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PROCEEDINGS
of
The Institute of Radio Engineers

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Fifth Annual Convention
Toronto - June, 1930

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 17 July, 1929 Number 7

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The Institute of Radio Engineers

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Preparation of Paper

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

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

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

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C. B. Jolliffe
Chairman, 1929 Convention Committee

All of the activities of the Institute are sponsored by and accomplished through the voluntary work of the many Institute Committees. The success of the recent Fourth Annual Convention in Washington is due to the splendid work of the various committees under the chairmanship of Dr. C. B. Jolliffe of the Bureau of Standards.

Associated with Dr. Jolliffe as chairmen of the subcommittees were: Thomas McL. Davis, registration and arrangements; Mrs. L. W. Austin, ladies' committee; S. S. Kirby, trips; F. P. Guthrie, dinner and entertainment; A. E. Kennelly, fellowship; W. G. H. Finch, publicity.

INSTITUTE NEWS AND RADIO NOTES

June Meeting of the Board of Direction

At the June 5th meeting of the Board of Direction, the following Board members were present: A. Hoyt Taylor, President, Melville Eastham, Treasurer, Alfred N. Goldsmith, Junior Past President, John M. Clayton, Secretary, Arthur Batcheller, W. G. Cady, J. H. Dellinger, J. V. L. Hogan, L. M. Hull, and R. H. Marriott.

The following were transferred or elected to higher grades of membership in the Institute: Elected to the grade of Member: A. Zacek, Y. Watanabe, M. H. Schrenk, J. A. Ratcliffe, T. Nakamura, and H. Rothe. Transferred to the grade of Member: Carl H. Butman, L. C. Young, and W. H. Gerns.

One hundred and three Associate members and thirty Junior members were elected.

It was decided by the Board that in view of the growing interest of engineers in telegraph and telephone engineering methods as applied to radio problems, the Institute PROCEEDINGS will contain a moderate proportion of papers on the subject of telegraph, telephone, and cable engineering.

The following resolution dealing with a revision of the Institute's policy with regard to standardization was adopted by the Board:

> "The Board of Direction of the Institute, believing that the urgent need for reasonably rapid progress in radio standardization calls for revision of its policy with respect to the position of the Institute in standardization, (and particularly with respect to the need for conjoint consideration of such questions by representatives of numerous and widely diverse interests), now recognizes the scope of the Institute in standardization with respect to radio communication and the closely allied fields of science and technology as the following:
>
> 1. Nomenclature, symbols, and definitions.
>
> 2. Methods of testing apparatus, equipment, devices, and materials used in radio communication.
>
> 3. Acceptable limits for performance, ratings, capacities, operation, and other characteristics and standards for such apparatus, equipment and devices.
>
> 4. Standardization of sizes and dimensions, and electrical and mechanical characteristics of parts, apparatus equipment, and devices to provide for interchangeability and interworking, or economy in manufacture and use.
>
> 5. Standardization of specifications governing quality of material and methods of test therefor.
>
> 6. Establishment of provisions for safety of operating and other personnel in relation to radio equipment.

"The Board accordingly adopts the policy of promoting such standardization through the activities of the Institute's Standardization Committee and through its sponsorship of the Sectional Committee on Radio of the American Standards Association."

As the official delegates of the Institute at the World Engineering Congress to be held in Tokio in October of 1929, the Board nominated F. B. Jewett and C. W. Latimer. Mr. Latimer is to present the symposium paper prepared in behalf of the Institute by a Committee composed of Alfred N. Goldsmith, E. L. Nelson, Julius Weinberger, D. G. Little, A. B. Clark, and J. H. Dellinger. The title of this contribution is "Technical Achievements in Broadcasting and its Relation to National and International Solidarity," the component parts of which are. Introduction, Radio Broadcast Transmitters and Related Transmission Phenomena, The National Broadcasting Company—A Technical Organization for Broadcasting, Speech Input Equipment, Wire Line Systems for National Broadcasting and Radio Broadcasting Regulation and Legislation.

Year Book and Standardization Report

To enable the 1929 Year Book to be mailed with the May issue of the PROCEEDINGS it was necessary to advance the mailing date of this issue considerably. Any member of the Institute not having received a copy of the Year Book by this time should notify the Institute Office.

The 1929 Year Book contains the complete report of the 1928 Committee on Standardization—representing a work of some one hundred pages. For the past two years the subcommittees of the Committee on Standardization and the main Committee itself, have been very active in the preparation of the 1928 report which represents the best thoughts on the subject of standardization the Institute was able to obtain throughout the entire world.

Reprint copies of the Standardization Report, alone, are available for distribution to members of the Institute free of charge upon application to the Institute office. The price to others is one ($1.00) dollar per copy.

European Radio Conference, Prague, 1929

*Translation of Final Protocol** of the European Radio Conference at Prague, 1929, signed by the delegations from the Telegraph Administrations of Germany, Austria, Belgium, Bulgaria, Denmark, Spain, Esthonia, Finland, France, Great Britain, Greece, Hungary, Irish Free State, Iceland, Italy, Latvia, Kingdom of Monaco, Norway, The Netherlands, Poland, Roumania, Kingdom of Serbs, Croats and

* French text in *Journal Teligraphique,* April, 1929.

Slovenes, Sweden, Switzerland, Czechoslovakia, Turkey, and the Union of Soviet Socialist Republics.

A

The European Radio Conference of Prague, after having heard the delegations and experts present, and in conformity with the reports of its committees, recommends that the Administrations agree to the following:

I

The European Administrations recognize the necessity for them to act in common, to protect their mutual interest in broadcasting matters. They will take the necessary measures to conform as soon as possible to the plan of wave-length allocation which has been established by the Prague Conference. (Annex).

In the future the following manner of procedure will be adhered to:

Some modifications may be made in this plan either by direct arrangements between the interested Administrations (on condition that these arrangements do not interfere with the rights of third parties), or by collective action of the Administrations who have agreed to the provisions of the Prague Conference.

It is desirable that any new arrangements be made in consultation with the International Radiophone Union. These arrangements should be made known to other Administrations through the International Bureau of the Telegraph Union.

The collective action of these administrations will be exercised by the delegates authorized from each Administration, who will group themselves together into a committee to be assembled each time the majority of European Administrations pronounce themselves in favor of a request for such a meeting made by an Administration, through the intermediary of the International Bureau of the Telegraph Union, for the examination of important questions of mutual interest, and especially with a view to remedying serious faults which shall have manifested themselves in the application of the allocation plan now in effect; and to establish new allocation plans.

The International Radiophone Union may be used for expert advice when it is question of such a collective action. However, when it is to be called in as technical adviser and expert, the International Radiophone Union must be ready to receive with the same rights as its other members all the Government organizations carrying on broadcasting service, and must have received those which have made such a request for membership. The programs for meetings of the International Radiophone Union shall be notified to the Administrations through the International Bureau of the Telegraph Union.

The International Radiophone Union must, moreover, admit as observers, in all its organizations, representatives of Administrations who shall have expressed a wish to be so admitted, as well as of the International Telegraph Union, for the study of questions whose solution might necessitate the intervention or agreement of the said Administrations.

Transmitting stations will be required to maintain a stability of the waves used, with all the accuracy which technical methods permit.

The Belgian Administration is requested to be good enough, as a provisional measure, and with no charges nor responsibilities accruing to it, to have measured, in such a way as it may choose, the waves transmitted by broadcast stations, and to communicate the results of these measurements to all the Administrations through the intermediary of the International Bureau of the Telegraph Union.

II

The wave, 1124 meters (267 kc) used by the German criminal police is recognized as carrying on an international service from Germany with other European nations. In accordance with the provisions of Article 5, Paragraph 14 of the Washington Regulations, the waves of 89.5 kc (3350 m) and 45 kc (6660 m) are allocated for synoptic meteorological messages.

B

The Conference has decided to request the Czechoslovak Administration to be kind enough to express to the Administration of the Netherlands its desire to have the following questions studied by the C.C.I.R. at the next meeting at the Hague:

1. The proper separation to be maintained between wavelengths for radio transmissions of all kinds.
2. Stability control for all radio transmissions.
3. The allocation of short waves for aviation and for the criminal police.
4. The allocation of short waves for national services.
5. Power limitation for broadcast stations, and the proper formula to be used for regulating such limitation.
6. Frequency separation in cycles to be maintained between stations in adjacent bands.
7. Study of the organization for a permanent international service for frequency measurements.

C

The Conference adopts the following resolutions:

1. **Concerning the Plan of Prague.**

It is desirable that the Administrations:

a. Reduce to the greatest extent possible, in conformity with national requirements, the number of broadcasting stations of low power; and limit in the future, in the band from 200–545 meters, the power of stations to the absolutely necessary value required to carry on a suitable service within the normal and regular service area defined by the laws of radio propagation.

b. Should use, whenever circumstances permit it, for stations of local or even regional interest, common national waves, carefully synchronized, and working on an exclusive wave for the transmission of the same program.

c. Carry on the strictest regulation requiring broadcasting transmitters to give reasonable guarantees from a technical standpoint as to their operation, and especially to require such stations to take all possible precautions to avoid transmission of harmonics of the fundamental wave, and not to modulate beyond reasonable limits.

d. Formulate the strictest requirements in order that transmissions from other radio services working outside the broadcast bands should be free from harmonics capable of interfering with radiotelephone transmissions.

e. Should study from now on, in view of the Madrid Conference, a better arrangement of wavelength bands allocated to different radio services, seeking for each type of transmission, in the light of technical progress, the wavelength bands most appropriate for such services, which would probably permit a notable increase of the possibilities available to satisfy the legitimate needs of broadcasting.

2. **Concerning Call Letters and Amateur Stations.**

It is desirable that:

a. Call letters of the International Series should be assigned to all radiotelegraph stations capable of causing international interference, except military and radiobeacon services. However, concerning military stations, the Administrations retain their right to assign or not to assign to them call leters of the international series.

b. The Administrations shall send to the International Bureau of the Telegraph Union a sufficient number of copies of the documents containing the provisions which they have drawn up for amateur stations. The Bureau will distribute them to other Administrations, who will thus be able to take note of them in the drawing up of their own regulations.

c. The Administrations which publish a list of amateur stations will send a copy to each Administration requesting it.

d. Irregularities found in amateur transmitting stations will be communicated to the interested Administration, and also to prevent any delay in these communications each administration will also notify the International Bureau of the Telegraph Union the address of the department which has charge of amateur regulation when such a department has not the ordinary Administration address.

3. Concerning waves used for aviation, it is desirable that the authorities of all the European countries should study the possibility of restricting the use by aviation of the wavelength band above 1340 meters (below 224 kc).

4. Concerning the interference caused by mobile and coast stations.

It is desirable:

That the different countries hasten as far as possible the modernization of the coast and ship stations, especially those which exchange many messages.

That by a more strict observance and a more judicious application of the Washington Regulations, especially by forbidding the transmission of superfluous signals, and the use of inordinately high power, a reduction should already be taking place, as far as possible, in the interference which coast and marine stations using damped waves cause to broadcasting services.

The Conference, as a result of this, requests the Administrations to be good enough:

To study the possibility, in so far as it shall be deemed desirable and practicable, of restricting transmissions on damped waves during the hours used by broadcasting stations.

To make sure that ship stations are adjusted and remain adjusted as accurately as possible upon their working waves, and that the damping of these waves be reduced to a minimum.

5. Concerning the work of the C.C.I.R.

It is desirable that the Administrations should carry on studies and preliminary tests which would be of such a nature as to facilitate the work of the C.C.I.R. which will meet at The Hague during the month of September, 1929.

6. Concerning the limits of power for broadcasting stations.

It is desirable, at least for a certain period, that countries limit the power of new or reconstructed broadcasting stations to a minimum value sufficient for the services to be carried on. The proposal has been made to take as a figure for such a power limitation 60 kilowatts in the antenna.

The C.C.I.R. is requested to determine whether a limitation on the effectiveness of broadcasting stations is practically possible, and according to what formula this limitation might in that case be determined.

7. Concerning the monitoring of waves, the Conference passed a resolution that a permanent arrangement for measuring frequencies used in radio services be organized.

The Conference recommends to the Administrations of Germany, England France, Italy and the U.R.S.S.:

a. To proceed to periodic measurements and to make periodic reports of the results to all the Administrations through the International Bureau of the Telegraph Union.

b. To put their measurement agencies at the disposal of the interested Administrations, in cases of interference, for the measurement of the frequencies in question.

The Conference invites the U.R.S.I. and the International Radiophone Union to cooperate with the above-mentioned agencies, giving them their scientific and technical collaboration.

The Conference requests Administrations having stations suitable for the periodic transmission of standard frequencies to inform the Administration of the Netherlands of the characteristics of these stations (frequency band, power, etc.) in order that the C.C.I.R. might study cooperative organization of these stations.

There are annexed to this protocol reports of the committees and subcommittees, as well as the minutes of the committees and of the plenary sessions.

Done at Prague, April 13, 1929

For Germany:—Otto Arendt, Dr. Steidle, Dr. Harbich, Munch.
For Austria:—Ing. Hans Pfeuffer.
For Belgium:—R. Corteil, Jean Marique.
For Bulgaria:—Tz. Christoff, Dr. R. Mednicaroff.
For Denmark:—C. Mondrup, C. Lerche, K. Christiansen.
For Spain:—Federico Aznar.
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For Great Britain:—F. W. Phillips, A. G. Lee.

For Hungary:—Bernhard Paskay.

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For Iceland:—G. Brien.

For Italy:—Col. Luigi Sacco.

For Latvia:—A. Auzins, Janis Linters.

For Principality of Monaco:—Ferrie.

For Norway:—Hermod Petersen, Arnold Raestad.

For the Netherlands:—C. H. de Vos, E. F. W. Volter, Warsinck.

For Poland:—Eugene Stallinger.

For Roumania:—Constantinesco.

For Kingdom of the Serbs, Croats, and Slovenes:—Ing. Claude Kotal, Ing. Mario Osana, Ing. Robert Weege.

For Sweden:—Seth Ljungqvist, Arthur Karlsson, H. Nordenmark.

For Switzerland:—Dr. Reinhold Furrer, E. Nussbaum.

For Czechoslovakia:—Ing. Strnad, Frant. Pixa, Stanislav Chocholin, Dr. Otto Kucera, Ing. A. Steinbach, Dr. Burda, Ing. Singer, Dr. Jar. Svoboda, Ing. Josef Stransky.

For Turkey:—M. Mazhar.

For the Union of Socialist Soviet Republics:—A. Vassiliev, L. Eichenwald.

ANNEX

Allocation of Wavelengths

According to the Plan of Prague, Becoming Effective June 30, 1929

Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
160	1875	Holland	(Huizen)
167	1800	Finland	(Lahti)
174	1725	France	(Radio Paris)
183.5	1635	Germany	(Zeesen)
193.0	1533	Great Britain	(Daventry)
202.5	1481	U.R.S.S.	(Moscou)*
207.5	1444	Aviation services and Eiffel Tower	
212.5	1411	Poland	(Varsovie)
217.5	1380	Aviation services	
222.5	1348	Sweden	(Motala)
230	1304	U.R.S.S.	(Kharkov)*
250	1200	Turkey	(Stamboul)**
		Iceland	(Reykjavik)**

* The U.R.S.S. did not participate in the Washington Conference.

** The use of these waves, which are situated in a band not allocated to broadcasting by the Regulations annexed to the Washington Convention, is authorized, provisionally, under the express condition that stations using these waves shall not interfere with the services occupying this band.

(See Article 5, Paragraph 1, of the Regulations.)

Particularly, the transmission of these stations must not be allowed to make inoperative alarm signals, distress signals, security or urgency signals transmitted on the wave 500 kc (600 m) and on 333 kc (900 m).

In case of interference the interested Administrations will do their best to seek another suitable solution.

Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
260	1153	Denmark	(Kalundborg)
280	1072	Norway	(X)**
297	1010	Switzerland	(Bale)**
320	930	U.R.S.S.	(Moscou C.C.S.P.)*
364	825	U.R.S.S.	(Moscou)*
375	800	U.R.S.S.	(Kiev)*
385	778	U.R.S.S.	(Petrozavodsk)*
395	760	Switzerland	(Geneva)**
442	680	Switzerland	(Lausanne)**
527	572	Germany	(Fribourg)**
		Kingdom of Serbs Croats and Slovenes	(Ljubljana)**
531.5	565	U.R.S.S.	(Smolensk)*
536	560	Germany	(Augsbourg)**
545	550	Hungary	(Hanover)**
554	542	Sweden	(Budapest)***
563	533	Germany	
572	525	Latvia	
581	517	Austria	
585.5	511	U.R.S.S.	(Arkhangelsk)*
590	509	Belgium	
599	501	Italy	
603.5	497	U.R.S.S.	(Moscou)*
608	493	Norway	
617	487	Czechoslovakia	
621.5	483	U.R.S.S.	(Gomel)*
626	479	Great Britain	
630.5	476	U.R.S.S.	(Simferopol)*
635	473	Germany	
644	466	France	(Lyon La Doua)
653	459	Switzerland	
666.5	450	U.R.S.S.	(Moscou S.P.)*
662	453	Common, No. 1	
671	447	France	(Paris P.T.T.)
680	441	Italy	
689	436	Sweden	
698	429	Kingdom of S. C. and S.	
702.5	427	U.R.S.S.	(Kharkov)*
707	424	Spain	
716	418	Germany	
725	413	Ireland	
729.5	411	U.R.S.S.	(Odessa)*
734	408	Poland	
743	403	Switzerland	
747.5	401	U.R.S.S.	(Koursk)*
752	399	Great Britain	
761	394	Roumania	
770	390	Germany	
779	385	Poland—Italy†	
783.5	383	U.R.S.S.	(Dnepropetrovsk)*
788	381	France	
792.5	379	U.R.S.S.	(Artemovsk)*
797	377	Great Britain	
806	372	Germany	
810.5	370	U.R.S.S.	(Tver)*
815	368	Spain	
819.5	366	U.R.S.S.	(Nikolaiev)*
824	364	Norway	
833	360	Germany	
842	356	Great Britain	
851	352	Austria	
855.5	351	U.R.S.S.	(Leningrad)*
860	349	Spain	
869	346	France	(Strasbourg)
878	342	Czechoslovakia	
887	339	Belgium	
891.5	337	U.R.S.S.	(Ivan-Voznesensk)*
896	335	Poland	
905	332	Italy	
914	329	France	(Montpellier)
923	325	Germany	
932	322	Sweden	
941	319	Bulgaria	

*** The wavelength allocated to Hungary will be brought back into the band allotted to broadcasting at the earliest favorable opportunity.

