospheric disturbances have been made at the Laboratory for Special Radio Transmission Research of the Bureau of Standards since February, 1927. During the winter months when atmospheric disturbances were low, records were made of Lafayette (LY) and Rugby (GBR) along with Tuckerton (WGG) or Rocky Point (WSS). During the heavy static season, measurements were confined to four American stations, namely, two New Brunswick stations, (WII and WRT), Rocky Point (WSS) and Marion (WSO), reception being on the small antenna. The large antenna, however, is used for reception of atmospheric disturbances.

Fig. 3 shows a typical 24-hour record of Lafayette (LY), Tuckerton (WGG) and atmospherics at 12 kc. (25,000 m.).

In Fig. 4 are given typical 24-hour summer curves, of WSS, WRT, WII, WSO and atmospherics, which show in the case of WSS and WSO an apparent interference of the reflected and direct waves during the night.

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

Lester L. Jones†: Dr. Vreeland's paper has been very interesting to us because it indicates the answer to selectivity problems in broadcast reception. The question of what can be done with the circuits of our old teacher, John Stone Stone, tends to be confused nowadays.

I am one of those who believe that a great deal may be accomplished by proper use of the selectivity inherent in the old

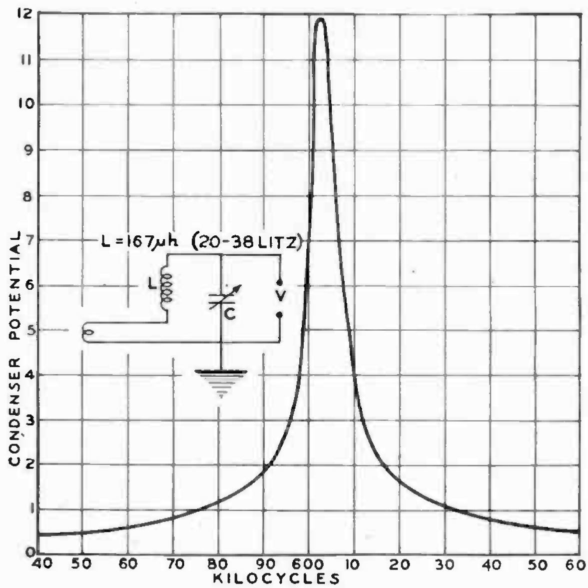


Fig. 1—Selection by a Tuned Circuit.

art circuits. Dr. Vreeland brings up very interesting viewpoints as to the selectivity of tuned circuits. There is one point, however, which appears to me to be somewhat misleading.

In the fifth and seventh paragraphs of the section "Limitations of Selectivity by Resonance," Dr. Vreeland states, "Because of the geometric property of such circuits the ordinates of each graph for a two-circuit system are equal to the squares of the corresponding ordinates for a one-circuit system" and

* Presented at the Annual Institute Convention, January 9, 1928. Published in the PROCEEDINGS, 16, 255, March 1928.

† Consulting Engineer, New York City.

referring to Figs. 1 and 3, that "These graphs are perfectly general and independent of any particular values of inductance, capacitance, or frequency, and they do not involve any assumptions as to whether the circuits are coupled by amplifying tubes or otherwise, or as to the degree of amplification." This statement raises a point which is at variance both with my own experience with coupled circuits and with the impression to be

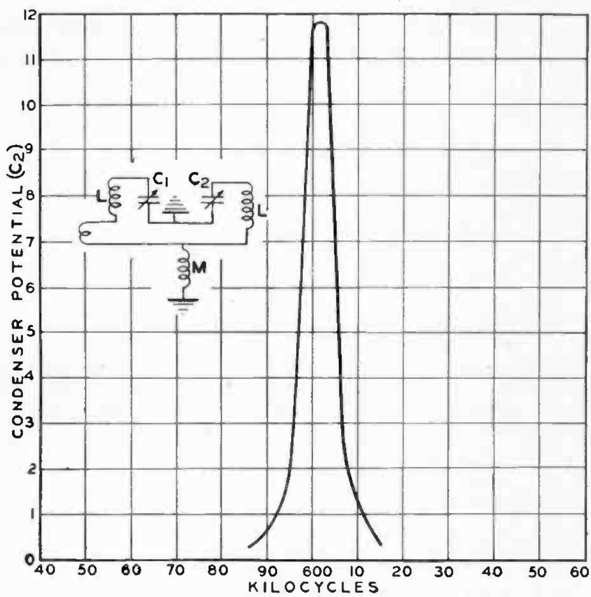


Fig. 2—Case of Optimum Inductance Coupling.

gotten from recent considerations on the question of selectivity. I think the truth is somewhere between Dr. Vreeland's statement and these recent considerations.

In fact, to check up on the theory I had learned years ago with Dr. Goldsmith, I had curves made today using coupled circuits with tube voltmeters for measuring amplitudes and confirmed my belief that coupled circuits of the old art are not nearly so bad as some would have us believe.

If you take two sharply tuned circuits having resonance curves, such as in Fig. 1, and couple them together moderately the curve of response for the second tuned circuit is as shown in Fig. 2. This is taken with the first circuit driven by an oscillator adjusted to the different frequencies shown as the abscissas. You will note that the curve of Fig. 2 is broader than that of Fig. 1 at the top and narrower at the base. It is only when the coupled circuits are coupled so loosely as practically to lose the desired signal that the response curve at the peak is of the form stated by Dr. Vreeland. But why should one couple tuned circuits so loosely as to lose the desired signal? At the base part the response curve for two moderately coupled circuits is hardly different from the geometrically selective response curve for two very loosely coupled circuits. Here, I believe, Dr. Vreeland's statement is correct.

I do not know what constants Dr. Vreeland has for his bridging reactance X_3. It appears to me, though, that his band

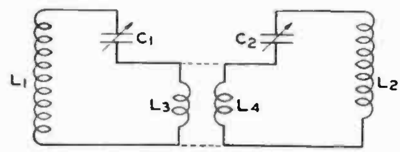


Fig. 3.

selector could easily be redrawn as a pair of coupled circuits as shown in Fig. 3, in which L_1 and L_2 are loading coils, C_1 and C_2 tuning condensers and L_3 and L_4 coupling inductances. By substituting a conductive coupling for the inductive coupling (see dotted line) these coupled circuits have the appearance of Dr. Vreeland's band selector.

In fact, by slighly over-coupling the tuned circuits a response curve having incipient humps and quite square topped could be obtained.

I am sure that if the attention of radio engineers is directed to these desirable characteristics in the old art some very good receiving circuits can be designed.

USE OF AN OSCILLOGRAPH FOR RECORDING VACUUM-TUBE CHARACTERISTICS*

By

W. A. Schneider

(Department of Physics, Washington Square College, New York University)

Summary—*This paper describes the method involved and results obtained in using an oscillograph for plotting photographically vacuum-tube characteristics. The main requirement is an alternating voltage of fairly pure wave-form with as few harmonics as possible. The "dynatron" action of vacuum tubes is shown very clearly when large alternating e.m.f.'s are applied to the grid. Static and dynamic characteristics can also be quite easily recorded.*

THE most common method used in the study of vacuum-tube characteristics is to employ voltmeters and ammeters, and, by connecting them into a suitable circuit, take readings of both instruments, as one of the factors (e.g., E_p) is deliberately varied. After this the readings are recorded in a table, and then transferred to a graph. In this way a picture is obtained of what actually takes place in the tube if we did not have to stop to take readings. The method is, however, long and tedious, especially so if all the various types of characteristics for the many changes which may occur in the study of the operation of a vacuum tube have to be plotted.