† Exclusive wave shared with the reservation that there shall not be any mutual interference.

Frequency kc	Approximate wavelength m	Name of Country	(Or of Station)
950	316	France	(Marseilles)
959	313	Poland	
968	310	Great Britain	
977	307	Kingdom of S. C. and S.	
986	304	France	(Bordeuz Lafayette)
995	301	Great Britain	
1004	298	Holland	
1013	295	Esthonia	
1022	293	France and Czechoslovakia	(Limoges)
1031	291	Finland	
1040	289	Great Britain	
1049	286	France	(Reims)
1058	283	Portugal	
1067	281	Denmark	
1076	279	Czechoslovakia	
1085	276	Germany	
1094	274	Italy	
1103	272	France	(Rennes)
1112	270	Greece	
1121	268	Spain	
1130	265	France	(Lille)
1139	263	Czechoslovakia	
1148	261	Great Britain	
1157	259	Germany	
1166	257	Sweden	
1175	255	France	(Toulouse P.T.T.)
1184	253	Germany	
1193	251	Spain	
1202	250	Czechoslovakia	
1211	248	Italy	
1220	246	Common, No. 2	
1229	244	Albania (provisionally Poland)	
1238	242	Great Britain	
1247	240	Norway	
1256	239	Germany	
1265	237	Monaco—Nice—Corsica (shared)	
1274	235	Norway	
1283	234	Poland	
1292	232	Kingdom of S. C. and S.	
1301	231	Sweden	
1310	229	Spain	
1319	227	Germany	
1328	226	Roumania	
1337	225	Ireland	
1346	223	Luxemburg	
1355	221	Finland	
1364	220	France	
1373	218	Common, No. 3	
1382	217	Common, No. 4	
1391	216	Common, No. 5	
1400	214	Poland	
1410	213	Italy	
1420	211	Roumania	
1430	210	Hungary	
1440	208	Belgium	
1450	207	Common, No. 6	
1460	206	Common, No. 7	
1470	204	Common, No. 8	
1480	203	Common, No. 9	
1490	202	Common, No. 10	
1500	200	Free	

Note

The Conference has taken note of the existence of the station of Kaunas (Lithuania) which has used different waves between 155 kc (1935 m) and 151 kc (1990 m) for broadcasting services. This station having interfered with mobile services carried on by the station at Portishead (Great Britain) using the wave of 149 kc (2013 m), situated in the band reserved exclusively for mobile services, the Conference has directed the British Administration to make suitable negotiations with the Administration of Lithuania, with a view to finding for the Kaunas station a wavelength which will not interfere with these mobile services.

The Edison Fellowship

In honor of Thomas A. Edison and in commemoration of the 50th anniversary of his incandescent lamp, an Edison Fellowship for research in the General Electric research laboratory at Schenectady, N. Y., has been established. Its object is to help determine the fitness of the Fellow for industrial or scientific research by arranging for a year's research in that laboratory. The opportunity will be given to the selected candidate who has adequate training and who has done sufficient original work to have indicated an aptitude for research. The year's fellowship carries a grant of $3,000.

The selection from applicants will be made by the National Research Council with the advice of the Director of Research of the General Electric Company. The committee includes: Dr. George K. Burgess, director of the U. S. Bureau of Standards and chairman of the National Research Council, chairman of the committee; Dayton C. Miller, professor of physics of the Case School of Applied Science and chairman of the division of physical sciences of the National Research Council; James E. Mills, chief of the research division of Edgewood Arsenal and chairman of the division of chemistry of the National Research Council; and A. E. Kennelly, professor of electrical engineering at Harvard University. Dr. Willis R. Whitney, vice president and director of the research laboratory of the General Electric Company, represents that company.

The choice of research work will be influenced by the preference of the individual, and may be the continuation of studies already begun at college if suitable laboratory facilities are available, or the Fellow may work on new or specially selected projects, either independently or in cooperation with others.

Any research man wishing to apply for the fellowship who is able to begin a year's work this fall (1929) should send to the Director of the Research Laboratory, General Electric Company, Schenectady, N. Y., before July 4, relevant information about his training and a recent photograph, and should arrange for a separate letter of recommendation to be forwarded by someone with whom he has done original scientific work.

Application Form

On pages XIX-XX of this issue of the PROCEEDINGS there is printed an abridged form of application for membership in the Institute. It is believed that this blank, which pertains to the Associate grade only, will be found convenient by the membership for use in canvassing friends who are eligible for membership in the Institute, and by non-members for filling out and either mailing to the Secretary of the Institute in New York City, or handing to an officer of a local Section. Standard application forms for membership in the other grades will be sent upon request to the Secretary of the Institute.

Standard Frequency Transmissions by the Bureau of Standards

The schedule of standard frequency transmissions by the Bureau of Standards for the months of July to December (inclusive) appear below.

Eastern Standard Time	July 22	Aug. 20	Sept. 20	Oct. 21	Nov. 20	Dec. 20
10:00 P.M.	1500	4000	550	1600	4000	550
10:12	1700	4400	600	1800	4400	600
10:24	2000	4800	700	2000	4800	700
10:36	2300	5200	800	2400	5200	800
10:48	2700	5800	1000	2800	5800	1000
11:00	3100	6400	1200	3200	6400	1200
11:12	3500	7000	1400	3600	7000	1400
11:24	4000	7600	1500	4000	7600	1500

For further particulars as to the method of transmission, readers of the PROCEEDINGS are referred to the past issues of the PROCEEDINGS.

Persons using these transmissions are invited to send suggestions or comment to the Bureau of Standards, Washington, D. C. The Bureau will particularly welcome descriptions of ways in which the signals are used or other comment that might assist in increasing their usefulness.

Institute Meetings

1929 CONVENTION

The 1929 Convention was pronounced a great success by all members of the Institute who were present in Washington on May 13th to 15th. Over five hundred and fifty members and guests registered for the Convention.

With some modifications, the complete program as outlined in the April, 1929, issue of the PROCEEDINGS was carried out. Due to illness, Professor M. I. Pupin was unable to be present. Professor A. E. Kennelly, of Harvard University, presented an interesting lecture on "Radio and its Ways."

In addition to the reception for all members of the Institute by President Hoover, Mrs. Hoover held a reception for the ladies attending the Convention.

Dr. and Mrs. Alexander Meissner and Dr. H. Rothe, from Berlin, Germany, and Professor Y. Watanabe of Japan made the trip to the United States to be present during all of the sessions.

At the banquet at the Mayflower Hotel on May 14th, at which four hundred and fifty members and guests were present, President Taylor announced that the 1930 Convention of the Institute is to be held in Toronto, Canada, during the month of June.

Eastern Great Lakes District Convention

Under the sponsorship of the Buffalo-Niagara, Cleveland, Rochester, and Toronto sections, a District Convention to which all members of the Institute are cordially invited, is being arranged for November 18–19, 1929 in Rochester.

A very interesting program is assured. The committee chairmen have been appointed as follows: executive committee, V. M. Graham; publicity committee, R. A. Hackbusch; transportation and accommodations, J. Eichman; fellowship, J. A. Victoreen; trips, A. L. Schoen; entertainment, E. C. Karker; ladies' entertainment, Mrs. Angevine; finance, H. J. Klumb.

The program will include inspection trips, a number of technical sessions and a banquet.

Proposed Cincinnati Section

Members of the Institute residing in the vicinity of Cincinnati, Ohio, have expressed the desire to organize a Cincinnati section of the Institute. W. W. Boes and R. H. Langley have been instrumental in the organization work.

The first organization meeting was held May 27th in the Chamber of Commerce Building, Cincinnati, Ohio. R. H. Langley and W. W. Boes presided. Short talks were given by O. H. Caldwell, former radio commissioner, C. D. Barbuleson, E. T. Flewelling, William Lukens, and R. H. Langley. Temporary officers were elected with the following results: R. H. Langley, chairman, and W. W. Boes, Secretary-Treasurer.

The next meeting of the proposed Cincinnati section will be held on September 9th.

Atlanta Section

The Atlanta section held a meeting May 8th in the Physics Laboratory, School of Technology, Atlanta, Ga. The meeting was presided over by the retiring chairman, Major W. Van Nostrand and Chairman Elect Henry P. Thornton. There was an attendance of ten members.

Professor Rodger S. Strout of the Department of Physics in Georgia Institute of Technology presented a paper, "Piezo-Electric Crystals." Mr. Strout went into detail as regards oscillation characteristics of quartz crystals in various commercial and laboratory forms. The lecture was accompanied by slides showing crystals in associated circuits, temperature coefficient curves and holder spacing characteristics. He also illustrated the proper method of cutting and grinding for maximum accuracy and energy output. After the presentation of the paper an informal discussion took place, supplemented by actual oscillation tests of various crystals cut and ground.

Detroit Section

Fifty members and friends attended the meeting of the Detroit section on March 22nd in the Detroit News Building, Detroit, Michigan. A. B. Buchanan, chairman of the section, presided.

Henry N. Kozanowski, Department of Physics of the University of Michigan, presented a paper, "The Quartz Crystal Oscillator as a Standard of Frequency." The importance of a standard of frequency in radio research laboratories and in commercial practice was stressed. Frequency standards are divided in two classes: first, the primary standards such as the gravity pendulum, vacuum-tube maintained tuning fork, magnetostriction oscillator, and the piezo-electric oscillator; second, those which are calibrated from the above and are operated under constant conditions, as for instance, the Hartley and dynatron oscillators. A historical survey of the discovery of the piezo-electric effect by J. A. and P. Carrie in 1881, and its application to radio circuits by the work of W. G. Cady and G. W. Pierce followed. This included a qualitative discussion of the probable mechanism of oscillation of a piezo-electric plate and the development of a mathematical theory for the frequency of oscillation in terms of the material constants and the dimensions of the plate.

The methods of cutting, grinding, and mounting plates and their frequency control by the rheostatic means were explained in some detail.

Finally there was described the calibration of a crystal oscillator by means of the best note between the fundamental frequency of the crystal oscillations circuit and known harmonics of an oscillator whose frequency was entirely governed by the frequency of a tuning fork. The frequency of this fork was determined by using a synchronous motor telechron clock in the circuit maintaining it. In this manner it has been found possible to determine the frequency of the quartz crystal oscillator to an accuracy of 3 parts in 100,000.

A general discussion followed the presentation of the paper.

The Detroit section held a meeting April 19th in the Detroit News Building, Detroit, Michigan. L. N. Holland, vice-chairman of the section, presided. Thirty-five members and friends attended the meeting.

J. E. Miller, instructor in Aeronautical Department of the University of Detroit, presented a paper, "Aircraft Radio Communication." The various phases of the present beacon system was explained. The transmitting range for beacons is 285–315 kc and for other communication 315–350 kc. The various means of utilizing radio transmission and reception as an accurate guide to a pilot when attempting a landing and the rotating loop method and the new polydirectional method which is still in the state of development were discussed. It was predicted that the present method of radio beacon would soon be replaced by the visual method. A motion picture on "Radio Beacons" was also shown.

A general discussion followed the presentation of the paper.

New York Meeting

President A. Hoyt Taylor presided at the New York meeting of the Institute held in the auditorium of the Engineering Societies Building, 33 West 39th Street, on June 5th.

Two papers were presented. The first, by Alan C. Rockwood and Warren R. Ferris, of the General Electric Company, was entitled "Microphonic Improvement in Vacuum Tubes."

The second paper, "A Study of the Output Power Obtained from Vacuum Tubes of Different Types," by H. A. Pidgeon and J. O. McNally, of the Bell Telephone Laboratories, was presented by Mr. McNally.

Both papers will be published in an early forthcoming issue of the Proceedings. No reprint copies are available.

Three hundred and fifty members of the Institute and guests attended the meeting, which is the last until the fall season opens on September 4th.

Philadelphia Section

On May 24th in the Bartol Laboratories of the Franklin Institute, Philadelphia, Pa., the Philadelphia section held a meeting. J. C. Van Horn, chairman of the section, presided. Fifteen members and guests attended. Gleason W. Kenrick and C. K. Jen, both of the Moore School of Electrical Engineering, University of Pennsylvania, presented a paper "Short Wave Radio Transmission Phenomena."

The paper described the problems introduced by signal to noise ratio in limiting long distance transmission, and the need and uses of a quantitative transmission theory were outlined. Methods of obtaining requisite information as to the constitution of the upper atmosphere and the part played by Kennelly-Heaviside echo studies and field strength observations were pointed out. The results of further echo studies showing a run obtained during February giving abnormal heights and transmission phenomena including long time retardation echoes on 4435 kc were described. Some preliminary results of a study on field intensities observed at Philadelphia from WCI and the perturbing effects of magnetic storms on this transmission were also outlined.

Seattle Section

On April 26th, the Seattle section held a meeting in Philosophy Hall, University of Washington, Seattle, Washington, presided over by A. V. Eastman, chairman of the section. Fifty-eight members attended.

A. V. Eastman presented a paper, "Shield Grid Tube as Intermediate R-F Amplifier." The paper described the action of the 22 tubes by comparing their characteristic curves with those of the 01A type. The method of measuring gain and selectivity of one or two 60-kc stages was explained. The r-f input was carefully shielded and varied by the IR drop method—the amplifier output was measured by microammeter readings. The curves showed many interesting advantages as well as shortcomings of the 22 type when used as i-f amplifiers.

Messrs. Libby, Deardorf, Carpenter, Kleist, and Willson participated in the discussion which followed.

A. V. Eastman, chairman, presided over a meeting of the Seattle section on May 24th in Philosophy Hall, Washington University, Seattle, Washington. Thirty-eight members and guests attended.

F. C. Dahlquist presented a paper, "The American Broadcast System." The paper explained the operation of the chain of stations on the American broadcast system. It also outlined the problems in each of the departments and showed the necessity of cooperation between the engineering, sales and program directing personnel. A few of the many problems and incidents of chain programs were told in a very interesting manner. Messrs. Budden, Clark, Kleist, and McNicholas participated in the discussion which followed.

A. V. Eastman announced that J. O. Tolmie had been chosen vice-chairman of the Seattle section.

After the meeting an inspection trip was made through radio station KJR.

Toronto Section

On May 8th the Toronto section held a meeting in the Electrical Building, University of Toronto, Toronto, Canada, attended by sixty members. A. M. Patience, chairman of the section, presided.

B. DeF. Bayly presented a paper, "Radio-Frequency Amplifier Design." Messrs. Smith, Fox, and Richardson participated in the discussion which followed.

The election of officers was held which resulted in the election of V. G. Smith, chairman; G. E. Pipe, secretary; and F. D. Dalton, assistant secretary.

Personal Mention

Harold E. Dinger is now associated with the firm of Catterall, Inc., of Canton, Ohio, as radio engineer. He was formerly associated with the Schoch Studios of Alliance, Ohio.

E. R. Doyle, of Leeds and Northrup Company, Philadelphia, is now Assistant Director of Development in that organization. He was formerly Chief of the Electrical Division of the Department of Development.

Beverly Dudley, recently with the American Telephone and Telegraph Company at Chicago, Ill., has joined the staff of the American Radio Relay League at Hartford, Conn., in charge of Technical Information Service.

Walter R. Jones, until recently research engineer with the Federal Radio Corporation of Buffalo, is now sales engineer for Sylvania Products Company of Emporium, Pa.

Alfred L. Kissell has joined the staff of the Cuban Electrical Company at Havana. Mr. Kissell left the United Electric Light and Power Company to assume his new connection.

Alexander H. Knights, formerly test engineer with the Radio Corporation of America, has joined RCA Photophone as installation engineer.

A. S. Lemoine is now chief engineer of the Radio Department of the Royal Board of Telegraphs of Stockholm, Sweden.

G. Edgar Locke, until recently with the Patent Department, U. S. District Court for the Southern District of New York, is now associated with Electrical Research Products, Inc., as Supervisor of Installation Engineers.

Leo R. Mead is now laboratory assistant, Electrical Research Laboratories, Chicago, Ill.

Howard K. Morgan, formerly a student of the University of California, has become associated with the General Electric Company at Schenectady, N. Y. as radio engineer.

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GEOGRAPHICAL LOCATION OF MEMBERS ELECTED JUNE 5, 1929

Transferred to the Member grade

Dist. of Columbia	Washington, Federal Radio Comm.	Butnam, Carl H.
	Washington, 1018 Douglas St., N. E.	Young, Leo C.
New Jersey	Newark, Brandes Products Corp., 200 Mt. Pleasant Ave.	Gerns, Wm. H.