The writer was interested in the study of the behavior of vacuum tubes when large positive potentials were applied to the grid of the tube, i.e., when the tube acts as a negative resistance. The characteristics in this case have been studied and interpreted by Hull.[1] The use of the negative resistance action of the vacuum tube has also enabled Barkhausen and Kurz[2] to obtain oscillations experimentally by means of a vacuum tube of enormously high frequency (λ about 10 cm.). Many papers have been published by Gill and Morrell[3] to explain the production of these very short waves.

The oscillograph was used very effectively in plotting these curves. Since the advent of a one-element oscillograph of low price on the market, this instrument has become more and more a piece of general laboratory equipment. Among its many uses

* Original Manuscript Received by the Institute, February 24, 1928.

[1] A. W. Hull, *Phys. Rev.* **7**, p. 1, 1916, and Proc. I.R.E., 5, p. 5, 1918.

[2] Barkhausen and Kurz, *Physikalische Zeitschrift*, Jan. 1920.

[3] Gill and Morrell, *Phil. Mag.* S 6, **49**, No. 290, Feb. 1925.

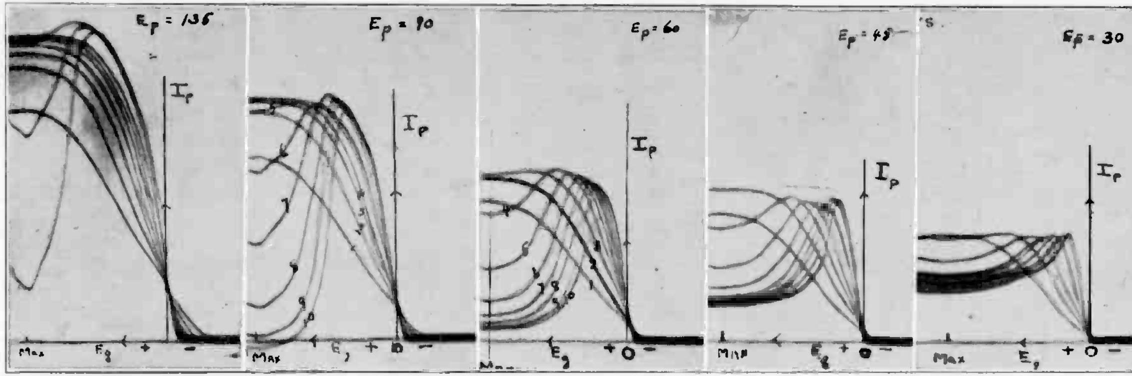


Fig. 1

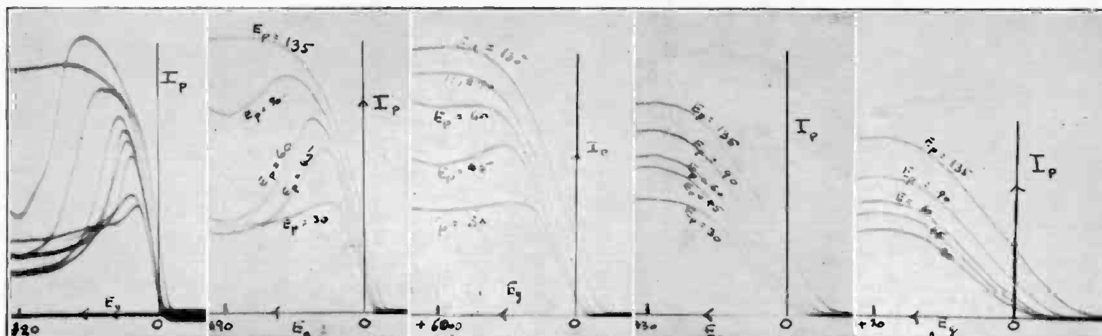


Fig. 2

such as tracing transient phenomena, wave shapes, current-voltage phenomena, etc., we can now add that of tracing vacuum-tube characteristics of almost any description. The only main requirements are a source of alternating current—frequency not important—of as pure a wave-form as possible. The lower the frequency, the more the characteristic will be spread out on the time axis. The writer after trying many different sources found that the wave-form as supplied in New York City is nearly enough sinusoidal so as not to affect the picture noticeably as recorded on the photographic drum. The harmonics may show up when large magnification is applied. If the power supply is not of good wave-form, a contact maker on a rotating slide wire, properly connected, will furnish the necessary variable e.m.f., this arrangement having the advantage that the frequency can be changed at will.

The only other requirement is that the oscillograph element shall have the necessary sensitivity. For most vacuum-tube work a sensitivity of 10^{-4} amperes per mm. deflection on the rotating drum is sufficient, although it is not difficult to obtain elements of much larger sensitivity.

Although the curves shown in the diagram were taken with a 3-element Siemens and Halske Instrument, a cheaper one-element oscillograph will suffice for this purpose just as well.

The curves shown in Fig. 1 were taken to show the "dynatron" action of an ordinary UX-201A vacuum tube. The plate voltage E_p was kept at a fixed value and to the grid was applied the alternating e.m.f. of various values (10 different values were used from 28.2 volts for curve I to 155 volts for curve 10) as shown in Table I.

TABLE I

Curve	Max. E_g (volts)	Curve	Max. E_g (volts)
1	28.2	6	98.7
2	42.3	7	112.8
3	56.4	8	126.9
4	70.5	9	141.0
5	84.6	10	155.0

The negative characteristic is very evident. The different pictures in Fig. 1 are for various fixed values of plate voltage. The graphs in each case must be read from the right to the left on account of the direction of rotation of the film and it will be further noticed that only one half is necessary to give the actual characteristic.

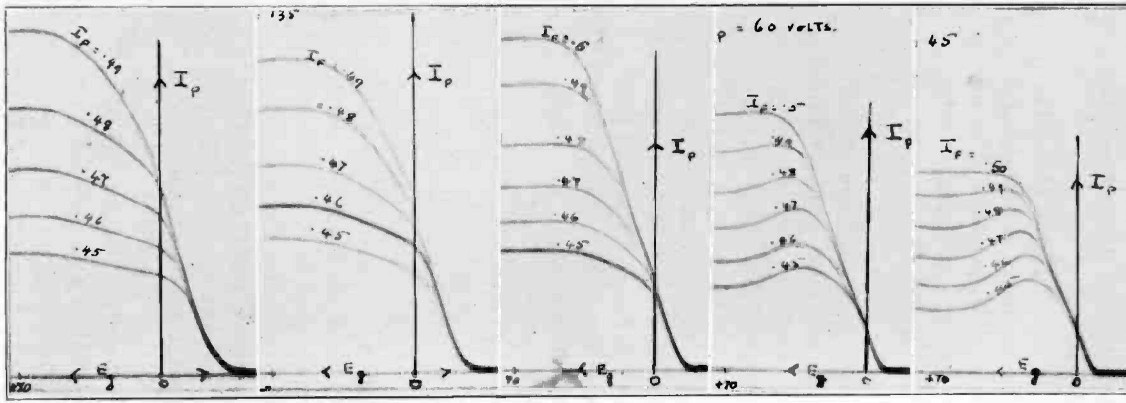


Fig. 3

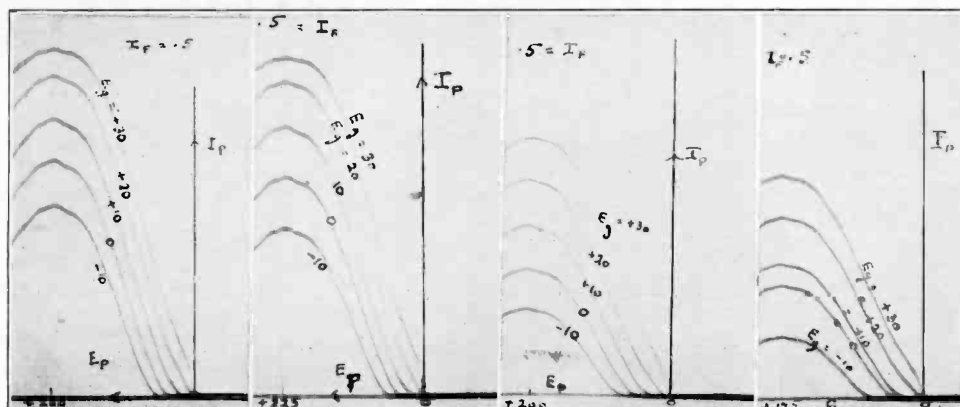


Fig. 4

Although the shape of the curves in Fig. 1 is interesting they can not be interpreted very easily because the units on the grid-voltage (E_g) axis are different for each curve, the maximum value on the figure representing all the values given in Table I.

In Fig. 2 this difficulty is overcome by photographing the various I_p–E_g characteristics under conditions of different plate voltages, the grid-voltage axis now being the same scale for all the curves in the same diagram, the different diagrams being plotted with grid values of 120, 90, 60, 30, and 20 volts respectively.

Very many interesting results can be seen from these curves. One of these is that the current through the tube under certain conditions will be larger from plate to filament than from the usual filament to plate. It is not the purpose of this paper, however, to go into the results found.

The next set of curves represented in Fig. 3 show the effect of changing the filament current in a plate-current, grid-voltage characteristic. The set of curves obtained in each picture of Fig. 3 are for a constant plate voltage. The different sets are for plate voltages of 165, 135, 90, 60, and 45 volts respectively, the variation in grid voltage in each case being between limits of ± 70 volts. The filament current was varied from 0.45 amperes to 0.5 amperes (for a UX-171).

In Fig. 4 will be seen the effect of grid voltage on displacement of the characteristic with respect to the plate-current axis. They are all E_p–I_p curves, each set being for a fixed filament current, but 5 different values of grid bias, viz. $+10$, 0, -10, -20, and -30 volts. Here again most interesting results are noticed. In all curves for a grid bias of -30 volts the characteristic takes a sudden dip at a small positive plate potential in such a fashion as just to give zero plate current when the variable plate voltage is zero. All these effects fall in line exactly with other methods and theory.

The above curves are typical of the results to be obtained by using the oscillograph for this purpose. Many other similar uses in connection with characteristics naturally suggest themselves, such as transformer characteristics, etc. In Fig. 5, for example, are curves showing the relation between static and dynamic characteristics. They are plate-current, grid-voltage characteristics (for constant I_F and E_p). The highest curve is the static characteristic. The other five lower curves are for resistances

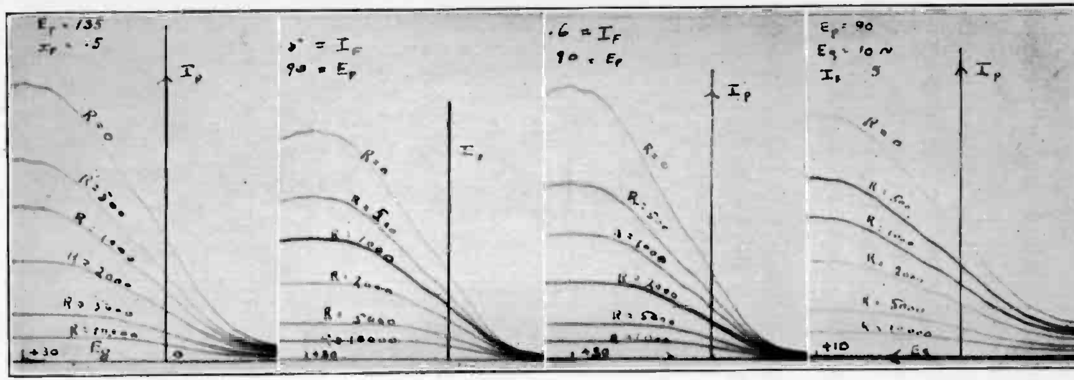


Fig. 5

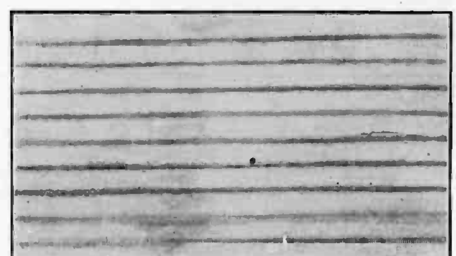


Fig. 6

in the plate circuit of 500, 1000, 2000, 5000, and 10,000 ohms respectively. The slopes of these curves play important roles in the operation of the tube in any type of vacuum-tube circuit.

Lastly in Fig. 6 is shown a calibration which is simply carried out by passing certain known currents through the element (in this case about 2 milliamperes) showing the uniform sensitivity for all parts of the film and at the same time giving a permanent record of the sensitivity of the element.

When it is remembered that each of the above curves are drawn in 1/120th of a second the advantages of such a method are obvious.

In conclusion the writer wishes to thank Mr. Frank Wenger for valuable aid rendered in carrying out the above tests.

BOOK REVIEWS

The Theory of Sound, BY LORD RAYLEIGH. Macmillan and Company, London. Revised Edition, 1926, 494 pages. 15 schillings net.

BY HARVEY FLETCHER†

"The Theory of Sound" by Lord Rayleigh has been the standard text on the subject during the last 50 years. It has been used to good advantage by investigators interested in the transmission of electrical vibrations. It is an interesting coincidence that the first edition of this book appeared in 1877, the same year that Alexander Graham Bell demonstrated his invention of the telephone before the British Association for the Advancement of Science. The previous year Lord Kelvin had seen Bell's demonstration at the Centennial Exposition in Philadelphia and had made reference to it in a lecture that fall at Glasgow. It is remarkable that a text which is still invaluable to a telephone engineer was written before the invention of the telephone. To one not familiar with the book, this may seem incredible.

Lord Rayleigh's treatment of the subject of vibrating systems was so thorough that when the art of electrical transmission of speech was developed, the equations which he had already written down proved to be adequate for the phenomena of this novel field provided only that the meanings of the constants were properly altered. Nowadays the tendency is in the opposite sense for most engineers are more familiar with electrical transmission than acoustical transmission. Consequently, when a problem involving the transmission of mechanical or acoustical vibrations presents itself, the analogous electrical circuit is sought so that one may better understand the process of transmission.

A second edition of "The Theory of Sound" appeared in 1894. It was greatly revised and enlarged over the first edition and contained among other additions a new chapter on "Electrical Vibrations." In this chapter it was shown that the equations which were formerly developed for representing mechanical motions could be applied directly to the new problems of electrical transmission. In recent years an owner of the two volumes of this edition spoke of his ownership with considerable pride as it was very difficult to obtain copies. In 1926, however, it was reprinted and now any one may obtain copies of this valuable work.

† Bell Telephone Laboratories, Inc., New York City.

In the introduction a general description of the phenomena of sound is given. The material in most elementary text-books on Physics is patterned very largely after that presented in its pages. It includes an account of experiments on the speed of sound in liquids and solids and a statement of the factors which govern the physical characteristics of musical sounds; namely, pitch, loudness, and quality. The nature of the various musical scales is explained in the way which has since become customary.

The author then proceeds to give the simple theory of harmonic vibrations and applied it to systems having a single degree of freedom. In his treatment of the so-called intermittent vibrations he laid the foundation for the theory of a modulated carrier current wave which is now so familiar to radio engineers. The equations developed in this connection can be applied directly to the modern problems of modulation. In his treatment of the asymmetrical natural vibrations of one degree of freedom, he derives equations which are applicable to the case of an overloaded vacuum tube or to a rectifier.