Elected to the Member grade

Dist. of Columbia	Washington, 1821 Rigga Place, N. W.	Schrenk, M. H.
New York	New York City, c/o Imperial Japanese Navy, Inspectors Office, 1 Madison Ave.	Nakamura, T.
Czechoslovakia	Prague 11, u Karlovu 5	Zzeek, August
England	Cambridge, Sidney Sussex College	Ratcliffe, J. A.
Germany	Berlin-Wilmersdorf. Guntzelstr. Berlin	Watanabe, Yasusi

Elected to the Associate grade

Alabama	Mobile, c/o Adams Glass Co., Inc., 17–19–21 So. Royal	Heyen, Rudolph J.
California	Hollywood, 1123 Poinsettia Drive	Signer, John J.
	Los Angeles, 4846 Rosewood Avenue	Cooper, George R.
	Los Angeles, 110 Center St.	Lee, Gilbert C.
	Los Angeles, 316 N. Reno St.	Ludlum, William T.
	Los Angeles, 921 W. 6th St.	McGonagil, H. A.
	Los Angeles, 2812 So. Main	Meyer, R. H.
	Los Angeles, 1609 Hipoint St.	Walter, Edward F.
	San Francisco, 1266 McAllister St. Apt. 8	Slavin, Samuel B.
	San Francisco, 715 Bush Street	Stanton, James M.
Connecticut	Hartford, 235 Collins St.	Heris, George
	Hazardville, South St.	Thompson, Stanley W.
Dist. of Columbia	Bellevue, U. S. N. Lab.	Wortman, E. C.
	Washington, National Electric Supply Co., 1330 New York Ave. N. W.	Burger, Clarence Walter
	Washington, 5013 8th St., N. W.	Seiler, Donald W.
	Washington, 1860 Clydesdale Place, N. W.	Struthers, Francis William
	Washington, c/o Federal Radio Comm.	Webster, Betheul M., Jr.
Illinois	Chicago, 4736 N. Racine Ave.	Alexander, Wayne
	Chicago, 1820 North Wells St.	Arnold, Lowell George
	Chicago, 2837 South St. Louis Ave.	Koutnik, J. A.
	Chicago, 5115 S. Winchester Ave.	Pletka, James
	Chicago, 5409 Agatite Ave.	Ramm, Carl H.
	Chicago, 312 N. Central Ave.	Walter, Wilbur Tayman
	Evergreen, 9343 Richmond Ave.	Randall, Lemuel E.
Indiana	Fort Wayne, 2925 Bowser Avenue	Ramm, Harold William
	Valparaiso, Stiles Hotel	Hayes, Arthur J.
	Valparaiso, 405 South Monroe St.	Munroe, A. D.
	Valparaiso, 505 E. Jefferson St.	Olinger, Robert
Iowa	Wapello, 312 Franklin Ave.	Fry, Lloyd L.
Massachusetts	Attleboro, Park Hotel	Bargamian, John
	Boston, Tropical Radio Tel. Co., 1 Federal St.	Kelly, Michael P.
	Cambridge, Stoughton Hall 14	Hazard, Willis Gilpin
	Jamaica Plain, Wireless Specialty Apparatus Co.	Blodgett, Edward D.
	Lynn, 87 Myrtle St.	Mayo, Royal E.
	Roxbury, 130 Marcella St.	Stone, Elmer F.
	Springfield, Am. Bosch Mag. Corp.	Benner, Howard J.
	Springfield, Am. Bosch Mag. Corp.	Bond, M. E.
	Springfield, Am. Bosch Mag. Corp.	Raskhodoff, Nicholas
	Winthrop, 23 Sagamore Ave.	Dalton, Robert E.
Michigan	Jackson, 306 Steward Ave.	Stoll, Paul A.
Mississippi	Jackson, 944 West Capitol St.	Meyers, James A., Jr.
Missouri	Independence, 819 W. Van Horn Road	Dennis, Ralph M.
	Independence, 630 Crysler St.	Johnston, Ivan F.
	Kansas City, 702 Shukert Bldg.	Blum, Sidney J.
	Kansas City, 1004 Davidson Bldg. 17th & Main	Clements, Thos. C.
	Kansas City, 1827 Norton	Haase, Edwin John
	Kansas City, 2112 Aberdeen Court	Hodge, Albert William
	Kansas City, 2722 Brighton Ave.	Kiefer, Harry Dukes
	Kansas City, 2503 Harrison St.	McCormick, Benjamin S.
	Kansas City, 4511 E. 23 St.	Payne, Harry Kenneth
	Kansas City, 2004 Prospect	Watter, George V.
	Kansas City, 3614 Brooklyn Ave.	Upham, Stewart W.
	Kansas City, 4012 Michigan St.	Vogel, Henry W.
	Kansas City, 1110 West 41st St.	Walter, Wm. J.

Montana	Froid	Jacobs, Marcellus L.
New Jersey	Camden, 315 N. 27 St.	Sumner, Raymond Stokes
	East Orange, 137 Halsted St.	Feindel, Abbott
	Little Falls, R. F. D.	Farnsworth, Daniel W.
	Paterson, 489 Main St.	Trifari, Edmund
New York	Brooklyn, 253 Cumberland St.	Bower, James
	Brooklyn, 616 Bainbridge St.	Rehbein, Arthur Frederick
	Brooklyn, 1715 West 13 St.	Romeo, Anthony
	Flushing, 19 Smart Ave.	Sage, Frederic H.
	Jackson Heights, L. I. 125 22nd St.	Hickman, C. Nicholas
	New York City, 89 Cortlandt St.	Blan, Michael
	New York City, 1010 First Ave.	Haug, Joseph
	New York City, c/o R.C.A. Van Cortlandt Park So.	Krueger, Barton
	New York City, 117 E. 24th St.	Kunc, Frank
	New York City, R.C.A. 70 Van Cortlandt Park So.	Malter Louis
	New York City, Bell Tel. Labs., 463 West St.	Morrison, Howard
	New York City, 894 Riverside Drive	Rathner, Jack
	New York City, 64 East 103 St.	Rifkin, J. L.
	New York City, c/o General Delivery	Svendsen, A. V.
	New York City, 1820 Bryant Ave. Bronx	Trapkin, Jack H.
	Ozone Park, L. I.	Misenheimer, Rob't. G.
	Rochester, 145 So. Fitzhugh St.	Foster, Charles W.
	Rockville Centre, 259 Raymond Ave.	Lester, Paul Sabine
	Southampton, Box 269	Buckingham, Wm. D.
	Woodhaven, 7424 87th Ave.	Cooper, Gustavus
North Carolina	Ashville, Battery Co.	Xorelle, J. L.
Ohio	Cincinnati, 2042 Baltimore Ave.	Fisher, Ellwood T.
	Columbus, 28 W. Longview Ave.	Graham, J. P.
Oklahoma	Tulsa, 114 West Third St.	Pitcher, J. W.
	Tulsa, 627 Main St. S.	Wise, James Orr
	Tulsa, Willard Hotel	Robinson, L. L.
Pennsylvania	Allentown, 1801 Liberty St.	Kurtz, Clyde R.
	Chambersburg, Box 139	Ramsey, R. W.
	Clearfield, 326 Locust St.	Moyer, Elmo Emerson
	Easton, 1852 Freemansburg Ave.	Fox, Paul S.
	Philadelphia, 843 E. Price St.	Benge, J. R.
	Phildaelphia, 457 No. 12th St.	Mousley, Franklin
	Philadelphia, 5205 Akron St.	Travis, Charles
	Pittsburgh, 5866 Burchfield Ave.	Schlesinger, Louis B.
	Pottstown, 53 N. Charlotte St.	Roeller, Henry S.
Rhode Island	Providence, 663 Academy Ave.	Thomas, Harold
Utah	Spanish Fork	Fullmer, Don A.
Virginia	Roda, Box 42	Brien, William J.
Washington	Seattle, 113 E. 55th St.	Fitzpatrick, George Wm.
	Seattle, 503 Melrose Ave. No.	Hemerich, Walter A.
England	London SW 12, 42-A Balham Park Road	Green, Charles M.
Japan	Kawasaki, c/o The Tokyo Elec. Co.	Kuno, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Kuwajima, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Matsui, K.
	Kawasaki, c/o The Tokyo Elec. Co.	Miyauchi, T.
	Kawasaki, c/o The Tokyo Elec. Co.	Ohtani, S.
	Kawasaki, c/o The Tokyo Elec. Co.	Otsuka, Y.
	Kawasaki, c/o The Tokyo Elec. Co.	So, Manabu
	Kawasaki, c/o The Tokyo Elec. Co.	Suga, Y.
	Kawasaki, c/o The Tokyo Elec. Co.	Suzuki, Hisao
	Sendai City, Harano-machi, Sending Station of JOHK, Sendai Broadcasting Station	Kanno, Gengo
	Tokyo, c/o Tokyo Central Broadcasting Station Atagoyamam	Fukushima, T.
	Near Tokyo, 1244 Hirahari, Magomemachi	Hamada, Shigenori
	Tokyo, c/o Tokyo Central Broadcasting Station, Atagoyamam	Koshikawa, Y.
	Tokyo, 59, Hitotsugicho, Akasakaku	Mita, S.
	Tokyo, c/o M. Kaneko, 2, 5-Chome, Kirakawa-Cho, Kojimachiku	Nagao, R.
	Tokyo, c/o Kaigun Kantokukan-Jimusho, 3, 1 Chome Uchisaiwai-cho, Kojimachiku	Nakajima, S.
South Africa	Tongaat, Natal	Howard, W. B.
South Australia	Eleanor Terrace, Murray Bridge	Miller, Francis G.
New Zealand	G. P. O. Box 188, Wellington	Russell-Boyle, H.

Elected to the Junior grade

Arkansas	Little Rock, 723 Wright Ave.	Stover, Arthur R., Jr.
Florida	Avon Park	Collins, Florine
Georgia	Atlanta, 933 Oak St.	Harrison, Richard H.
	Commerce	Hood, Sam
Illinois	Carpenter, Box 272	Bennett, Leslie W.
	Waukegan, 653 Mill Court	Herrmann, Albert, Jr.
Indiana	Connersville, 1948	Hamilton, Charles Ed.
	Valparaiso, 557 So. Locust St.	Cox, Hestor S.
	Valparaiso, 155 College Ave.	Johnson, Julien S.
	Valparaiso, 502 East Jefferson	Mealy, Max B.
	Valparaiso, 155 College Ave.	Reid, Herbert G.

Maryland	Baltimore, 2449 Lauretta Ave.	Ridenour, Wm. S.
Massachusetts	Boston, 570 Columbus Ave.	Hatten, Arthur Thomas
	Dorchester, 894 Blue Hill Ave.	Berkowitz, Louis
Michigan	Harbor Springs	Wright, Wilford C.
	Jackson, 302 Biddle St., E.	Atkins, Carl Edward
New Jersey	Elizabeth, 419 Livingston St.	Engel, Albert L.
	Pleasantville, 1507 S. Main St.	English, James G.
New York	Brooklyn, 1121 Bedford Ave.	Gray, De Wayne R.
	Brooklyn, 1272 E. 10th St.	Charlat, Arnold
Ohio	Cleveland, 2915 E. 130th St. No. 10	Goetz, V. Wm.
	Cleveland, 2088 Cornell Road	Hybarger, H. Kenneth
	Payne	Huhuenin, Glenda
Oklahoma	Tulsa, KVOO	White, Karl K.
Pennsylvania	Allentown, 618 N. 12th St.	Richardson, George A.
	Cynwyd, 407 State Road	March, Hallman W.
	Easton, 17 So. 6th St.	Deutschman, Borah
Washington	Seattle, 7811 Stroud Ave.	Thomson, Howard M.
Federated Malay States	271 Kota Road Taiping	Sinh, Harbaksh
Hawaii	Honolulu, E. 1518 Liliha St.	Hisamoto, Masayuki

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APPLICATIONS FOR MEMBERSHIP

Applications for election to the various grades of membership have been received from the persons listed below, and have been approved by the Committee on Admissions. Members objecting to the election or transfer of any of these applicants should communicate with the Secretary on or before August 1, 1929.

For Transfer to the Member grade

Dist. of Columbia	Washington, c/o Federal Radio Commission	Segal, Paul M.
	Washington, 3314 Newark St.	Mirick, C. B.

For Election to the Member grade

California	San Francisco, Signal Office, Presidio of San Francisco	Winner, William Lane, Jr.
Dist. of Columbia	Washington, Dept. of Commerce, Radio Division	Barron, J. H., Jr.
Illinois	Alton, 1124 Washington St.	d'Adrian, A. L. Duval
	Chicago, 1400 Union Trust Bldg.	Caldwell, Louis G.
Massachusetts	Waban, 100 Devon Road	Replogle, Delbert E.
Montana	Bozeman, c/o Montana State College	West, Glenn Edwin
New Jersey	Boonton, Radio Frequency Laboratories, Inc.	Wilmotte, R. M.
	Maplewood, 26 Berkeley Road	Pidgeon, Howard A.
New York	New York City, USS *Bridge*, c/o Postmaster	Johnson, C. M.
	New York City, 711 Fifth Avenue, Room 1223	McElrath, George
Pennsylvania	State College, 234 West Fairmount Ave.	Woodruff, Eugene C.
Canada	Toronto, Ont., Windsor Arms Apts., St. Thomas and Sultan Sts.	Schwarz, Bertram A.
England	Leeds, Yorks, 35 Reginald Terrace, Chapeltown	Harvey, Lionel
	Leeds, 6 Blenheim Terrace, Northeastern School of Wireless	Russell, M. W. G.
	Manchester, British Broadcasting Corp.	Bird, R. J.
	Norbury, SW, 119 Headcorn Road	Shaw, A. C.
Germany	Berlin, Fritschestrasse 41, I, Charlottenburg	Roder, Hans
Italy	Milan, Corso Italia, 13, c/o S.I.R.A.C.	Osiatinsky, L.
New Zealand	Christchurch, Canterbury University College, Elec. Dept.	McLellan, Roderick Arthur
	Wellington, G. P. O. Box 638	Thow, Keith H.
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Part II

TECHNICAL PAPERS

Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

A HIGH PRECISION STANDARD OF FREQUENCY*

By
W. A. Marrison
(Bell Telephone Laboratories Inc., New York, N. Y.)

Summary—*A new standard of frequency is described in which three 100,000-cycle quartz crystal-controlled oscillators of very high constancy are employed. These are interchecked automatically and continuously with a precision of about one part in one hundred million. They are checked daily in terms of radio time signals by the usual method employing a clock controlled by current maintained at a sub-multiple of the crystal frequency. Specially shaped crystals are used which have been adjusted to have temperature coefficients less than 0.0001 per cent per degree C.*

To meet the demands for increased precision in measurement and greater reliability of operation a new reference standard frequency system has been developed in the Bell Telephone Laboratories having an absolute accuracy that may be relied upon at all tames to better than one part in a million. This reference standard is similar in many respects to one described by Horton and Marrison a little over a year ago[1], but a number of important changes have been made which have contributed to increased accuracy and reliability.

The standard is based on the quartz crystal-controlled oscillator, with a synchronous motor-driven clock, used to determine its rate. It differs from others of the same general type in having a number of similar crystal-controlled oscillators which may be interchanged at will and which are intercompared continuously and automatically with a precision of one part in one hundred million. A number of improvements have been made in the crystal and mounting, and in the circuit, which justify this precision of measurement.

By far the most important element in a crystal-controlled oscillator is the crystal itself and great care was taken in selecting the type to be used in the new standard. A crystal was required as nearly independent as possible of ordinary variations in temperature and pressure and which could be mounted so as to vibrate freely. The effect of temperature appeared to be especially serious as the changes in frequency thus obtained with an ordinary crystal, even with the best commercial thermal regulators available, are greater than are caused by any other single factor in the new standard.

* Dewey decimal classification: R210. Original manuscript received by the Institute, May 17, 1929. Presented before New York meeting of the Institute, April 3, 1929.

[1] J. W. Horton and W. A. Marrison, "Precision Determination of Frequency," Proc. I. R. E., 16, 137; February, 1928.

It has been known for some time that plates of quartz cut in the plane of the optic and electric axes usually have positive temperature coefficients and that plates cut in the plane of the optic axis but perpendicular to an electric axis have negative coefficients. It has also been known that oscillations may be produced in a crystal either paral-

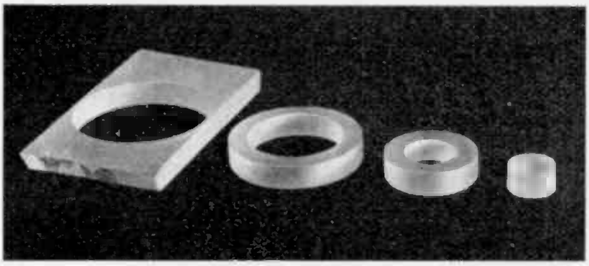

Fig. 1—Crystals Used in Preliminary Temperature Coefficient Tests.

lel to the impressed electric field or perpendicular to it, the socalled longitudinal and transverse effects. There is a certain amount of mechanical coupling between such different modes of vibration within the crystal, more or less close, depending upon the shape, and in particular depending upon the ratio of dimensions in the principal directions

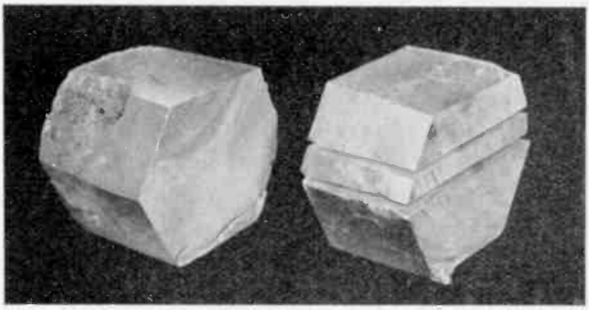

Fig. 2—Partly Assembled Crystal Showing the Relation of the Slab to the Crystal Axes.

of vibration. In view of these facts it was thought probable that crystals could be produced with such coupling between the modes which have inherently positive and negative coefficients that the resultant temperature coefficient would be nil.

Series of crystals of rectangular and circular shape were made to test this fundamental assumption. It was found that the temperature coefficient does vary with the shape of a resonator and, in particular, that crystals may be proportioned so as to have a coefficient that is practically nil. The relations between the temperature, coefficient and the dimensions in the case of rectangular plates, have been further studied in detail by F. R. Lack[2] of the Bell Telephone Laboratories.

In the first experiment performed with circular disks for this study a large disk was first cut and smaller ones cut from it, after measurement, to insure constancy of material, thickness and orientation with respect to the crystal axes. The parts remaining after three sizes of disks had been cut in this way, with the remainder of the slab from which they were obtained, are shown in Fig. 1. The slab is shown in the partly assembled original crystal in Fig. 2 to show the manner of cutting. With such circular disks it was found that at least one diameter could be found for which the temperature coefficient is very small throughout the entire room-temperature range.

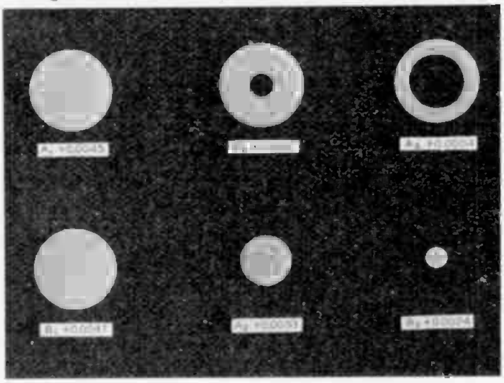

Fig. 3—Temperature Coefficients of Some Disks and Rings.

Low temperature coefficient crystals obtained in this way are subject to the usual mounting difficulties, namely that the friction on the mounting considerably increases the decrement, and by an amount which may vary with time. A form of crystal is desired which can be mounted so that the parts vibrating at relatively large amplitude do not bear heavily on any portion of the mounting.

Further study of temperature coefficients showed that the rings remaining after the small disks had been cut from the larger one, shown in Fig. 1, have a temperature coefficient lower than disks of the same diameter and thickness. This is further illustrated in Fig. 3, which

[2] F. R. Lack, "Observations on Modes of Vibrations and Temperature Coefficients of Quartz Plates," Proc. I. R. E., 17, 1123; July, 1929.

gives the temperature coefficient of two disks and the four parts remaining after holes of different diameters had been trepanned in them.

It is possible to make ring-shaped crystals having negligible temperature coefficients in a considerable range of frequencies, and, since the ring shape permits of an improved method of mounting in which

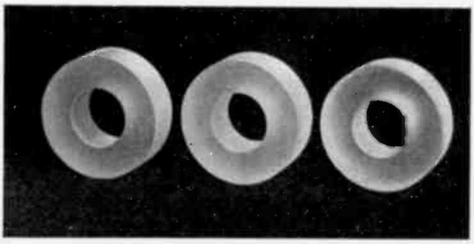

Fig. 4—Three 100,000-Cycle Low-Temperature Coefficient Rings used in Frequency Standard.

there is very little friction on the holder, they have been adopted for use in the present standard. Such a crystal having a frequency of 100,000 cycles is of substantial size and is reasonably easy to make and adjust. Three of the crystals used in the present standard, adjusted to 100,000 cycles, and having temperature coefficients less than one part in a million per degree C, are shown in Fig. 4.

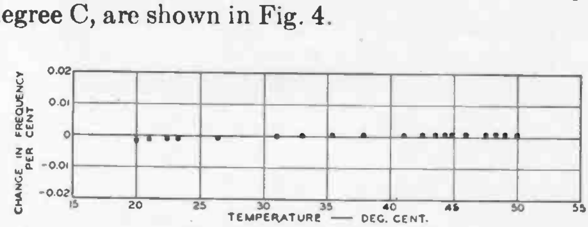

Fig. 5—Variation of Frequency with Temperature for a 100,000-Cycle Ring Crystal Adjusted for Low-Temperature Coefficient.

The variation of frequency with temperature for one of the ring-shaped crystals is given in Fig. 5, showing that it is very small over the usual room temperature range. All of the ring-shaped 100,000-cycle crystals made thus far are alike in having a coefficient which is small throughout this range[3]. The temperature coefficient of a disk of the same frequency having the same outside dimensions as the 100,000-cycle rings is approximately 30 parts in a million per degree C, more than thirty times that of the adjusted crystal.

[3] Where an accuracy of the order of only one part in 100,000 is desired, as in some portable standards, such a crystal could be employed without any form of temperature control.

The manner in which the ring-shaped crystals are mounted in their operating position is shown in Fig. 6. The hole is shaped so that when the crystal hangs on a horizontal cylinder the point of contact is at a theoretical node for mechanical vibration. There is evidence of slight vibration where the central plane intersects the double conical hole, but it is small in comparison with that obtained at the outer

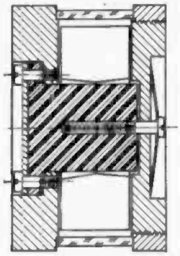

Fig. 6—Section of Crystal Mounting Showing Point Support.

surface where a crystal is usually supported. The decrement of the crystal when so mounted is considerably less than when it is supported on one of its plane surfaces.

In the mounting the crystal is spaced from the electrodes and is kept approximately central by means of paper spacers on each side. The crystal is free to move laterally in a narrow region but, since it is

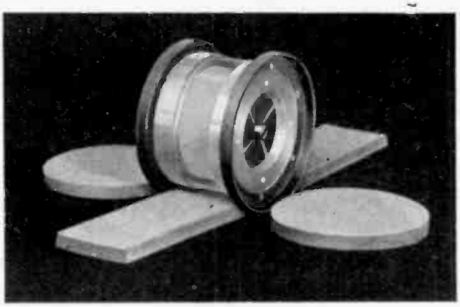

Fig. 7—Crystal Mounting with Crystal.

centrally located, the frequency is at a maximum value and hence a slight motion of the crystal to either side has only a second order effect on the frequency.

The variation of frequency with total electrode spacing is appreciable, but variations due to this factor are avoided by keeping the electrodes accurately spaced by means of a ring of pyrex glass. The temperature coefficient of pyrex is about one-quarter of that of crystal quartz perpendicular to the optic axis, so the variation in spacing that is obtained is due almost entirely to the expansion of the crystal. The effect on the frequency due to the differential thermal expansion of the crystal and crystal holder is, however, less than one part in 10^7 per degree C and so it may be neglected. If it is desired to eliminate this effect entirely, a spacer should be used having the same temperature coefficient of expansion as quartz perpendicular to the optic axis, but for practical purposes a material such as pyrex glass or fused quartz is entirely satisfactory.

The crystal holder is constructed so that a slight variation can be made in the total spacing between electrodes. Since the frequency varies with electrode spacing this can be used for making a slight ad-

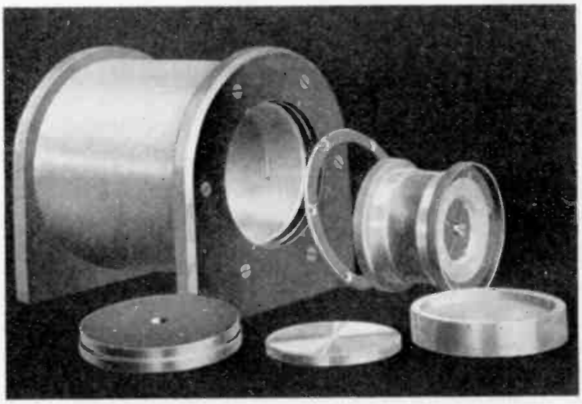

Fig. 8—Temperature Control Chamber with Crystal Mounting.

justment of frequency. The thread on the adjustable plate is kept tight by spring tension to prevent the spacing from varying irregularly. A crystal holder and a 100,000-cycle crystal are shown in Fig. 7.

Even though the crystal and its mounting have very low temperature coefficients, it is desirable to control their temperature, for which purpose the temperature controlling device shown in Fig. 8 has been constructed. It consists of a cylindrical aluminum shell with a wall about one inch thick, with a heater (not shown), and with a temperature responsive element in the wall to control the rate of heating. The aluminum shell has a metal plug that screws into the open end forming a chamber for the crystal which is then completely closed except for a small hole for electrical connections.

Since aluminum is a good thermal conductor the shell equalizes the temperature throughout the chamber and thus avoids the use of a fluid bath. The main heating coil is wound in a single layer over the whole curved surface of the aluminum cylinder, being separated from it only by the necessary electrical insulation. Auxiliary heating coils are wound also on the ends so as to distribute the heating as uniformly as possible. This, in effect, makes the short cylinder behave like a section from an infinite cylinder. To protect the thermostat from the effect of ambient temperature gradients the heating coil has an out-

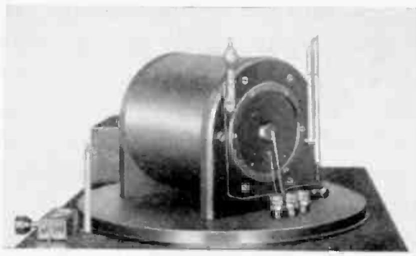

Fig. 9—Complete Temperature Control Unit.

side covering consisting of four layers each of thin felt and sheet copper spirally wound so that alternate layers are of copper and felt, the innermost layer being of felt and the outer one of copper. This is the covering that appears on the complete device shown in Fig. 9. This covering is very effective in reducing surface gradients since the conductivity in directions parallel to, and perpendicular to, the surface differ by a large ratio.

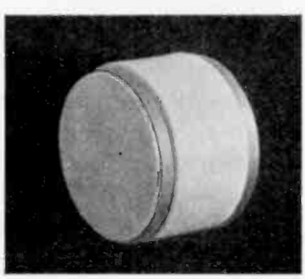

Fig. 10—Crystal Mounting with Felt Insulation.

The temperature of the shell rises and falls periodically by about 0.02 deg. C, but even this variation is prevented from reaching the crystal in its mounting by a layer of felt about half a centimeter thick surrounding the crystal holder. At the period of thermostat operation obtained the temperature variations actually reaching the crystal are reduced more than a thousand-fold. The complete temperature controlling device is shown mounted in its operating position in Fig. 9. One of the mounted crystals wrapped in its felt protecting layer is shown in Fig. 10.

To protect the resonator from humidity and pressure variations it is kept under a bell jar at a pressure slightly below atmospheric. With the crystals used the frequency varies approximately one part in a million for 10 cm of mercury change in pressure. It is aimed, therefore, to maintain the pressure constant to about ± 1 mm. A small mercury gauge within the bell jar indicates the pressure, which may be adjusted by a vacuum pump through a valve in the surface plate. The pressure within the bell jar is affected somewhat by the temperature, and in order to keep it within the required limits it is necessary to maintain a rough control of the temperature within the jar. The pressure gauge does not indicate a change in pressure due to a change in temperature, but will indicate any slow leak into the jar

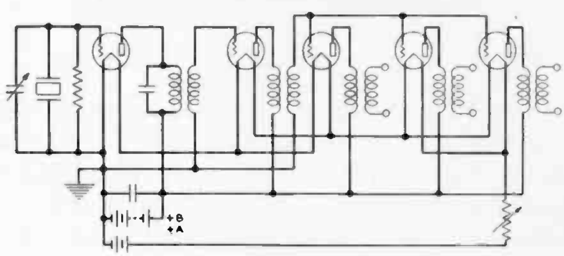

Fig. 11—Circuit of Standard Frequency Oscillator.

that may develop. A thermometer within the bell jar indicates the temperature, from which the change of pressure, and the correction of frequency due to it, may be computed if desired.

Since the frequency varies with the pressure surrounding the crystal an approximate adjustment of the frequency may be made conveniently by an adjustment of pressure.

The circuit of the crystal-controlled oscillator and the first amplifier stages is shown in Fig. 11. The oscillator is of the familiar type in which the crystal electrodes are connected to grid and ground and in which a tuned plate circuit is used. The great advantage in being able to ground one electrode was the major consideration in choosing this circuit. With this circuit, as in the one described a year ago,[1] it has been found possible to choose plate tuning elements such that slight variations in either the inductance or the capacity have little effect upon the frequency. For certain values of inductance and capacity the frequency, as a function of their product, takes on a maximum value. The adjustment that gives the maximum value of frequency is used, therefore, so that slight variations, such as those due to temperature coefficient and aging of the tuning elements, will have a negligible effect on the frequency.

The output circuit of the oscillator is very loosely coupled to three independent output amplifiers. This arrangement provides three independent output circuits free from mutual interference and unable to react to an appreciable extent on the crystal oscillator.

The final adjustment of frequency is made with a small cylindrical condenser, having a capacity of about 5 $\mu\mu$f, connected in parallel with the crystal electrodes. The size of this condenser is chosen such that

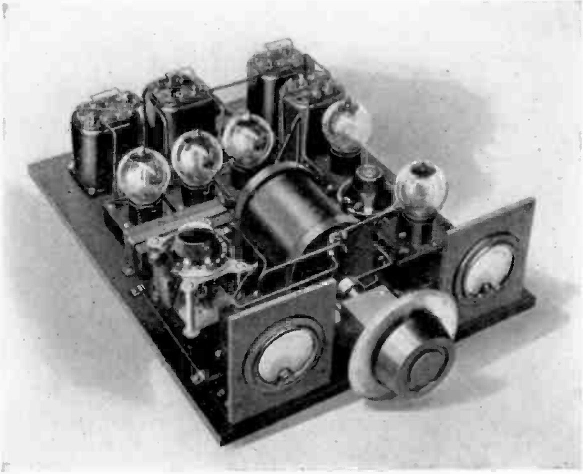

Fig. 12—Standard Frequency Oscillator without Shield.

an adjustment of one division on the dial corresponds to a change of frequency of about one part in a hundred million. There are 100 divisions on the dial and a total of 10 turns may be made corresponding to a total possible adjustment of about one part in 100,000. This condenser is shown at C in the circuit drawing.

The oscillator circuit, showing the tubes and transformers, the plate tuning elements, the filament and plate current meters, and the frequency adjusting condenser is shown in Fig. 12. The adjusting condenser is mounted between the meters and is controlled by the large knob and dial.

One complete oscillator unit, consisting of a 100,000-cycle crystal-controlled oscillator with three independent 100,000-cycle outputs, having a self-contained temperature and pressure controlled crystal, and having a temperature-controlled, electrically shielded circuit, is shown in Fig. 13.

The submultiple generator circuit that is used to obtain outputs at 10,000 cylces and 1000 cycles is shown in Fig. 14. It consists of an inherently unstable vacuum-tube oscillator with the tube operating on the curved part of its characteristic. The frequency of this oscillator may be controlled readily by any frequency which is a small multiple or submultiple of it. In this instance the oscillator is controlled by an input having the frequency of its tenth harmonic, the controlling high-frequency input being resistance coupled into the plate circuit of the lower frequency oscillator. The frequency of the controlled oscillator remains indefinitely at an exact submultiple of the controlling frequency.

Fig. 13—One Complete 100,000-Cycle Standard Frequency Unit.

Two such circuits are used, one to obtain current at 10,000 cycles and one for 1000 cycles. Of course, additional amplifier circuits are required in order to supply outputs of considerable magnitude at these frequencies, and in such a way that there can be no reaction on the controlling circuits due to load variations or to stray currents at other frequencies fed backward through the output circuits.

A 1000-cycle motor, operated by current controlled at the 100th submultiple of the standard, drives generators for producing current at 100 cycles and 10 cycles. There are available, therefore, frequencies in decade steps from 100,000 cycles to 10, all controlled by the 100,000-cycle primary oscillator.

The 1000-cycle motor is geared to a clock in such a way that, when the controlling frequency has its nominal value exactly, the clock keeps accurate time. In order to check the frequency of the system, therefore, it is only necessary to observe changes in rate of the clock so controlled.

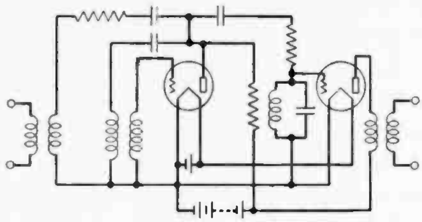

Fig. 14—Circuit of Sub-Multiple Generator.

An error of 0.864 second per day in the rate of the clock corresponds to an error in the frequency controlling it of one part in 100,000. It is possible to check the rate of the clock visually with an accuracy of about 0.2 second from audible time signals, but obviously this is not

Fig. 15—1000-Cycle Synchronous Motor, Generators, and Clock.

sufficiently accurate for our purpose, giving an accuracy of only about one part in 400,000 in a day's observation. In order to facilitate the comparison with time signals, a contact operated by a cam driven by the 1000-cycle synchronous motor makes a contact once each second, or to be exact, once for each 100,000 cycles of the primary oscillator.

This contact operates one element of a two-element recorder while time signals operate the other. Comparisons may thus be made by actual measurements on tape and can be made with greater accuracy than can be judged by eye.

The 1000-cycle synchronous motor, with its two generators and induction starting motor geared to the clock, is shown in Fig. 15. In this figure the seconds contact mechanism may be seen on the vertical shaft intermediate between the shaft of the motor and the second-hand shaft of the clock.

The assembled rotor of this motor is shown in Fig. 16. The large disk is the 1000-cycle motor rotor. The disk below it is a hollow steel flywheel filled with mercury used to reduce hunting. The small rotor below the flywheel is the rotor of the unipolar 10-cycle generator. The disk above the motor rotor is the armature of the 100-cycle generator. The squirrel cage armature of an induction motor for starting is immediately above the 100-cycle generator rotor.

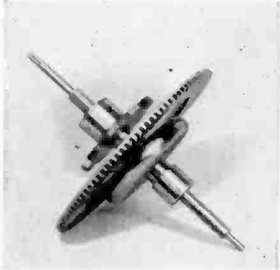

Fig. 16—Rotor of Motor Generator.

A single constant frequency generator is no longer sufficiently reliable as a standard of frequency of high precision and, as has been the practice where accurate time standards are maintained, three similar units have been installed. Means are provided for interchecking them continuously and automatically with the highest precision justified. The use of three such generators with means for interchecking them makes it possible to determine very quickly if and when one generator fails to operate properly.

Only one submultiple generator, clock, and multiple output amplifier is provided, but a special 3-way switch is used by means of which any one of the three primary oscillators may be selected and used as the controlling unit. The oscillators may be interchanged in any order without interrupting the circuits controlled by them.

In the method used for automatic interchecking a fourth oscillator unit is used, identical with the other three except that the frequency is maintained at a slightly different value. The difference between the frequency of this oscillator and that of the other three is kept at about 1 cycle in 10 seconds. The number of beats between the fourth oscillator and each of the other three oscillators is recorded automatically during each 1,000-second interval. The number of beats thus recorded is approximately 100 during each interval.