Next comes the development of the theory of a vibrating system having any number of degrees of freedom. The sets of linear differential equations used for representing the behavior of such a system are the same as those used for representing the behavior of a connected system of electrical networks; consequently, the theory expounded by Rayleigh can be transferred readily to the analysis of the properties of electrical systems such as wave filters, artificial lines, and other complicated networks. The only alterations required are those to be made in the meanings of the various constants. One is astonished to observe how completely the theory developed in this book parallels the more recent generalized theory of electrical networks.

The reciprocal theorem is proved for a very general case. It is shown that it holds for impulses as well as for steady-state frequencies. As an illustration of this theorem, the case of the struck piano wire is cited. If the hammer strikes the wire at a point X_1 the displacement at a point X_2 is the same as the displacement would be at X_1 if the stretched wire were struck at the point X_2. One familiar with electrical circuits can very readily apply the equations to a corresponding electrical case. There is an interesting application of this reciprocal theorem in the case of telephone booths. If two people, one inside such a booth and one outside of it, talk to one another with voices of equal strength, they hear one another equally well, provided of course there are no other sounds present.

It is well to give a word of warning here. There are frequent misapplications of this reciprocal theorem because the meaning of sources of equal strength is often misunderstood. For example, in fluids sources of equal strength are those "produced by the periodic introduction and abstraction of equal quantities of fluid or something whose effect is the same." This does not necessarily mean that the same amount of sound power is radiated from two sources of equal strength. "For instance, a source close to the surface of a large obstacle emits twice as much energy per second as an equal source situated in the open."

In his treatment of the transverse vibration of strings both when free and when loaded, Rayleigh laid the foundation for the theory of transmission of electrical vibrations on loaded and non-loaded cables. The general equations for determining the arbitrary constants from the initial conditions of the system, which he developed for the acoustic case, are equally valid for the electrical problem.

The next subject is the vibration of bars. For the longitudinal and the torsional oscillations, Rayleigh shows that the same equations hold as for the transverse oscillations of stretched strings, provided that the constants which in the earlier case stand for the tension and linear density of the string are in this case interpreted as the elasticity and the volume-density of the material of the bar. In the author's characteristic language: "A bar under tension which is sufficient to double its length will emit the same note as that due to longitudinal vibration."

The transmission of vibrations from one bar to another of different material and size across a mechanical junction corresponds quite closely to the transmission of electrical vibrations from one circuit to another with different constants. It is strikingly difficult to transmit energy of vibration from air to steel, or vice versa, for the amount which crosses the junction is only 0.00001 of that which arrives at it. In other words, a transmission loss (sometimes called reflection loss) at a junction between air and steel is about 50 TU. It is shown that the free period of torsional vibrations of bars must lie between 1.4 and 1.7 times the longitudinal free period.

The treatment of the lateral vibration of bars leads to much more complicated differential equations, but the subject is treated in a masterful fashion. He shows that *the period of vibration of a solid object of any shape whatever varies as the linear dimension if the material and shape are kept constant.* As one of the practical applications, it is shown that the period of vibration of a tuning fork is independent of the thickness perpendicular to the plane of bending, inversely proportional to the thickness in the plane of bending, and proportional to the square of the length.

The treatment of the vibration of stretched membranes leads to a differential equation which is the same as for a stretched

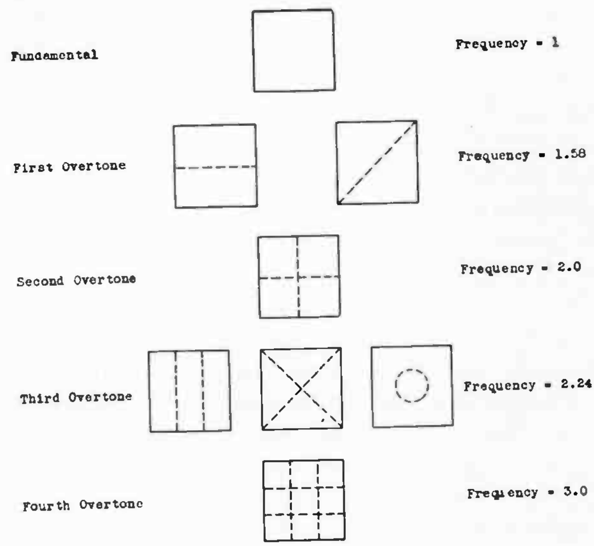


Fig. 1

string except that an additional term is added. When the boundary is rectangular, frequencies are given by the equation

$$f = \sqrt{\frac{T}{\rho}}\sqrt{\frac{m^2}{a^2}+\frac{n^2}{b^2}}$$

where T is the tension, ρ the superficial density, a and b the dimensions of the rectangular boundary, and m and n the integers. When the boundary is rectangular the solution leads to a Fourier series and when the boundary is circular to a series of Bessel functions. It is interesting to note the modes of motion associated with the harmonics of such a stretched membrane. The sketches in Fig. 1 indicate the forms for the first four overtones of the square membrane.

Similarly, in Fig. 2 are shown the frequencies and modes of vibration for a circular boundary. It is seen that most of the periods are inharmonic so that a sound emitted from such a membrane would not in general be musical. However, the author

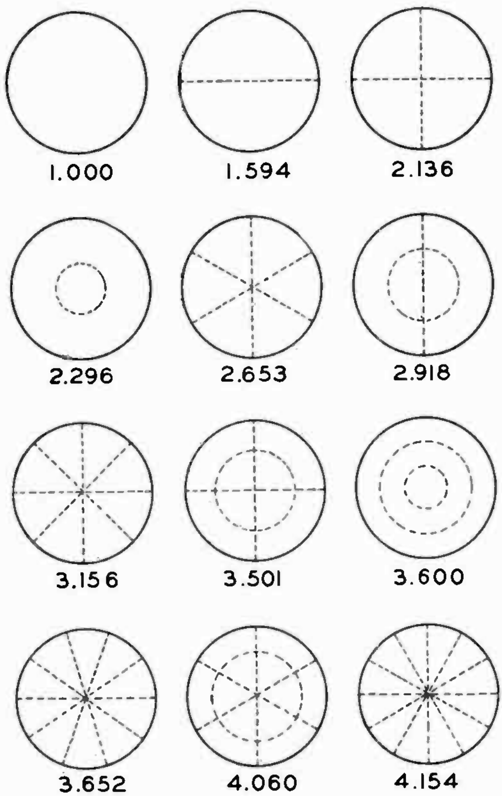


Fig. 2

points out the interesting fact that the first, the second, the fourth, and the sixth overtones form a series of musical intervals which are approximately 4/3, 5/3, and 2, that is, notes on the major musical scale. A circular membrane has a fundamental frequency 4 per cent lower than that of a square membrane of the same material, equal area, and equal tension.

In the treatment of the vibration of plates the mathematical difficulties are still greater and only approximate solutions can be obtained. However, they prove to be sufficiently accurate to check with what experimental values are available. Rayleigh treats the case of a vibrating ring and from the results is able to make some interesting deductions concerning the pitch of bells.