In 1,000 seconds each oscillator generates approximately one hundred million waves. The numbers that are recorded are, therefore, the number of parts in one hundred million by which oscillator No. 4 differs from each of the three primary oscillators during the interval. If the numbers recorded during successive intervals remain the same, the oscillators either did not vary, or they all varied in the same direction by the same number of cycles. If the numbers recorded in successive intervals vary by say 1, 2 or 5, it means that the oscillators have drifted, relative to each other, by so many parts in one hundred million.

Designating the frequencies of the four oscillators by

$$f_1,\ f_2,\ f_3,\ f_4 \tag{1}$$

the three numbers recorded are

$$1000(f_4-f_1),\quad 1000(f_4-f_2),\quad 1000(f_4-f_3). \tag{2}$$

The mean of these numbers is

$$1000\left(f_4-\frac{f_1+f_2+f_3}{3}\right). \tag{3}$$

If we subtract each of the original three recorded numbers from the mean we obtain

$$1000\left(f_1-\frac{f_1+f_2+f_3}{3}\right)=\delta_1 \tag{4}$$

$$1000\left(f_2-\frac{f_1+f_2+f_3}{3}\right)=\delta_2 \tag{5}$$

$$1000\left(f_3-\frac{f_1+f_2+f_3}{3}\right)=\delta_3 \tag{6}$$

Thus we may compute readily the performance of each of the four oscillators referred to the mean of the three similar primary oscillators. It is obvious that the accuracy of intercomparison of the three similar oscillators does not in any way depend upon the constancy of oscillator No. 4. For convenience in reducing the results, however, it is controlled as carefully as the others.

The records and computed results for approximately ten hours are given in Table I. During this time the largest relative variation between any two of the four oscillators taken in pairs was 5 parts in 10^8. The random variations between 1000-second periods appear to be in

TABLE I

A Ten-Hour Record Obtained by Means of the Beat Recorder

The columns δ_1, δ_2, and δ_3 indicate the difference between each oscillator and the mean of the three during each 1000-second interval expressed in parts in one hundred million.

Serial	Mean	(f_4-f_3)	δ_3	(f_4-f_2)	δ_2	(f_4-f_1)	δ_1
45	86	92	+6	98	+12	69	−17
44	86	92	+6	98	+12	68	−18
43	87	92	+5	99	+12	69	−18
42	87	93	+6	99	+12	70	−17
41	86	92	+6	99	+13	68	−18
40	87	94	+7	98	+11	68	−19
39	86	93	+7	99	+13	67	−19
38	87	94	+7	99	+12	67	−20
37	86	93	+7	99	+13	67	−19
36	87	95	+8	99	+12	66	−21
35	86	93	+7	98	+12	67	−19
34	87	95	+8	100	+13	66	−21
33	87	94	+7	100	+13	66	−21
32	87	95	+8	101	+13	66	−21
31	87	95	+8	101	+14	65	−22
30	87	94	+7	101	+14	66	−21
29	87	94	+7	101	+14	65	−22
28	87	95	+8	101	+14	66	−21
27	87	94	+7	102	+15	65	−22
26	87	95	+8	101	+14	66	−21
25	88	94	+6	103	+15	66	−22
24	88	94	+6	103	+15	68	−20
23	89	96	+7	103	+14	68	−21
22	89	95	+6	103	+14	68	−21
21	89	95	+6	103	+14	68	−21
20	90	95	+5	105	+15	69	−21
19	89	95	+6	103	+14	69	−20
18	89	95	+6	104	+15	68	−21
17	88	94	+6	102	+14	68	−20
16	89	95	+6	104	+15	69	−20
15	89	95	+6	102	+13	69	−20
14	89	95	+6	103	+14	69	−20
13	89	95	+6	102	+13	69	−20
12	89	94	+5	103	+14	70	−19
11	89	95	+6	103	+14	69	−20
10	90	95	+5	103	+13	71	−19
9	89	95	+6	103	+14	70	−19
8	89	95	+6	103	+14	69	−20
7	89	94	+5	103	+14	70	−19

the order of one or two parts in a hundred million. These random variations are superposed on slow drifts of a quasi-periodic nature probably caused by temperature changes in the circuit and amounting to less than one part in ten million. In addition to these effects a slow, steady drift is expected due to a settling-down of the oscillator circuit and the crystal in its mounting as well as due to aging of the vacuum tubes and even of the crystal itself. The effects of aging can, of course, only be determined after long continued operation.

It is preferable in some cases to refer the performance of each of the four oscillators to the mean performance of all four. This is in the event that all four oscillators are equally reliable, in which case the mean of all four makes a better reference standard than the mean of any three. If we designate the numbers

$$1000(f_4-f_1), \quad 1000(f_4-f_2), \quad \text{and} \quad 1000(f_4-f_3)$$

by a, b, and c, respectively, it can be shown readily that the numbers

$$a-\frac{a+b+c}{4}, \quad b-\frac{a+b+c}{4}, \quad c-\frac{a+b+c}{4} \quad \text{and} \quad -\frac{a+b+c}{4} \tag{7}$$

represent the difference between each of the oscillators Nos. 1, 2, 3, and 4, respectively, and the mean of all four, expressed in parts, in

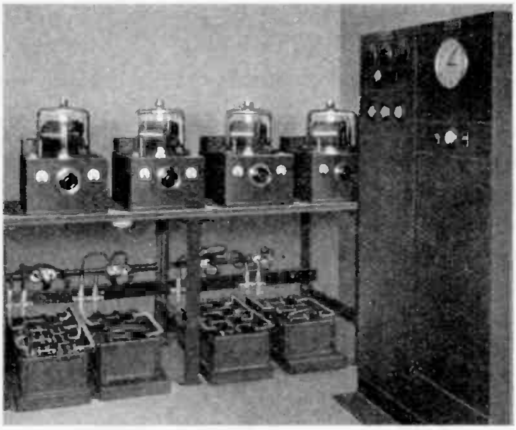

Fig. 17—Four 100,000-Cycle Oscillators With Auxiliary Equipment.

one hundred million. This method treats all four oscillators symmetrically. The symmetry is evident if we substitute in (7) the values (2) assigned to a, b, and c, whence we get:

$$a-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_1\right) \tag{8}$$

$$b-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_2\right) \tag{9}$$

$$c-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_3\right) \tag{10}$$

$$-\frac{a+b+c}{4}=1000\left(\frac{f_1+f_2+f_3+f_4}{4}-f_4\right). \tag{11}$$

The four oscillators used in the equipment described are shown in Fig. 17. The panels on which the controlling and measuring circuits are mounted are at the right of the picture. The 1000-cycle motor-driven clock is at the top of the nearest panel. A schematic of the apparatus showing the general arrangement of parts is given in Fig. 18.

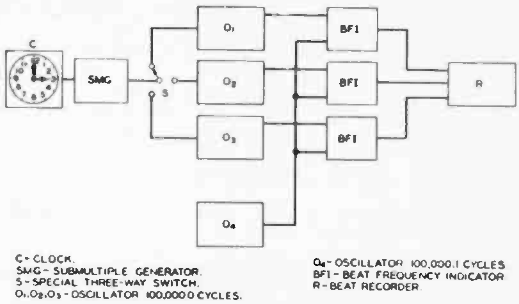

Fig. 18—Schematic of Complete Frequency Standard System.

The circuit of one element of the modulator for producing low-frequency beats is shown in Fig. 19. The input circuits *A* and *B* are supplied from oscillator No. 4 and one of the other three, respectively. The plate circuit includes the windings of a balanced relay which makes a contact once for each cycle difference between the input frequencies at *A* and *B* and which operates the recording mechanism accordingly.

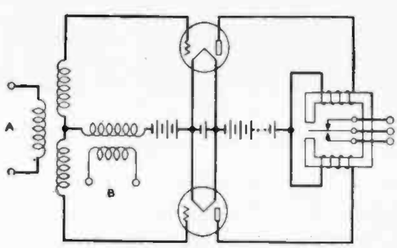

Fig. 19—Balanced Modulator of Beat Frequency Indicator.

The beat recorder is a counter arranged to count these relay operations for a definite time interval, in this case for 1000 seconds, and then to print the total and reset to zero. Five such units are provided which print on a wide strip of paper similar to that used in an adding machine. Three of the counters are used as outlined above. The fourth counter is to be used for recording the mean of these three numbers, computed automatically by an auxiliary device. The remaining one is a serial counter which is used to record the time, either directly or by numbering the 1000-second intervals consecutively.

The five-element counter is shown in Fig. 20 with the cover removed to show part of the mechanism. The energy for actuating the counting and resetting mechanism is obtained from a small motor run-

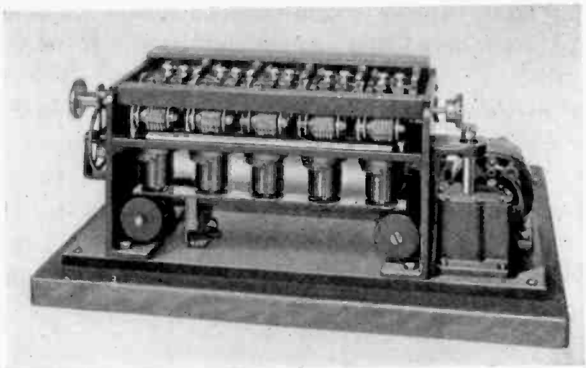

Fig. 20—Automatic Beat Counter.

ning continuously. These elements are operated at the proper times by clutches controlled by electromagnets which are selected by the relays in the modulator circuits described above. The counting, printing, and resetting operations are interlocked by means of cams and relays so

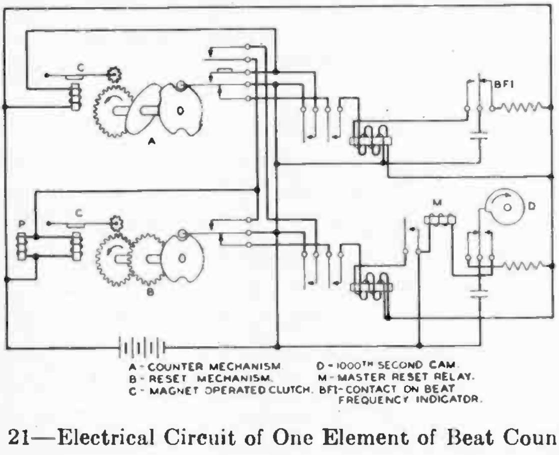

Fig. 21—Electrical Circuit of One Element of Beat Counter.

that no counts may be missed through superposition of operations. The electrical circuit of one unit of the recorder is shown in Fig. 21.

The 1000-second intervals are determined by a cam operated by the 1000-cycle synchronous motor. It might be questioned whether one of the crystals being checked should be used to determine the 1000-

second intervals. No serious error arises from this, however, since the percentage variation in the interval due to a change in rate of the crystal is only one millionth of the percentage variation in the recorded beat number. Thus, using one crystal to determine the intervals, used in comparing its rate with other crystals, makes the final measurement subject to an error from this cause of only about 0.0001 per cent.

In order to determine extremely small relative variations in frequency between two oscillators a method of measurement is used in which the duration of individual beats between two oscillators may be measured with an accuracy of about one part in 10,000. This is equivalent to saying that the average beat frequency during each 10-second interval is measured with an accuracy of one part in ten thousand. Since the percentage error in the beat frequency is one

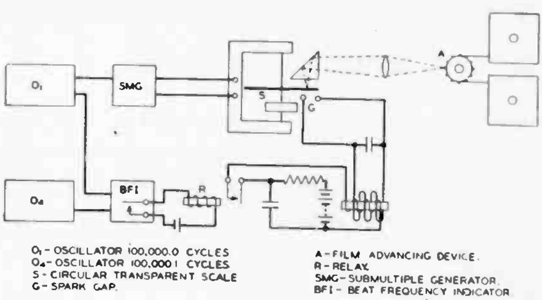

Fig. 22—Circuit of Device for Determining Beat Periods Accurately.

million times greater than the percentage error in the primary frequency, to measure the beat frequency with an accuracy of one part in ten thousand is equivalent to intercomparing the primary frequencies with a precision of one part in ten thousand million. By such a precise method of measurement a great deal can be learned about the nature of the variations that do occur.

The circuit of this device is shown in Fig. 22. Fig. 23 is a photograph of the actual apparatus used in obtaining the data given in Fig. 24. A circular transparent scale *S*, having 100 numbered divisions, is driven at 10 revolutions per second by a 1000-cycle synchronous motor controlled by one of the crystals. A modulator operates the balanced relay at the difference frequency between the crystal-controlled oscillators. This relay discharges condenser C_1 through the primary in an induction coil, which discharge produces a spark across the gap below the circular scale. The portion of the scale illuminated by the spark is photographed on slowly moving film at *A*. In this manner, assuming a beat frequency of 0.1 cycle per second, 360 checks per hour may be obtained with practically no supervision.

If the sparks occur at exactly an even number of revolutions of the motor apart, the same portion of the scale will be photographed

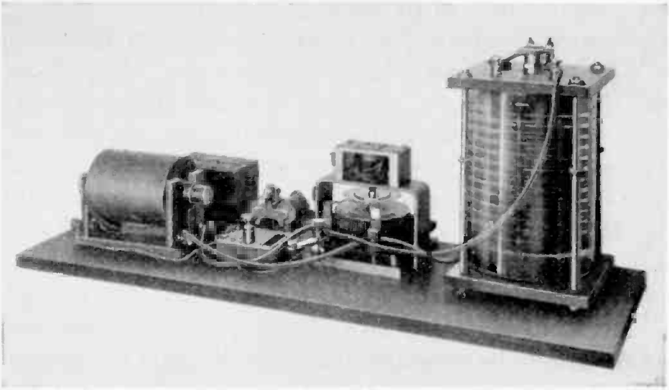

Fig. 23—Apparatus Used for Measuring Beat Periods.

by each spark. If the intervals differ from such a value by 0.001 second, the successive photographic images will differ by one scale division. Thus, the length of the beat periods may be read directly from the photographic records with an accuracy of 0.001 second, which

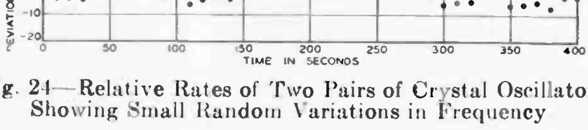

Fig. 24—Relative Rates of Two Pairs of Crystal Oscillators Showing Small Random Variations in Frequency

determines the length of the 10-second periods with an accuracy of one part in ten thousand. Thus a variation of one division on the photographic record corresponds to a relative variation of one part in ten billion between the two frequencies, compared during an interval only ten seconds long. The whole number of revolutions of the scale may be determined readily by auxiliary means.

The two graphs in Fig. 24 show typical variations between two crystal oscillators operating under rather unfavorable conditions. One crystal was not in its sealed bell jar and one circuit was only partially shielded and was exposed to draughts of varying temperature. Even under these conditions, however, the variations from the mean did not exceed one part in 10^8 during the test.

The checking methods just described are intended primarily to indicate more or less rapid changes in frequency. Slow changes, and, of course, the absolute rate, can best be determined in terms of standard time. This is done, as previously indicated, by checking the rate of a clock controlled by one of the crystals against radio time signals. Unfortunately no long checks have been obtained as yet in this way, but several tests made over periods of a few days indicate a constancy of rate in the order of 0.01 second a day.

The measurements made so far indicate that the frequency of a crystal-controlled oscillator such as described when suitably controlled, may be expected to be constant to at least one part in 10^7 over periods of seconds or over periods of days. It is hoped that it will be possible in the near future to present accumulated data on the performance of the frequency standard system described.

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OBSERVATIONS ON MODES OF VIBRATION AND TEMPERATURE COEFFICIENTS OF QUARTZ CRYSTAL PLATES*

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Summary—*The characteristics of piezo-electric quartz crystal plates of the perpendicular or Curie cut are compared with parallel or 30-deg. cut plates with reference to the type of vibration of the most active modes, the frequency of these modes as a function of the dimensions, and the magnitude and sign of the temperature coefficients of these frequencies.*

It is pointed out that the two principle modes of the perpendicular cut plate appear to be of the longitudinal type, the high-frequency mode being a function of the thickness while the low-frequency is a function of the width (along the electric axis). Both modes have a negative temperature coefficient of frequency. Of the two corresponding modes of the parallel cut plates, a shear vibration is responsible for the high frequency. This frequency has a positive temperature coefficient. The low-frequency mode is of the longitudinal type and has a negative temperature coefficient.

Considering only the high-frequency vibration of these plates it is observed that there are characteristic variations of the frequency and temperature coefficient with the ratio of dimensions of the plate and the temperature, which are peculiar to the parallel cut plate. These variations can be attributed to a coupling of the shear and longitudinal modes.

It is then shown that if the parallel cut plate be treated as a group of coupled oscillatory systems with appropriate temperature coefficients the usual coupled system analysis will explain the curves of frequency vs. dimensional ratio, frequency vs. temperature, and temperature coefficient vs. dimensional ratio that are characteristic of this plate. This analysis offers an explanation of the low temperature coefficients which can be produced by a proper choice of the dimensional ratios.

WITH the increasing demands of the radio industry for a high degree of carrier frequency stability, considerable attention has been focused recently on the piezo-electric quartz crystal as a circuit element in frequency generating systems. The low damping of these mechanical oscillators, combined with their piezo-electric properties, makes them particularly suitable for frequency control where a high degree of constancy is required. The frequency stability of the quartz plates prepared in the usual manner is, however, often not sufficient for many of the demands for constant frequency. For instance such a crystal plate does not compare favorably as a substandard of frequency with a good astronomical clock. To meet the demands for frequency sub-standards as well as many other practical

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problems concerning frequency generation in the communication art, it becomes necessary to devise methods for improving the frequency stability of these crystal systems. This involves a study of the many factors upon which this stability depends.