As I said before, the last chapter of the first volume deals with electrical oscillations; the important formulas used in alternating-current theory are deduced, including coupled circuits and a detailed account of the induction bridge. The author shows how a branch containing a self-inductance and a resistance may be treated mathematically as though it were a single resistance. In this connection it may be interesting to remark that Lord Rayleigh frequently refers the reader to Heaviside's work for more complete solutions of the electrical problems dealt with. It will be remembered that this second edition came out in 1894. His frequent reference to Heaviside's work indicates his high regard for it even at this early period. Inasmuch as this book appeared in its second edition six years before the invention of the loading coil, it is interesting to quote the following paragraph:

> For a further discussion of the various cases that may arise the reader must be referred to the writings of Heaviside already cited. The object is to secure, as far as may be, the propagation of waves without alteration of type. And here it is desirable to distinguish between simple attenuation and distortion. If, as in (16) and (18) P is independent of p, the amplitudes of all components are reduced in the same ratio, and thus a complex wave travels without distortion. The cable formula (15) is an example of the opposite state of things, where waves of high frequency are attenuated out of proportion to waves of low frequency. It appears from Heaviside's calculations that the distortion is lessened by even a moderate inductance.
>
> The effectiveness of the line requires that neither the attenuation nor the distortion exceed certain limits, which, however, it is hard to lay down precisely. A considerable amount of distortion is consistent with the intelligibility of speech, much that is imperfectly rendered being supplied by the imagination of the hearer.

The second volume is concerned principally with a particularly detailed study of aerial vibrations. The general equations representing the motion in a disturbed liquid or gaseous medium are first developed. These equations are then applied to several important cases. The first is the simple case of the vibration of air in a tube. The equation for representing such a disturbance is the same as that obtained for the transverse vibration of strings, or the torsional or longitudinal vibration of solid bars. These three types of vibrators produce sounds with overtones harmonically related to the fundamental. For this reason they are usually employed in making musical instruments.

Rayleigh shows that the transference of energy along a wavetrain of plane sound waves can be described by equations with constants formally identical with those used in circuit theory. To take an example; there is a quantity, the product of the density of a fluid by the speed of sound in it, which enters the equations in precisely the same manner as electrical resistance into the circuit equations, and is in fact designated as "radiation resistance." The rate of flow of energy through a unit area parallel to the plane of the wave-fronts is the product of this quantity by the square of the particle-speed. Analogous formulas for other forms of Ohm's law also hold—the velocity of the particles corresponding to the electrical current, the amplitude to the quantity of electricity flowing in the circuit, and the pressure change to the electrical potential difference. The formulas for the velocity of propagation of sound in terms of the gas constants are developed along the usual lines; in addition it is shown that an exact solution of the problem requires that different frequencies be propagated at different rates. However, the differences are very small and are usually negligible.

From his equations the author predicts that an object placed in a fluid traversed by sound waves must experience a pressure —in certain conditions, a torque—the amount of which can be computed from the intensity of the sound. This was the origin of the "Rayleigh disk" (the qualitative theory is given in this book, the quantitative theory being first worked out by Koenig) which is now used in the fundamental work of calibrating instruments to measure sound intensities.

In connection with the development of the theory of vibration of air columns, he deduces from the theoretical equations the end correction of the tube, i.e., the amount by which its length departs from one-quarter or one-half of the wavelength of its fundamental according as it is closed at both ends or only at one. The conditions at the boundary between two media having different constants are considered and equations deduced which give the amount of reflection and refraction of a sound beam striking such a boundary at any angle. As a practical application, it is shown that regular corrugations on a reflecting plane do not impair the reflection of sound unless their height is comparable with the wavelength. Considering the size of the wavelengths of ordinary sounds, one sees that even a wall which seems very rough to eye or hand will reflect sound like a perfect mirror.

Next the author deduces the general equations for spherical waves and makes some important applications, notably to the theory of conical horns and ear trumpets; this problem involves the reciprocal theorem which I have already mentioned. It is shown that a listener will obtain the same loudness when holding a conical horn to his ear as he would obtain if the horn were inverted and its small end held at the speaker's mouth. This conclusion, however, is correct only under certain conditions to which the connection between ear, horn, and mouth must conform. He points out the definite limitations of a horn radiating sounds having wavelengths larger than the opening of the horn. Similarly, Rayleigh shows why it is that no appreciable shadows are cast by solid objects in the path of sounds usually encountered, and also shows why concave mirrors for concentrating sound are of no avail except when they are very large compared to the wavelength. Concerning the acoustics of buildings, this very significant paragraph occurs:

> In connection with the acoustics of public buildings there are many points which still remain obscure. It is important to bear in mind that the loss of sound in a single reflection at a smooth wall is very small, whether the wall be plane or curved. In order to prevent reverberation it may often be necessary to introduce carpets or hangings to absorb the sound. In some cases the presence of an audience is found sufficient to produce the desired effect. In the absence of all deadening material the prolongation of sound may be very considerable, of which perhaps the most striking example is that afforded by the Baptistery at Pisa, where the notes of the common chord sung consecutively may be heard ringing on together for many seconds. According to Henry it is important to prevent the repeated reflection of sound backwards and forwards along the length of a hall intended for public speaking, which may be accomplished by suitably placed oblique surfaces. In this way the number of reflections in a given time is increased, and the undue prolongation of sound is checked.

From the equations for the transmission of sound through air of uneven temperature, it is clear that sound must be refracted upward through air of which the temperature increases with height and consequently that a speaker's voice must be heard more clearly by a listener above than by one below him.

Rayleigh gives a thorough treatment of the behavior of air resonators and deduces formulas which have since been checked by experiment and have proved very useful in the design of resonators and other acoustic apparatus involving air chambers. Before leaving the subject of air vibrations in tubes, he considers the various methods of exciting the natural frequencies, including the theory of the excitation of organ pipes and whistles, reed instruments such as the clarinet and the oboe, the Rijke tube which is excited by a hot flame, etc.

In considering the reflection of sound, some formulas are developed which have important application in the design of radio and telephone apparatus involving vibrating diaphragms. Formulas for the extra mechanical impedance which the surrounding air imparts to a circular diaphragm supposed for mathematical convenience to be cut out of an infinite plane are given in terms of functions which may be readily calculated for any numerical case. Formulas are likewise given for the corresponding quantity in respect to a solid sphere oscillating in air. When the sphere is small compared to the wavelength, the effective mass added by the air is one-half of the mass of the air displaced by the sphere. The resistance due to the air is very small and consequently very little sound energy is radiated by such a vibrating device. For example, for a sphere one centimeter in radius vibrating at 1000 vibrations per second, the resistance is only approximately 1/1000 of the mass of displaced air while the mass reactance is 500 times this value. The mechanical impedance offered by the air to the vibration of a small circular disk in an open space is greater than for a sphere, the mass reactance being about 25 per cent greater than for a sphere having the same radius.

The equations given for calculating the intensity near a solid sphere due to a distant source may be used to good advantage in calculating the intensities near the human head, an important use when considering the theory of binaural location of sounds. The air reaction on other types of vibrating bodies, including the string, is calculated. For example, it is shown that the air reaction on the vibrating string is so small that the energy directly radiated is less than 1/40,000 of that radiated when it is attached to a sounding board. Similarly, wires or small objects of any shape offer little obstruction to the passage of sound waves.

When the viscosity of the air is taken into account the equations indicate that the decline in amplitude of advancing sound waves is very small. It is fastest for the high frequencies. For example, a sound having a wavelength of one centimeter loses two thirds of its initial amplitude in travelling through 88 meters, while a sound of 10 centimeters advances through 8800 meters before suffering an equal reduction. In this treatment important formulas are developed which give the velocity and the attenuation of a sound wave travelling in a tube. These equations have since been shown by direct experimental tests to be valid over wide ranges of frequencies and sizes of tubes. For example, a tube 1.4 inches in diameter has an attenuation of 0.15 TU per foot for a sound of 1000 cycles. In other words, such a sound would be reduced to about 3 per cent of its original intensity in travelling a length of 100 feet of tube. The attenuation for other frequencies is proportional to the square root of the frequency.