A crystal plate constitutes an extremely complex vibration system with a large number of degrees of freedom which are for the most part combinations of certain fundamental types of vibration. The ultimate frequency stability attained with a given crystal-controlled frequency generator is then a function of the equivalent electrical characteristics of the combination vibration set up in the crystal plate as well as the constants of the rest of the generator circuit. In particular the frequency change in a crystal oscillator with changes in tube constants or attached load is a function of the equivalent electrical decrement of the vibration which the crystal happens to be executing. Further, the temperature coefficient of frequency of the crystal oscillator depends largely upon the temperature coefficient of frequency of the crystal vibration, which in turn depends upon the change with temperature of the various mechanical elastic constants that are called into play by this vibration.

The general relation between stress and strain, which in an ordinary isotropic medium involves only two constants, in crystal quartz requires six.[1] The choice of a particular constant or constants that enter into a given mode of vibration depends upon the orientation of the plate with respect to the original crystal axes, and the particular type of vibration, whether longitudinal, torsional, etc.

It is to be expected, therefore, that there will be a variation among the characteristics of the modes of vibration of plates cut in a different fashion, as well as between the different modes of a given plate. In practice we have found considerable difference in the magnitude of the electric and electro-thermal constant, between the various modes of vibration of a given crystal plate, even when the vibration frequencies are within a few hundred cycles of each other.

To secure uniformity of results with respect to frequency stability it becomes necessary, therefore, to study the various possible modes of vibration of these crystal plates in detail, and set up certain criteria by which it will be possible to produce plates that will vibrate in a definite mode whose characteristics are known.

The theoretical aspects of this problem offer considerable difficulty, for it will be remembered that the classical case of the vibrations of an isotropic plate whose edges are free has as yet only been solved

[1] Voigt's "Kristallphysik," pp. 749–755, or Love's "Mathematical Theory of Elasticity," Chap. VI.

approximately[2] and with the extension of the theory made necessary by the crystalline nature of quartz, the complexity of the problem is considerably increased, with the possibility of a complete solution very remote.

Using long rods or bars of crystal, instead of plates, other investigators[3] have been able to set up the three types of vibration (longitudinal, flexural, and torsional) common to isotropic bars. Moreover, the formulas for these vibrations in isotropic material can be used to determine the frequency of the quartz rods to a good first approximation.

Returning to the problem of the plate, if the experimentally determined facts concerning plates of certain definite orientations are examined, it will be seen that they suggest the treatment of the plate as a special case of a bar. A résumé of these facts will illustrate this point and at the same time indicate the effect of orientation on the character of the modes of vibration.

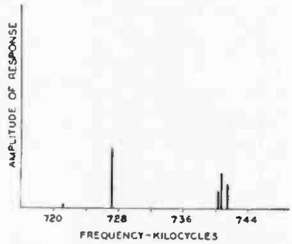

Fig. 1—Showing the response frequencies of 32×47×2.760 mm parallel-cut crystal plate in the region of the major high frequency.

In general, a quartz crystal plate cut with any orientation with respect to the crystal axes will respond to a large number of frequencies. A plot of these frequencies showing their spacing and the relative magnitudes of response[4] may be termed the frequency spectrum of the plate. Fig. 1 shows part of the high-frequency region of such a spectrum. In these frequency spectra there are usually one or more frequencies at which the crystal will react with sufficient voltage to drive a vacuum tube in the usual crystal oscillator circuit.

The relation between these major response frequencies and the dimensions of the plate for the two principal orientations can be outlined as follows:

[2] Rayleigh, "Theory of Sound," Chap. X and X$_A$.
[3] Cady, Proc. I. R. E. 10, 83; April, 1922.
Harrison, Proc. I. R. E. 15, 1040; December, 1927.
Giebe, *Zs. f. Phys.*, 46, 607, 1928.
[4] The amplitude of response in this case is the maximum amplitude of current through the crystal at constant voltage which in turn is a measure of the equivalent series resonant impedance of the crystal system.

Curie or Perpendicular Cut

When the crystal plate is so cut that its major surfaces are parallel to the optic axis and perpendicular to an electric axis (the Curie or perpendicular cut, see Fig. 2) there are two principal response frequencies, one high and one low.[5] The high frequency is a function of the thickness of the plate and to a good approximation is given by the expression

$$f=\frac{K}{t} \tag{1}$$

where t is the thickness in millimeters and $K=2.860\times10^6$.

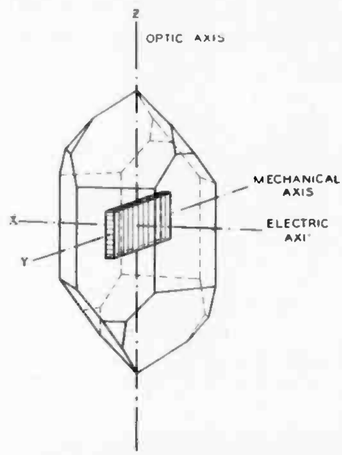

Fig. 2—Showing the orientation of a perpendicular or Curie-cut plate with respect to the crystal axes.

If the plate could be considered as a bar of length t then the frequency of a simple longitudinal vibration would be given by the expression

$$f=\frac{1}{2t}\sqrt{\frac{E_{xy}}{d}} \tag{2}$$

where E_{xy} is Young's Modulus in the X-Y plane and d is the density. If the numerical values[6] of E_{xy} and d are substituted in the above expression it is found that the same value for K is obtained as that of (1).

[5] For this discussion the low-frequency flexural vibration of the type described by Harrison will not be considered.

[6] For numerical values of the elastic constants and the density of quartz see Sosman, "The Properties of Silica," the American Chemical Society Monograph Series, 1928.

The low frequency is a function of the width, the dimension parallel to the Y axis, and is given by the same expression as (1) with the same value of K, the width in millimeters being substituted for the thickness.

For this type of crystal plate there are then two possible major modes which appear to be of the longitudinal type and depend upon the same elastic constant. (Young's modulus in the X-Y or equatorial plane has the same magnitude in any direction.)

The temperature coefficient of both these frequencies is negative which is in agreement with the temperature coefficient of Young's modulus for the equatorial plane.[7]

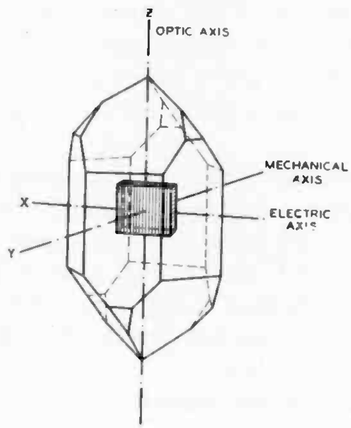

Fig. 3—Showing the orientation of a parallel or 30-deg. cut plate with respect to the crystal axes.

The Parallel or 30-degree Cut

When the crystal plate is so cut that its major surfaces are parallel to both the optic and electric axes (the parallel or 30-deg. cut, see Fig. 3) this 30-deg. shift in orientation from the perpendicular changes the characteristics in some important respects. As before there is a high and a low principal frequency, but in this case the high frequency sometimes occurs as a doublet (two response frequencies a kilocycle or so apart).

For thin plates of large area the high frequency is a function of the thickness of the plate, and is given by the approximate expression

$$f = \frac{K}{t} \tag{3}$$

[7] Perrier and Mandrot, Mem. Soc. Vaudoise Sci. Nat. (1923) 1, 333–364.

where t is the thickness in millimeters
and K is now 1.96×10^6.
It will be noted that this constant differs from that found in the case of the perpendicular cut crystal. Moreover, the temperature coefficient of this frequency is positive.

These facts lead one to believe that this is not a simple longitudinal vibration. Cady[8] has pointed out that if it be considered as a shear vibration in the X-Y plane the frequency can be calculated using the appropriate shear modulus.[9]

The low frequency is a function of the width, the dimension parallel to the electric or X axis, and is given by the same expression and constant as the frequencies of the perpendicular cut plate. It has the same characteristic negative temperature coefficient.

For these parallel cut plates there are then two possible major modes which, however, differ in type of vibration and sign of temperature coefficient.

Limiting this discussion to the high-frequency region, it is seen that these parallel and perpendicular cut plates have different frequency-thickness constants and temperature coefficients of opposite sign. On closer examination it is found that there is an additional difference which involves the variation of the magnitudes of these frequency thickness constants and temperature coefficients with the ratio of width to thickness of the plate.

For the perpendicular cut plate the frequency-thickness constant changes but little with the size of the crystal. The same is true for the temperature coefficient, and from recent measurements on a number of sizes of plates the magnitude of this coefficient lies between minus 20 and minus 35 cycles in a million per degree centigrade.

The parallel cut plate, on the other hand, has a frequency thickness constant which for any but thin plates of large area varies considerably with the width. The temperature coefficient also varies with the width, and is in addition a function of the temperature. This coefficient has a wide range of values whose limits are approximately plus 100 cycles in a million per degree centigrade and minus 20 cycles in some special instances, with all possible intermediate values including zero. Then, as has been mentioned before, these parallel cut crystals frequently have two high-frequency modes of vibration within a kilocycle or so of each other and will start on either of these modes if the circuit con-

[8] W. G. Cady, *Phys. Rev.*, 29, 617, 1927.

[9] If it could be shown that the shear modulus of this plane had a positive temperature coefficient it would substantiate this assumption, but there is no information at present available regarding the effect of temperature on the elastic constants other than for the two values of Young's modulus.

stants are changed slightly. These two modes usually have widely different characteristics.

Apart from this seemingly erratic variation it has been the experience of this laboratory that the parallel cut crystal will oscillate more readily in the Pierce type of oscillator circuit. For this reason this type of crystal has been used for a number of purposes and these observed variations have been the object of considerable study.

As a result of this work an explanation has been evolved to account for these variations. This explanation not only suggests reasons for the above mentioned phenomena, but what is more important, it indicates the procedure by which it is actually possible to produce crystals having negligible temperature coefficients. Before outlining this theory the experimental facts which served as its foundation will be discussed in detail.

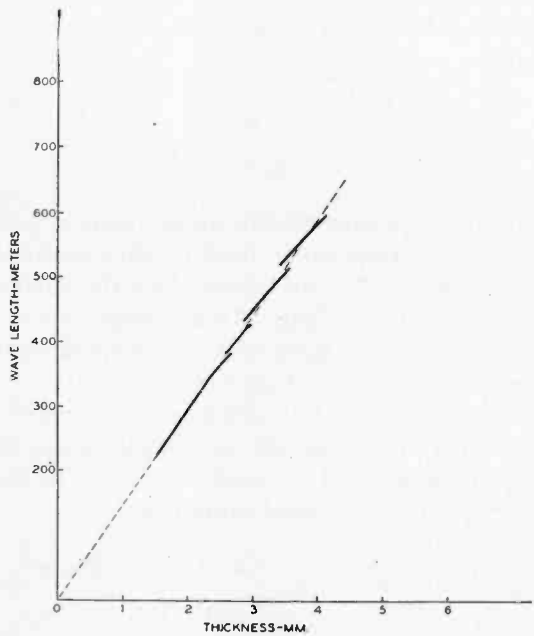

Fig. 4—The wavelength at which a 2.5-cm square parallel-cut crystal plate will operate, in an oscillator circuit, as its thickness is progressively reduced.

Frequency-Thickness Constant as a Function of Dimensions

When work on the production of parallel cut crystals in the broadcast frequency band was first started, it was found that it was very difficult to grind crystals for certain low frequencies using a 2.5-cm square plate because of discrete jumps in frequency for a small reduction of thickness. Fig. 4 is a typical curve showing the wavelength[10] as a function of the thickness for a 2.5-cm square crystal. This curve should be a straight line (for from equation (3) it is evident that $\lambda = K't$) but it will be noted that there are certain discontinuities at the upper end. It was found that these discontinuities were present at frequencies that could be identified with harmonics of the frequency which the crystal would have if it were vibrating in the direction of its length along the electric axis.

This was the first definite indication obtained in these laboratories that the longitudinal vibration of the crystal in the direction transverse to the applied field could affect the frequency supposed to depend only on the thickness. It was checked by further work on crystals of other dimensions, and in each case the position of these discontinuities was found to depend on the width of the crystal.

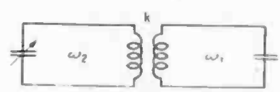

Fig. 5

The presence of a resonant system whose frequency depends upon the width is evidently responsible for this phenomenon, this system affecting the frequency of the vibration along the thickness through some form of mechanical coupling. At the suggestion of R. A. Heising of the Bell Telephone Laboratories, an explanation of these experimental facts was developed based on the treatment of the plate as a system of coupled circuits.[11] Consider the two coupled oscillatory circuits shown in Fig. 5, having the uncoupled radian frequencies ω_1 and ω_2, then the frequencies of the coupled system in the absence of damping will be given by the usual expression[12]

$$\omega = \frac{\sqrt{\frac{1}{2}(\omega_1^2 + \omega_2^2) \pm \frac{1}{2}\sqrt{(\omega_1^2 - \omega_2^2) + 4k^2\omega_1^2\omega_2^2}}}{\sqrt{1-k^2}} \tag{4}$$

k being the coupling.

If these two frequencies be plotted as a function of the tuning of the second circuit, i.e., ω_2, the familiar set of curves shown in Fig. 6 results.

[10] In plotting the change in rate of vibration of a crystal plate as a function of the dimensions it is more convenient to use wavelength instead of frequency because of the direct linear relation between the dimensions and the wavelength.

[11] The term "circuit" is introduced here to describe a mechanical oscillatory system because many readers are accustomed to think in terms of electrical circuits.

[12] See Pierce, "Elec. Osc. and Waves," Chap. VII.

Suppose now other circuits are added to the system as shown in Fig. 7, each additional circuit being fixed at a harmonic of the uncoupled frequency of circuit No. 2, and so linked with this circuit mechanically that the group is tuned as a whole.

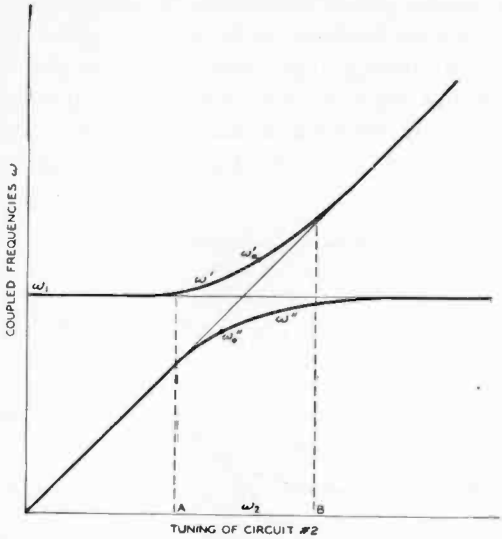

Fig. 6—Showing the radian frequencies of a system of two coupled circuits as a function of the tuning of one circuit, the tuning of the other circuit being fixed.

There are now two possible combinations depending upon which circuit or group of circuits is kept fixed while the other is varied. If the case in which the second group of circuits is kept fixed be examined first, it will be seen that as the frequency of circuit No. 1 is varied, it

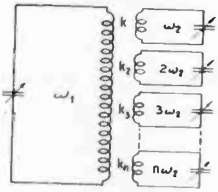

Fig. 7

will come into tune successively with each of the circuits of the second group. The result will be a series of coupling curves with the characteristic reaction illustrated by Fig. 6 repeated at each coincident point. If it be assumed that the coupling decreases as the order of the harmonic increases, then the magnitude of the reaction also decreases. This is illustrated by Fig. 8 which shows the coupling curves of such a system plotted in terms of the equivalent electrical wavelength.

Returning to the crystal plate, if the vibration in the direction of the thickness be identified with circuit No. 1 while the width vibration and its harmonics be identified with circuit group No. 2, then Fig. 8 should represent what happens to the crystal wavelength as the thickness is reduced. Comparing Figs. 4 and 8 it is seen that this is true in a restricted region but that the wavelengths which depend upon the width vibration do not continue much beyond the coupling region in the experimental curves. This is to be expected, for these wavelengths-

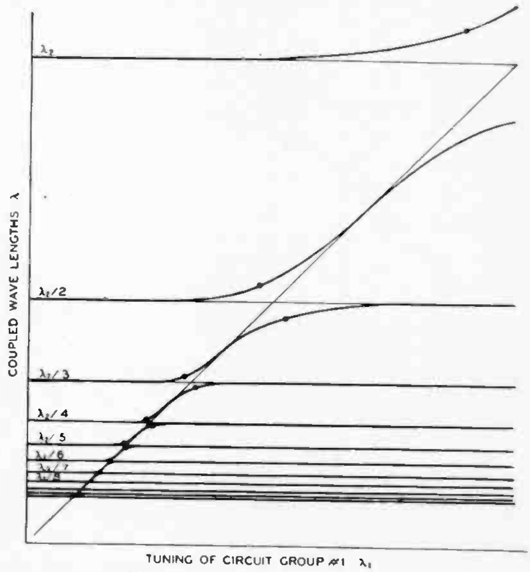

Fig. 8—Showing the wavelengths of the system of coupled circuits of Fig. 7 as a function of the tuning of circuit No. 1, the tuning of circuit group No. 2 being fixed.

which depend upon a harmonic of a vibration transverse to the ap, plied field, are more difficult to excite than the fundamental in the direction of the field. This particular point is discussed further in connection with temperature coefficients.

If now the case be examined in which the tuning of the second group of circuits is varied, it will be seen that the coupling curves are slightly different in character. The curves for this case are illustrated by Fig. 9, which shows the wavelengths of this system as a function of the tuning of circuit group No. 2. Fig. 10 shows the wavelengths at which a parallel cut plate will oscillate plotted as a function of the width. The similarity between this experimentally determined curve and Fig. 9 is at once apparent. There is one anomalous segment of a curve between the 7th and 8th harmonics, the line AB; but it is possible that this is caused by the coupling of some third free period which has not been considered, perhaps a high order harmonic of a flexural vibration. In general, however, the curves of wavelength versus width or wavelength versus thickness for these crystal plates are of such a character as to indicate that the analogy between the two systems of coupled circuits and the crystal modes of vibration is sufficiently good to serve as a useful guide.