The author next develops, in the familiar way, the equations for water waves of two distinct types (gravity waves and capillarity waves). He then discusses at great length the behavior of jets of water under various conditions. One of his interesting conclusions is that a jet having a circular cross-section is the only one which will maintain its form. If a jet issues from an orifice with a non-circular cross-section, its form as it proceeds through the air will vary cyclically about the circular form. Jets of air are also considered and it is shown how to construct a flame which is very sensitive to high-pitched sounds. It is interesting to note that such a sensitive flame is affected most at those points of a standing wave where the ear indicates there are silences. In other words, the ear indicates a maximum loudness of sound at those places where the pressure changes are greatest, whereas the sensitive flame becomes disturbed most at those places where the pressure changes are zero and the velocity of the air particles is at a maximum.

The last chapter is concerned with a description of the facts and theories of audition. Although this portion of the work has lost much of its value owing to the quantity of data subsequently assembled, it shows how competently the author judged the significance of such data as were available when he wrote. He also stresses strongly the need of more accurate experimental data.

As would be expected, he gives a clear presentation of the correct theory of hearing as well as the correct theory of the formation of the vowel sounds. This statement probably would be disputed by some investigators now working in this field, but I think only by those who do not have a clear notion of the dynamics involved. The additional experimental facts have made it necessary to modify somewhat the views which he has expressed. However, the clear-cut fashion in which he expounds both of these theories is quite in contrast to the confused thinking of many who have written on this subject since his time. Papers are still appearing which show that the authors do not grasp the important points so ably discussed by Lord Rayleigh. For example, he expounds the Helmholtz resonance theory of hearing with the understanding that the pitch is determined from the position of the maximum response, realizing full well that a considerable portion of the end organ must be stimulated by every tone. He also gives an explanation of the production of the summation and difference tones which is undoubtedly correct; namely, that they are due to the non-linear response of the hearing mechanism of the middle ear.

After his clear explanation of the relationship between the two rival theories of vowel production, namely, that championed by Willis and sometimes called the inharmonic theory, and that championed by Wheatstone and Helmholtz and sometimes called the harmonic theory, it is hard to see why there has been such a discussion of the relative merits of these two theories since his book was published. He plainly indicates that these two theories are only different ways of looking at the same phenomena and each is convenient and useful according to the purposes of the problems at hand.

It is frequently stated that when a treatise on a scientific subject has become 10 or 15 years old, it is ready for the cellar or the garret, its obsolescence being due to the rapid advances which science is making. This book on "The Theory of Sound" is certainly an exception. It is now more than 50 years old and it will continue to be used for a good many years to come as one of the principal sources of information concerning the theoretical aspects of the production and transmission of sounds and will contribute largely to all fields of work where vibrations are concerned.

Cunningham Tube Data Book. E. T. CUNNINGHAM, INC., New York City. 84 pages, 9 x 12. Price $2.50.

This book presents in compact form much necessary information on current types of radio tubes used in receivers and socket power devices. There are brief pointed chapters on radio tube operation and performance with some special reference to the thoriated filament. But the principal value of the book is the detailed description of each of eighteen types of Cunningham radio tubes and the curves and data showing average characteristics of each of these tubes. With the multiplicity of tube types on the market at present, and as other manufacturers make similar lines, this book is a valuable aid in the selection and operation of a tube for best performance, and in the design of equipment to use with the tube.

S. S. Kirby

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April 4, 1928

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South Carolina	Charleston, The Citadel	Guthrie, Frederick P
Wisconsin	Milwaukee, 251 East Wells Street	Davis, Chester L.

Elected to the Member grade

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	New York City, 40 Rector Street, Room 618	Smith, John S.
	Tuxedo Park,	Loomis, A. L.
Utah	Salt Lake City, 3477 South 23rd Street East	Baldwin, Nathaniel
England	S. Farnsborough, Hants., Elm Grove Road	Warner, H. J.

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California	Los Angeles, 1122 Olive Drive	Tobey, E. S.
	San Francisco, Fort Winfield Scott, 6th Coast Artillery	Smith, Harold W.
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	Washington, 2623 Garfield Street	Greeley, Philip H.
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	Sarasota, c/o Radio Station WJBB	Skelton, Kenneth W.
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	New Bedford, 31 Brigham Street	Hodgdon, Herbert J.
	Ware, 35 W. Main Street	Ballou, E. T.
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	Detroit, 2000 Second Blvd., Room 721	Firestone, Samuel
	Ferndale, 1611 Dover Avenue	Harlan, M. F.
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	Saginaw, 301 Birch Street	Elias, Louis Wm.
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	Northants, Radio Research Station, Dogsthorpe, Peterborough	Green, Alfred L.
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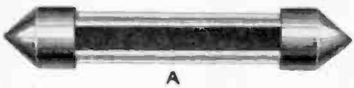
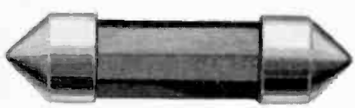


A

Type A for grid leaks and light power purposes. Will dissipate ½ watt safely.

W

Types W and X for greater power dissipation.



X

All types furnished in any resistance value desired.

In use continuously for a number of years by the largest manufacturers.

Types E2 and D2 furnished with wire leads soldered to coppered ends, are for soldering permanently into position in apparatus where they are to be used.

E 2

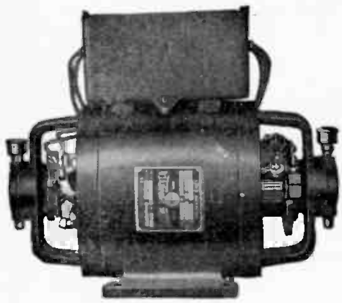
D 2

Samples for test sent on receipt of specifications.

CONTINENTAL CARBON, *Incorporated*

WEST PARK, CLEVELAND, OHIO

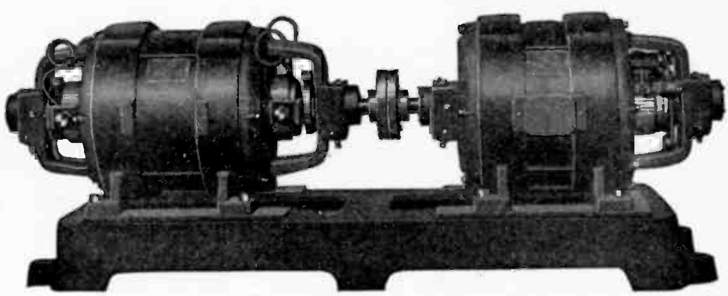
A.C. radio receivers in the D.C. Districts? *Certainly!* with an "ESCO" dynamotor or motor-generator—



Dynamotor with Filter for Radio Receivers

The type R143 rotary converters are suitable for phonographs with vacuum tube amplifiers such as the Orthophonic Victrolas and Brunswick Panatropes without radio receivers. No filters are required.

The dynamotors and motor generators are suitable for radio receivers and for combination instruments containing phonographs and receivers. Filters are usually required. The dynamotors and motor-generators with filters give as good or better results than are obtained from ordinary 60-cycle lighting sockets. They are furnished completely assembled and connected and are very easily installed.



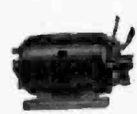
"ESCO" two and three unit sets have become the accepted standards for transmission. The "ESCO" line consists of over 200 combinations. These are covered by Bulletin 237D.

Our engineers are always willing to cooperate in the development of special sets.

"ESCO" is the pioneer in designing, developing and producing Generators, Motor-Generators, Dynamotors and Rotary Converters for all Radio purposes.

How can "ESCO" Serve You?