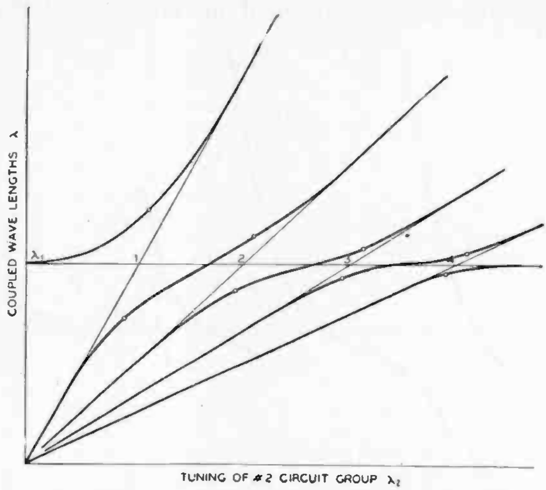

Fig. 9—Showing the wavelengths of the system of coupled circuits of Fig. 7 as a function of the tuning of circuit group No. 2, the tuning of circuit No. 1 being fixed.

If, then, these parallel cut crystal plates are considered as a system of coupled circuits the reason for the variation of the frequency thickness constant with dimensional ratios and the presence of the frequency doublets is at once apparent. With the coupling at the various harmonics determined, the character of these variations can be predicted. Given an experimentally determined series of coupling curves similar to Fig. 10, the coupling at the nth harmonic can be determined from the expression

$$k_n = \frac{\left(\frac{\lambda'}{\lambda''}\right)^2 - 1}{\left(\frac{\lambda'}{\lambda''}\right)^2 + 1} \tag{5}$$

where λ' and λ'' are the wavelengths of the coupled system at the point where $\lambda_1 = n\lambda_2$.

Temperature Coefficient as Function of Dimensions and Temperature

As mentioned above, when the temperature coefficients of these parallel cut crystals were studied it was found that there was considerable variation between plates having the same thickness but slightly different areas, and the temperature coefficient of a given plate was found to be a function of the temperature. To illustrate this last point a typical frequency-temperature curve for a parallel cut crystal is shown in Fig. 11. It will be noted that the frequency increase is linear until a given temperature is reached, at which point the curve flat-

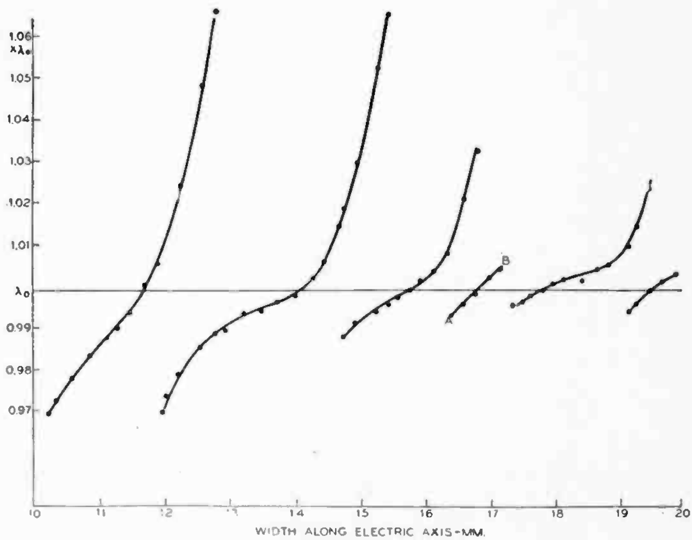

Fig. 10—The wavelengths at which a parallel-cut crystal will operate in an oscillator circuit as its width (the dimension along the electric axis) is progressively reduced. The other dimensions are fixed. $\lambda_0 = 153 \times$ thickness.
Thickness along mechanical axis = 1.64 mm
Length along optic axis = 54.8 mm

tens off and then begins to reverse. Just beyond the point of reversal the frequency jumps to a new value, and if the curve is continued the frequency increases again at the same rate as originally. This type of frequency-temperature curve is common to a large percentage of parallel cut crystals, the only difference being the width of the flat part of the curve and the temperature at which the discontinuity occurs.

W. A. Marrison of the Bell Telephone Laboratories first suggested that low temperature coefficients could be obtained with parallel cut crystals by utilizing the coupling of two modes of vibration having individual coefficients of opposite sign. Several of this type of low temperature coefficient crystal were produced by Marrison and are described in his concurrent paper, "A High Precision Standard of Frequency."

If Heising's coupled circuit analysis is extended to include the effect of temperature, and if the proper temperature coefficients with due regard to relative magnitude and sign are identified with each circuit, the change in temperature coefficient with dimensional ratio and

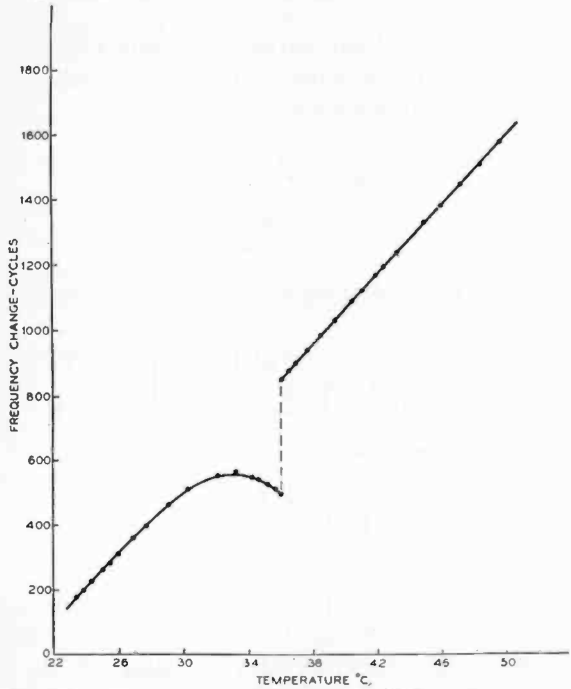

Fig. 11—The frequency change of a 32×47×2.760 mm parallel-cut crystal with temperature.

temperature can be explained. In addition, the relative value of the tuning of the oscillatory circuits or, in terms of the crystal plate, the dimensional ratios which yield zero temperature coefficients for a given temperature can be predicted if the coupling is known.

Referring again to Figs. 5 and 6, suppose the two coupled circuits have temperature coefficients of opposite sign, circuit No. 1 being positive and circuit No. 2 negative, then for ω_2 less than ω_1 say at the point A, Fig. 6. ω' has a positive and ω'' a negative temperature coefficient. For a value of ω_2 greater than ω_1 say at B, ω' now has a negative and ω'' a positive temperature coefficient, ω' and ω'' having interchanged roles. Somewhere between, therefore, both ω' and ω'' must have had a zero temperature coefficient. Returning to (4), if this expression for ω be differentiated with respect to the temperature, regarding k, the coupling, as constant, and the result placed equal to zero, the condition that ω is independent of temperature[13] is obtained as follows:

$$\omega^2 = \frac{\omega_1^2\omega_2^2(m-n)}{(m\omega_1^2 - n\omega_2^2)} \tag{6}$$

where $m = (1/\omega_1)(d\omega_1/dT)$ = temperature coefficient of circuit No. 1
$n = -(1/\omega_2)(d\omega_2/dT)$ = temperature coefficient of circuit No. 2.
Now let $Q = n/m$; then (6) becomes

$$\omega^2 = \omega_2^2 \frac{1-Q}{1-Q\left(\dfrac{\omega_2}{\omega_1}\right)^2} \tag{7}$$

Solving (7) for ω_2/ω_1 and replacing ω^2 by its value from (4) we obtain

$$\left(\frac{\omega_2}{\omega_1}\right)^2 = \frac{k^2(1-Q)^2}{2Q} + 1 \pm \sqrt{\left[\frac{k^2(1-Q)^2}{2Q}\right]^2 + \frac{k^2(1-Q)^2}{Q}}$$

which when k is small becomes

$$\left(\frac{\omega_2}{\omega_1}\right)^2 = 1 \pm \frac{k(1-Q)}{\sqrt{Q}} \cdot \tag{8}$$

This equation gives the tuning points, or the values of ω_2, at which the radian frequencies of the coupled system, ω' and ω'', will have zero temperature coefficients, in terms of the ratios of the uncoupled temperature coefficients and the coupling.

Referring again to Fig. 6, ω_0' and ω_0'' represent the values of ω' and ω'' which have zero temperature coefficient provided that m is greater than n, that is, the temperature coefficient of ω_1 is greater in magnitude than that of ω_2. Carrying this idea over to the case of the group of circuits for which the curves of Figs. 8 and 9 are drawn, there will be points of zero coefficient in the neighborhood of each coupling point as indicated by the circles on the curves.

The above conditions for zero temperature coefficient apply only if the coefficient as a function of the tuning be considered in the region of some given temperature. If the temperature is varied over a consider-

[13] F. B. Llewellyn of the Bell Telephone Laboratories is responsible for this analysis.

able range, a small change in the tuning of both circuits is effected, one having its frequency raised, the other lowered. The result of this tuning on the frequencies of the coupled system can be illustrated by Fig. 12, which shows the tuning with temperature on a magnified scale. In this figure the lines ω_1 and ω_2 represent the change in frequency of these circuits with temperature if there were no coupling between them. The change in the frequencies of the coupled system with temperature is shown by the curves ω' and ω''. It will be seen that both these frequencies pass through regions of zero temperature coefficient.

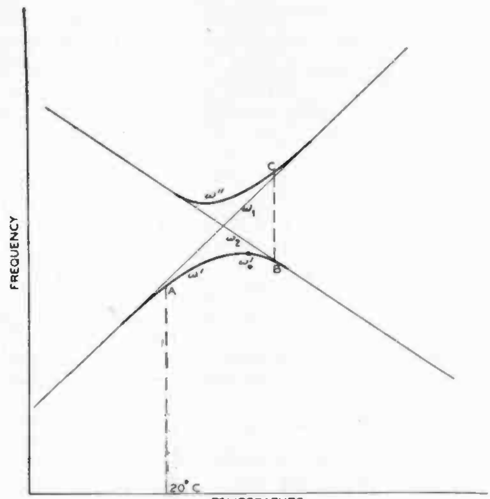

Fig. 12—Effect of temperature on the radian frequencies of a system of two coupled circuits having temperature coefficients of opposite sign.

Such frequency-temperature curves can be derived graphically by a construction similar to that shown in Fig. 13. This figure illustrates what happens when the tuning of both circuits No. 1 and No. 2 is varied, and consists of a series of the usual coupling curves (the coupled frequencies plotted as a function of ω_2) each set of curves of the series being drawn for a different value of ω_1. When the temperature is increased from T_1 to T_2 the uncoupled frequency of circuit No. 2 is reduced by an amount $\Delta\omega_2$ and the uncoupled frequency of circuit No. 1 is increased by an amount $\Delta\omega_1$. The result is that the frequencies ω' and ω'' move from curve to curve in the direction shown by the lines AB and CD.

If now the variation of the temperature coefficient of a crystal plate when used in an oscillator circuit be examined at a given temperature as the width is changed (which amounts to a change in the tuning of the transverse vibration) it will be seen that the experimental results are in accord with the above treatment. Fig. 14 shows the temperature coefficient of the two frequencies of a crystal plate at 58 deg. C as its width is progressively reduced in the neighborhood

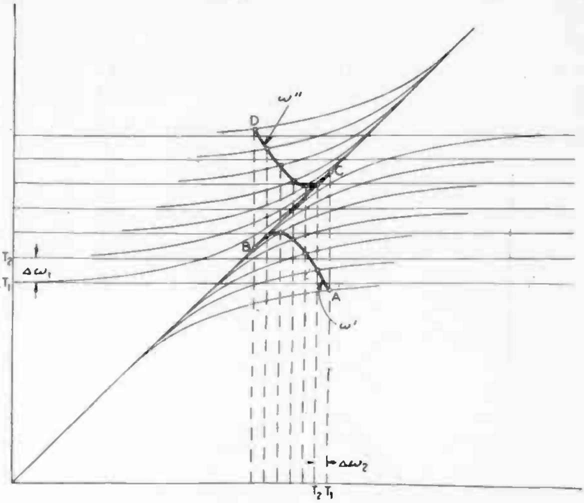

Fig. 13—Effect on the radian frequencies of a system of two coupled circuits as the individual circuits are tuned simultaneously in opposite directions.

of the 5th harmonic of the transverse vibration. These curves show how the temperature coefficients change sign in this region. The dotted sections of the curves are extrapolated, for owing to the rapid reduction in activity once a coupled frequency acquires a negative

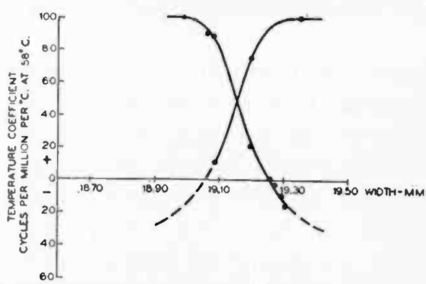

Fig. 14—The change of temperature coefficient of a parallel-cut crystal at 58 deg. C as the width is progressively reduced in the region where the fifth harmonic of the vibration in the direction of the width coincides with the frequency of the vibration in the direction of the thickness.

coefficient, data on the crystal plate used as an oscillator are difficult to obtain in this region.

Returning to the experimentally determined curve of frequency versus temperature for a parallel cut crystal plate shown in Fig. 11, this can also be explained with the aid of the above analysis. Referring to Fig. 12, if it be assumed that at 20 deg. C the crystal is oscillating with a frequency A, this is in the region where this particular frequency has a positive temperature coefficient. As the temperature increases the frequency increases in the direction of B, passing through a maximum at the point ω_0' where it has zero coefficient, and then decreases. As the frequency decreases the activity of this particular mode decreases rapidly and finally the crystal frequency hops to point

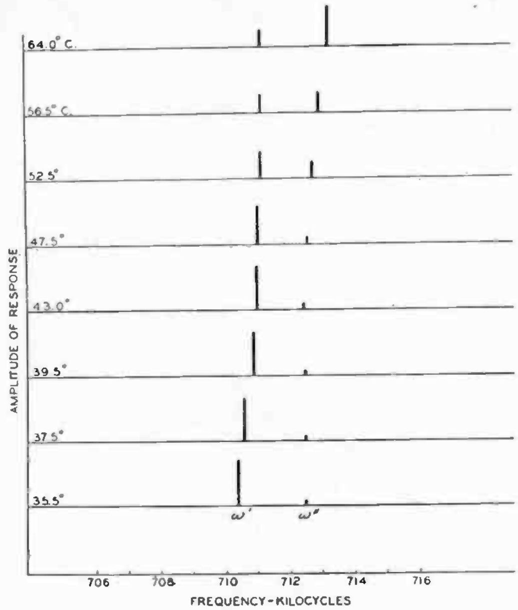

Fig. 15—The response frequency spectra of a parallel-cut crystal plate at different temperatures illustrating the interchange of activity between the two frequencies as the frequencies of the two modes of vibration pass through a coincident value.
Length of plate along optic (Z) axis = 47 mm
Width along electric (X) axis = 19.35 mm
Thickness along mechanical (Y) axis = 2.75 mm

C on the ω'' curve. From this point on the frequency increases with temperature, for this frequency has a positive temperature coefficient in this region.

If it were not for the decrease in activity of the period with the negative temperature coefficient it would be expected that the crystal frequency, instead of "hopping" would continue to decrease with increase in temperature. In some instances (for low order of harmonics) the crystal frequency will decrease for a few degrees, and it is found that the magnitude of the negative coefficient for this region approximates that to be expected for the transverse vibration alone. In general, however, a frequency jump occurs just after the zero temperature coefficient region is passed.

This interchange of activity of these two periods as they interchange temperature coefficients can be studied in detail by examining the changes in the spectrum of a crystal at different temperature levels. Fig. 15 shows a series of spectra of a crystal taken for different tem-

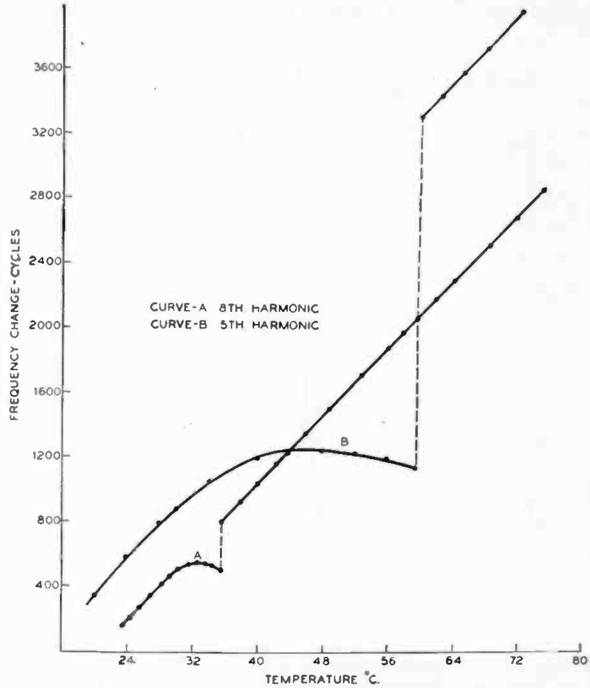

Fig. 16—The frequency change with temperature of two parallel-cut crystals of different width.
Curve *A* region of eighth harmonic (width = 32.0 mm)
Curve *B* region of fifth harmonic (width = 19.35 mm)
Both plates[14] have a length of 47 mm and a thickness of 2.75 mm.

peratures in the region of zero temperature ceofficient, the dimensions of the crystal being unchanged. These spectra illustrate the rapid decrease in activity of the frequency ω' after it passes through zero temperature coefficient while at the same time ω'' increases and assumes the place of major activity vacated by ω'.