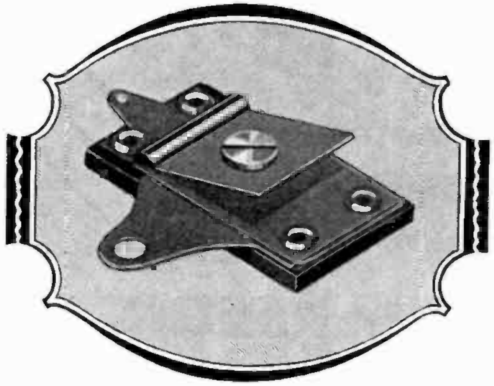
ELECTRIC SPECIALTY COMPANY



TRADE "ESCO" MARK

300 South Street **Stamford, Conn.**


Get the Latest
From Formica!
This is the time when layouts for the new season are being made in the engineering departments.
Before you complete the details of the insulating parts consult Formica. Some new grades and qualities of material have been developed since last year.
They show better insulating qualities and decidedly better working qualities than we believe, have ever been available before.
Ask for samples.
The Formica Insulation Company
4646 Spring Grove Avenue
Cincinnati, Ohio
FORMICA
Made from Anhydrous Bakelite Resins
PANELS FOR SIGNS



The New HAMMARLUND Equalizing Condenser

(Markedly Improved)

A SMALL INSTRUMENT of great importance in manufacturing efficiency and economy—for neutralizing, balancing or compensating inequalities of capacity in radio circuits. Has an exceptionally wide adjusting range; 3 mmfds to 40 mmfds. Compact and rugged. May be attached directly to socket or condenser. Mica dielectric and adjustable phosphor-bronze spring plate firmly riveted to Bakelite base. Cannot slip or short.

Let us quote on your requirements.

HAMMARLUND MANUFACTURING COMPANY
424-438 West 33rd Street, New York

More than a score of radio designers officially specify Hammarlund Precision Products for their newest circuits.

For Better Radio
Hammarlund
PRECISION
PRODUCTS

Trade inquiries invited concerning several new and appealing Hammarlund developments, having a wide sales demand.

Four Advanced Developments

1. SHIELDING. Shielding r. f. coils is accepted as improving the modern receiving set. Three additional leading manufacturers have recently tested overall "gain" in their receivers using aluminum cans on the r. f. coils. Both as a shield and in its effect on the coil characteristics aluminum was found to be eminently satisfactory.

Aluminum r. f. Coil Shield

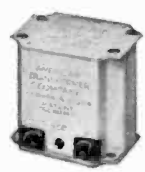
Aluminum possesses advantages of lightness, workability and permanent, pleasing appearance that are offered by no substitute metal. It does not require lacquer or other treatment.

In diameters up to 2.75 inches our extrusion process of making deep cylindrical Aluminum cans is decidedly economical. In drawn Aluminum shells intermediate annealing is eliminated.

2. CONDENSER BLADES. Aluminum condenser blade sheet is now available with tolerance of ±.001, and with *total* variation within one sheet limited to .0005 inch. This company produces finished blades of gauge tolerance and flatness hitherto unattainable.

3. SOLDERING TO FIXED CONDENSERS. The Research Bureau of the Aluminum Company of America has developed a satisfactory method of soldering terminals to aluminum foil fixed condensers.

4. CASINGS. Aluminum casings for audio transformers and similar apparatus possess unique electrical advantages, lightness and excellent appearance. Paint or lacquer is unnecessary.



Aluminum Transformer Casing

Radio Engineers are invited to send for data on all subjects involving the use of Aluminum in radio design.

ALUMINUM COMPANY OF AMERICA

ALUMINUM IN EVERY COMMERCIAL FORM

2470 Oliver Bldg. Pittsburgh, Pa.

ALUMINUM

The mark of Quality in Radio

RADIO PARTS

EXCESSIVE overhead due to constant changes and improvements in the radio has spelled the doom of many a promising concern. Why not reduce this item to a normal size by using Scovill as one of your production units? Given a sample, blueprint, or even an idea, Scovill will assume production responsibilities for large quantities of radio parts such as condensers, screw machine parts, switches, etc. Then you can increase or decrease production at will. Scovill-made products can be depended on for consistent quality and exactness of detail. Every step in the manufacturing process is supervised by trained men.

Scovill means SERVICE to all who require parts or finished products of metal. Great factories equipped with the last word in laboratories, and modern machinery manned by skilled workmen, are at your disposal. Phone the nearest Scovill office.

SCOVILL

MANUFACTURING COMPANY Waterbury, Connecticut

NEW YORK - CHICAGO - BOSTON - SAN FRANCISCO
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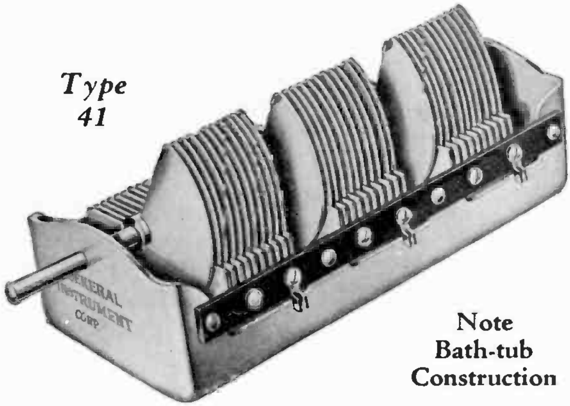
PROVIDENCE - CLEVELAND - CINCINNATI

Member, Copper and Brass Research Association

Universally Used by Amateur Builders
Adopted by Leading Set Mfgrs.
First Choice of Professional Builders
Endorsed by Foremost Radio Engineers
FIRST CHOICE
of the Keenest Minds in Radio!
POWEROHM
DURHAM
metallized
FIRST CHOICE—because Durham was the first and original "metallized filament" resistor—because years of heavy production and the confidence of leading radio manufacturers have given us *time* to produce a perfect product.
Durham Resistors and Powerohms are the leaders in their field because their uniform, unfailing accuracy and absolute reliability have been proved time and time again.
This is why they are the first choice of foremost engineers, leading manufacturers, professional set builders and informed radio fans who demand quality results.
Like Durham Resistors and Powerohms, Durham Resistor Mountings are also the leaders in their field. The only upright mountings made, takes minimum space—made of high resistance moulded insulation—best quality tension-spring bronze contacts. Single and double sizes.
Durham standard resistors are made in ranges from 500 ohms to 10 megohms. Durham Powerohms for "B" Eliminators and Amplifier circuits are made in 2.5 watt and 5 watt sizes in ranges from 500 to 100,000 ohms.
Adopted by Leading Radio Manufacturers
Philco
Fansteel Products Co.
Kellogg-Switchboard
Western Electric
F. A. D. Andrea
Sterling Mfg. Co.
Kokomo Electric
Garod Radio Corp.
Browning-Drake
Howard Radio
A-C Dayton
DURHAM
METALLIZED
RESISTORS & POWEROHMS
INTERNATIONAL RESISTANCE CO., Dept. T, 2½ South 20th Street, Philadelphia, Pa.

These New GI CONDENSERS Will Speed Up *Your Production!*

Type 41

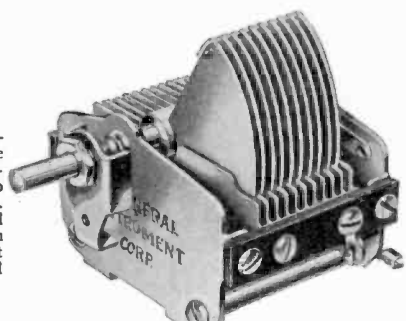


Note
Bath-tub
Construction

OUR six years' knowledge and experience as condenser specialists designed and built these new GI Condensers. The bath-tub construction of the type 41 double and triple condensers greatly simplifies their assembly. This feature will speed up your production. The new GI Condensers are more accurate because: first, they are more rigidly built; second, plate spacings are wider; third, plates are made of a special process material that is more efficient. It will pay you to consider the new GI Condensers for your new receivers. Their prices are surprisingly low.