[14] The information represented in Figs. 11, 14, and 16 was obtained from four different crystal plates of a group which were exactly similar with respect to orientation and original dimensions.

The assumption that the coupling increases with the decrease in the order of the harmonic finds confirmation in the experimentally determined facts as computed from curves of the type shown by Fig. 10. As the coupling increases the temperature range for which there is no frequency change with temperature increases, that is, the region of zero temperature coefficient becomes extended. To illustrate this, Fig. 16 shows two curves of frequency versus temperature, one for the coupling of a 5th harmonic, the other for an 8th.

It would, of course, be desirable to extend the zero temperature coefficient range over the limits of temperature to be expected in normal operation. This necessitates tight coupling of the two modes which in turn demands a dimensional ratio in the neighborhood of unity. The cross sectional area of such a plate in the direction of its thickness and width approaches a square in shape which, for high-frequency crystals, is of very small dimensions.

Before concluding it should be noticed that since both modes of the perpendicular cut crystals have a negative temperature coefficient it is to be expected that it would be impossible to obtain zero temperature coefficient crystals with this orientation. This seems to be true as far as our experience with those crystals is concerned.

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THE KYLE CONDENSER LOUD SPEAKER*

BY

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Summary—*By using the Kyle principle of construction, it has been possible to develop a practicable condenser loud speaker. The Kyle construction uses a flexible dielectric diaphragm in contact with the high points of a rigid, undulated metal plate. The electrodes of the condenser are the rigid plate and a flexible metal layer attached to the opposite surface of the dielectric. A comparatively large actuating force is thereby obtained and at the same time sufficient amplitude of motion is permitted to give efficient and faithful reproduction.*

I. INTRODUCTION

BY electrical means it is possible to produce a mechanical force in one of two ways, magnetically or electrostatically. In most practicable loud speakers up to a recent date only magnetic forces have been used. It has long been recognized that an electrostatic loud speaker is theoretically possible, but numerous attempts to design one have met with indifferent success. The fundamental difficulty seems to have been that in order to obtain sufficient attractive forces, electrode separations have had to be so small that the device was impracticable to construct, and that the small separations did not permit sufficient amplitude of motion.

However, a way of surmounting this difficulty has been shown by Colin Kyle[1] and a loud speaker has been designed on the Kyle principle which gives very satisfactory performance.

This paper will present some of the theoretical considerations involved in the design of the Kyle type of speaker, together with a brief discussion of the practical problems met with in its design and application.

II. THEORETICAL

a. Electrostatic Attraction in a Condenser.

Considering an electrical condenser formed by two flat parallel plates with the space between the plates partly filled by a slab of dielectric material of thickness t and dielectric constant K, and the remainder of the space filled by air, the force between the plates is given by

$$F = \frac{A V^2}{8\pi \{ h - t(1 - 1/)K \}^2} \qquad (1)$$

* Dewey decimal classification: R376.3. Original manuscript received by the Institute, April 9, 1929.

[1] U. S. Patent No. 1,644,387

where A = area of plates, V = potential difference between the plates, and h = distance between the plates.

As h approaches t, the force will approach F_1 which is given by

$$F_1 = \frac{AV^2K^2}{8\pi t^2}. \tag{2}$$

If the relationship between h and t is given by $h = nt$, (1) will reduce to (3)

$$F_n = F_1 \frac{1}{\{1+(n-1)K\}^2}. \tag{3}$$

In Fig. 1 is presented graphically the computations from (3) for three values of dielectric constant. The curves show that the force between the plates falls off very rapidly as the thickness of the air layer increases relatively to that of the dielectric slab.

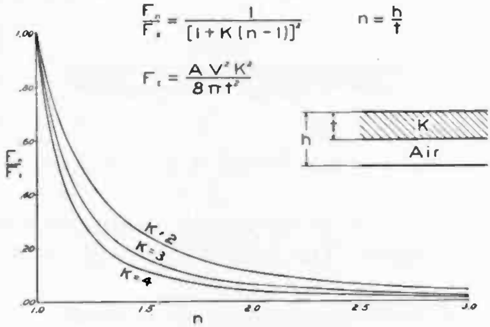

Fig. 1—Variation of Force between Condenser Plates with Relative Thickness of Air Film.

b. Action of Kyle Reproducer.

The Kyle reproducer is shown diagrammatically in Fig. 2. It consists essentially of a perforated metal back plate *a* having corrugations or other undulated surface, a flexible dielectric diaphragm *b* stretched over this back plate so as to bridge across the depressions, and a thin flexible conducting coating *c* cemented or otherwise secured to the surface of the diaphragm opposite the back plate.

As illustrated in Fig. 1, the attractive force is largely confined to a narrow zone adjacent to the contact point, and in this zone it may be comparatively large if the dielectric is thin and K is not too small.

As the diaphragm is attracted under the influence of the electrostatic force, the area of contact is increased and the diaphragm rolls down the slopes of the depressions. The air space is still wedge-shaped near the point of contact so the attracted area moves down the slope also. The reproducer owes its efficiency to the fact that we have this wedge-shaped air space which permits a large force to be exerted and at the same time allows a large amplitude to motion.

c. The Biasing Voltage.

As shown above, the attraction between the back plate and flexible diaphragm may be expressed in the form

$$F = MV^2 \tag{4}$$

where M is a constant and V is the potential difference between the plates. This is a law of force which is analogous to the law in the magnetic telephone receiver and the thermophone, and so it appears that a permanent biasing potential is required in the condenser speaker just as a permanent magnetic field is required in the magnetic receiver and as a d-c heating current is required in the thermophone.

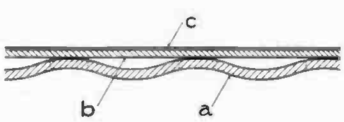

Fig. 2—Cross Section of Kyle Speaker.

To illustrate we shall take the case of an applied direct voltage and two alternating voltages. The force acting between the plates is then given by (5)

$$F = M(V_0 + V_1 \cos pt + V_2 \cos qt)^2 \tag{5}$$

V_0 being the direct voltage, V_1 and V_2 being the maximum values of the alternating voltages, p and q being their respective angular velocities. Expanding (5) we get,

$$\begin{aligned} F = {} & M(V_0^2 + \tfrac{1}{2}V_1^2 + \tfrac{1}{2}V_2^2) && \text{(a)} \\ & + M(\tfrac{1}{2}V_1^2 \cos 2pt + \tfrac{1}{2}V_2^2 \cos 2qt) && \text{(b)} \\ & + M(V_1V_2 \cos [p+q]t + V_1V_2 \cos [p-q]t) && \text{(c)} \\ & + M(2V_0V_1 \cos pt + 2V_0V_2 \cos qt). && \text{(d)} \end{aligned} \tag{6}$$

Part (a) represents a steady component of the force which draws the diaphragm away from its neutral position but does not contribute to the sound.

Part (b) represents alternating components of the force with frequencies double those of the impressed alternating voltages and which therefore introduce double frequency distortion into the sound.

Part (c) represents alternating components of the force with frequencies which consist of sums and differences of the incoming frequencies considered in pairs, and which introduce the corresponding distortion into the sound.

Part (d) represents the alternating components of the force which correspond to the impressed voltages and which produce the desired sound.

Consideration of the coefficients of the terms in (b) and (c) as compared with (d) shows that the predominance of the desired sound represented by (d) over the undesired sound from (b) and (c) depends on the predominance of V_0 over V_1 and V_2. If V_0 is large compared with V_1 and V_2, then $2\ V_0V_1$, and $2\ V_0V_2$ are large compared with $V_1\ V_2$, $\frac{1}{2}V_1^2$ and $\frac{1}{2}V_2^2$. In other words, the correct biasing voltage V_0 must be large compared to the amplitudes of the alternating voltages in order that the resulting sound wave forms may be a reasonably good representation of the wave forms of the alternating voltages.

Since the coefficients in (d) contain V_0 as a factor, the efficiency as well as the tone quality depends on V_0. With a given amplitude of alternating voltage the amplitude of the force varies directly with V_0 and the energy output varies directly with V_0^2.

d. Operating Characteristics of the Kyle Speaker.

Frequency response curves of these speakers taken with a constant alternating voltage applied between the plates show the following characteristics. The response is practically flat between 100 and 1000 cycles. Above 1000 cycles there is a strong rising tendency, the curve reaching a maximum at about 5000, above which it drops very slowly, retaining a considerable intensity at 10,000. There is practically a total absence of peaks and irregularities in the curve.

We have in the wave emitted from this speaker a condition which is seldom met with in acoustic devices. The different parts of the radiating area move independently and accurately in phase so that in the case of the flat speaker the result is the emission of practically a perfect plane wave at all frequencies. Very interesting diffraction effects are observed when the speaker is operated in a deadened room. There is a well defined interference pattern and a marked dependence upon frequency of the divergence of the sound beam. These effects are, of course, not particularly noticeable in the ordinary room but they make it difficult to obtain a single response curve which adequately represents the preformance of the speaker.

The above description of the characteristic was derived from consideration of curves taken at a large number of positions and weighted mentally.

The performance of this type of speaker, as of any other type, is influenced by the characteristics of the circuit in which it is used. Being a voltage operated device, anything which affects the voltage appearing across the plates will have the corresponding effect on the response. A satisfactory approximate analysis of the circuits may be made by considering the impedance of the condenser speaker as being due only to its static capacity. The experiments bear out the fact that this component of the impedance is the predominating one.

An example of this analysis is illustrated in Fig. 3. The circuit shown is approximately the equivalent, as far as the a-c characteristics are concerned, to the output circuit of a vacuum-tube choke coupled to a condenser speaker. The graph shows the variation with frequency

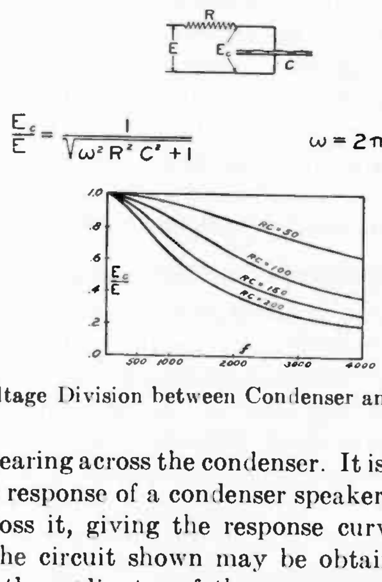

Fig. 3—Voltage Division between Condenser and Resistance.

of the voltage appearing across the condenser. It is therefore seen that if we measure the response of a condenser speaker maintaining a constant voltage across it, giving the response curve described above, the response in the circuit shown may be obtained by multiplying the ordinates by the ordinates of the proper curve of Fig. 3. The fact that the speaker has a rising characteristic makes it possible by choosing the proper value of *RC* to match it into the circuit so as to give almost a perfectly flat response over practically all of the useful part of the audible range.

III. Practical Design

a. The Back Plate

An extensive series of experiments has led to the form of back plate which is being used at present. In order to reproduce successfully low-frequency sounds it is necessary to have a considerable portion of the diaphragm moving with a considerable amplitude. On the other hand, the force on the diaphragm depends on the length of the wedge shaped air spaces which increases with the number of points of contact. The present design is a compromise in which the greatest linear contact length is used which will permit of satisfactory frequency response. It has been empirically determined that for the kind of diaphragm material used the best compromise is effected when the back plate is corrugated with a shallow wave 0.012 in. deep and 3/4 in. from crest to crest. The design of the plates depends also to some extent on the biasing voltage to be used. The present plate has been designed to use from 500 to 600 volts as it has been found that voltages of this order are necessary to procure satisfactory efficiency and tone purity.

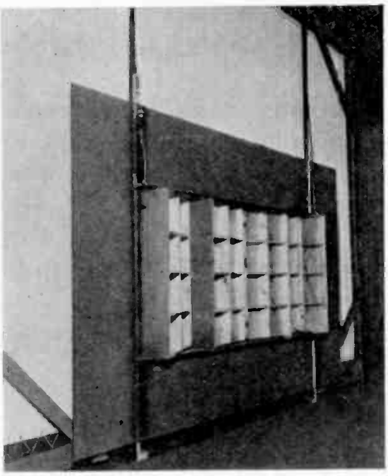

Fig. 3a—48-Section Speaker for Sound Pictures.

In order to procure freedom of motion of the diaphragm it is necessary that the back plate be perforated to permit free passage of the air in and out of the space between it and the diaphragm. A slot has been determined which satisfactorily vents the plate without reducing the area too greatly and which reduces excessive viscous resistance to the air movement. To insure that the diaphragm remain in close contact with the crests of the corrugations the plate is made slightly convex toward the diaphragm.

The back plate should be made of fairly thick metal to give as much stiffness as possible. The kind of metal is not so important being chiefly governed by cost considerations and the necessity for avoiding corrosion.

The speakers are at present being made in self contained units of 8 in. by 12 in. size. This plan offers flexibility in their use, as various sizes and shapes of speakers can be built up from these units.

b. The Dielectric.

Referring to (2) it is seen that in order to get the largest force the dielectric must be as thin as possible and have a high dielectric constant. However, in order to obtain sufficient dielectric strength and also to remain within manufacturing limits it is hardly practicable to use thicknesses below 0.005 in. or 0.004 in., in the materials which have proven to be satisfactory. To obtain a sufficient margin of safety it is desirable that the dielectric strength be at least 2000 volts. The speakers are tested at this voltage in order to discover any weak spots or pin holes. There is not much freedom of choice in the matter of dielectric constant and so far the material has been used which has satisfactory properties in other respects.

It is absolutely necessary that the diaphragm material possess a degree of flexibility approximately equal to that of rubber dam. Additional stiffness seriously affects the freedom of motion, especially at low frequencies.

The material must not deteriorate rapidly with respect to its dielectric strength and flexibility. A life of three or four years is perhaps the minimum that may be permitted.

A special rubber compound called Kylite has been developed giving these desired properties.

c. The Metal Coating.

The metal coating on the front surface of the diaphragm must be sufficiently flexible so that no appreciable stiffness is added to the diaphragm. Beaten leaf is perhaps the most satisfactory material so far tried. If a leaf or foil is used it must be not much thicker than 0.0001 in. and preferably thinner.

IV. Application

a. Mounting.

The performance of any loud speaker is improved by use of an appropriate baffle. The Kyle speaker requires less additional baffle than a small cone because its own area acts as a partial baffle. To reproduce satisfactorily the lowest frequencies of which the speaker is capable it is desirable to have a baffle which adds a margin of at least 10 in. around the edge of the reproducing unit. This may be in the form of a rectangular box or flat, as shown in Fig. 4.

It is necessary that considerable freedom be left behind the speaker for movement of the air. The rear should not approach closer than 6 in. to a solid wall, but the space back of the sections can be utilized for a radio set and power pack provided that they do not fill up the area too solidly. For the speaker sections to be used most effectively they should all be in approximately the same plane, the plane facing the normal position of the listener.

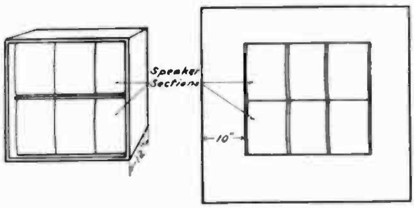

Fig. 4—Kyle Speaker Baffles.

Care must of course be taken that nothing in the baffle or speaker mounting resonates appreciably with a natural period in the audible frequency range. An exceptionally objectionable resonance comes in occasionally if a large area Kyle speaker is solidly supported all around its periphery. In this case the whole speaker itself is likely to vibrate as a diaphragm and attain sufficient amplitude to cause the Kylite to be thrown away from the back plate and produce a buzzing sound. The remedy for this condition is to divide the speaker by a stiffening member or to use braces attached to the center of the speaker.

b. Circuits.

As ordinarily hooked up, the circuit using the condenser speaker may be considered equivalent to that of Fig. 3, where R is the output impedance of the amplifier and a constant input voltage E is being applied. The capacity C of the speaker averages about 0.004 μf per 8 in. by 12 in. section. Referring to the curves of Fig. 3 it is seen that we can alter the frequency response of the combination by changing the value of the product RC. We can change R by changing the output tube or by using a transformer between it and the speaker, and we can change C by using different numbers of sections in the speaker or for special purposes by connecting groups of sections in series-parallel. The series-parallel connection is not very desirable for most installations as it complicates the biasing circuit. It may be mentioned that we can increase R by merely inserting an auxiliary resistance in series with the speaker. This is not very desirable as we thereby improve the frequency response only at the expense of efficiency.

With the present type of 8 in. by 12 in. units a value of about $RC = 65$ (R being expressed in ohms and C in μf gives the flattest frequency response for a small speaker of four 8 in. by 12 in. sections, while $RC = 100$ gives the best result on a speaker of, say, six sections. The difference is due mainly to the fact that the high frequencies emerge in a beam and that the beam is sharper with the larger speaker.

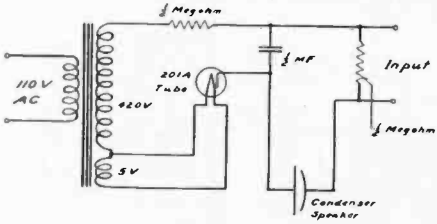

Fig. 5—Biasing Unit for Kyle Speaker.

The higher value of RC gives less total response in the high frequencies, but on account of the fact that they are more effectively concentrated on the listener in the usual listening position, the effect is practically the same.

If an exceedingly large speaker is built the beam effect becomes rather objectionable if the sections are all used in the same plane. A 24-section speaker was found to give good response over an angle

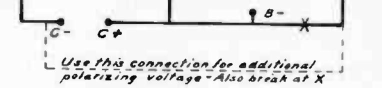

Fig. 6—Use of Plate Voltage for Biasing Kyle Speaker.

of about 30 deg. using a value of $RC = 180$, but outside of this angle the high frequencies were low in intensity.

A 48-unit speaker designed for talking picture reproduction is shown in Fig. 3a. This unit is inserted integral with the sound transparent picture screen and can be hoisted as a fly.

If the front of the speaker is set on a curved surface instead of flat