GI Single Condenser

What a sturdy little condenser the new GI single type is! And it is as dependable as it looks! No finer condenser is built. There are both single and double hole mountings. Can be easily mounted on front or sub-panel. May be had in any capacity.



Write TODAY for Further Details and Prices

GENERAL INSTRUMENT CORP.

"Condenser Headquarters"

225 Varick St. :: New York City

A Smooth Positive Volume Control For Circuits Using "AC" Tubes

THE delicate balance of "AC" circuits require a different method of volume control than that commonly used with battery sets.

Centralab Radiohms RX-100 or RX-025 have been developed especially for smooth volume control with "AC" tubes. They have the same appearance as standard Radiohms, but the taper of resistance is entirely special.

The RX-100 Radiohm in the secondary of an R. F. stage will control oscillation as well as volume. The RX-025 across an R. F. primary provides volume control and does not detune. The same unit has the proper resistance for antenna circuit control, but no antenna circuit resistance will prove as uniformly satisfactory as when used across one of the R. F. stages.

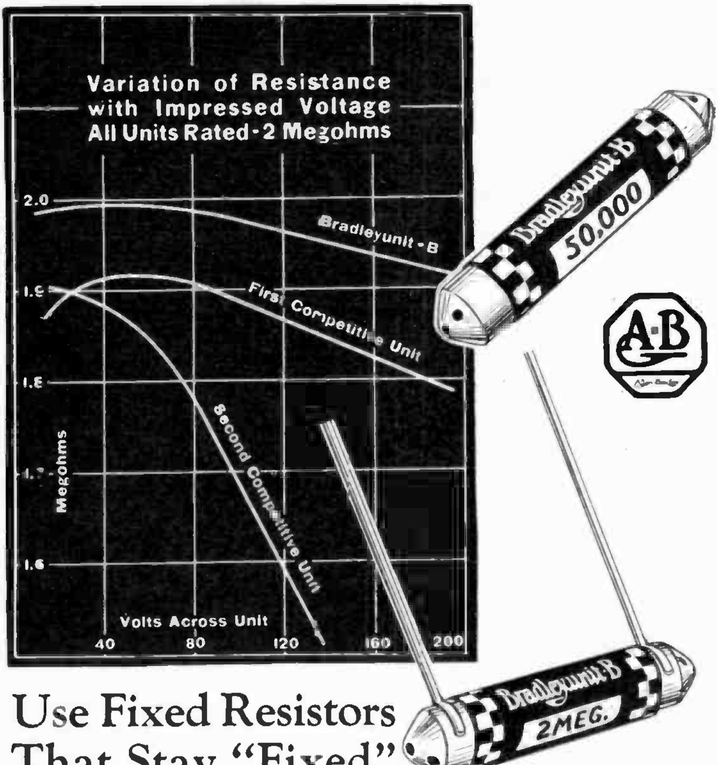
A Centralab PR-050 Power Rheostat in series with the "AC" transformer will provide accurate voltage control and lengthen the life of the tubes. Centralab wire wound Potentiometers and Fixed Resistors will prove trouble free in the power circuits.

Write for full information about these high quality controls.
The new "AC" information sheet is
now ready for you.

CENTRAL RADIO LABORATORIES

Keefe Avenue, Milwaukee, Wisconsin

Centralab



Use Fixed Resistors That Stay "Fixed"

The above curves show the comparative stability of Bradleyunit-B resistance under various voltages as compared with the resistances of two other well-known makes of units.

With a voltage variation from 0 to 200 volts, the Bradleyunit-B resistance varied about 3.5%. The first competitive unit varied 7%, and the second competitive unit varied over 21% with only 140 volts across the unit.

Hence, radio manufacturers using Bradleyunit-B do not need to use special test conditions in checking the resistors used in their equipment.

Bradleyunit-B
for Radio Manufacturers

These remarkable solid-molded resistors are practically unaffected by moisture. They do not depend upon a glass enclosure for protection.

Can be furnished with or without leads for soldering. Made in values from 500 ohms to 10 megohms.

Tapped resistors also offered to meet your specifications. Write today.

Allen-Bradley Co., 282 Greenfield Ave., Milwaukee, Wis.

Allen-Bradley Resistors

Alphabetical Index to Advertisements

News of the completion of the Erie Canal on October 26, 1825, was passed across the state by firing cannon, placed at intervals, each being fired as soon as the nearest one was heard. The news thus traveled from Buffalo to the Battery in New York City in the amazing time of one hour.

Get it Better with a Grebe

Doctor Mu

GREBE RADIO
TRADE MARK

Among true enthusiasts, probably no feat of present-day radio engineering has aroused greater interest than the Grebe Synchrophase A-C Six. Probably none has been awaited with greater expectancy—not from Buffalo to the Battery, but from Coast to Coast.

For those who appreciate real radio enjoyment—the utmost in tonal beauty, range and selectivity—have long since come to a realization that the nineteen-year-old Grebe method of slow, painstaking production has in each step of radio development resulted in perfection.

The Grebe Synchrophase A-C Six is no exception to the rule. With distinctive Grebe innovations it proves that there is as wide a difference between Alternating Current (All-Electric) sets as between those using batteries.

Grebe Synchrophase Seven, $145; Grebe Synchrophase Five, $105; Grebe Natural Speaker, $35; Grebe No. 1750 Speaker, $17.50.

Hear the Grebe Synchrophase A-C Six today, or send for Booklet I, which fully explains this new receiver.

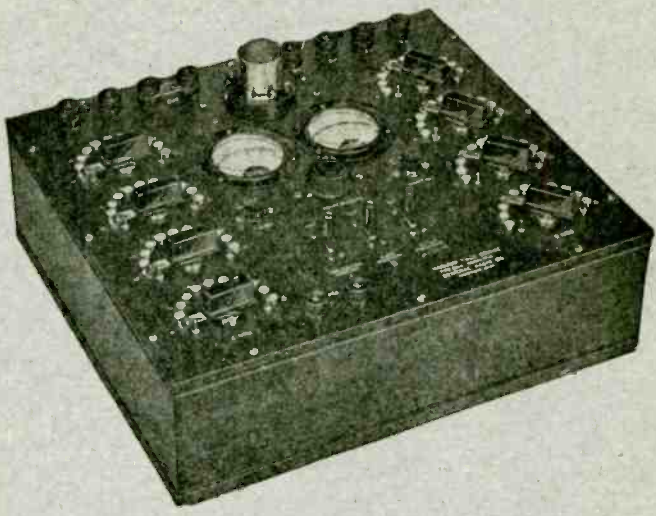
GREBE
SYNCHROPHASE
A-C Six
RADIO

A. H. Grebe & Co., Inc., 109 W. 57th St., New York City

Factory: Richmond Hill, N. Y. *Western Branch*: 443 So. San Pedro St., Los Angeles

Makers of quality radio since 1909

Vacuum Tube Bridge



Type 361-B Vacuum Tube Bridge

The type 361 Vacuum Tube Bridge provides circuits for the quick and accurate determination of vacuum tube characteristics. The bridge reads the dynamic characteristics directly (amplification factor, plate resistance, and mutual inductance) no computation being required.

The new type 361-B bridge is designed to accommodate the new alternating current tubes as well as the direct current types.

Type 361-B Vacuum Tube Bridge. Price, $220.00.

Described in Bulletin 4201.

GENERAL RADIO COMPANY

Manufacturers of Electrical and
Radio Laboratory Apparatus

30 STATE STREET CAMBRIDGE, MASS.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN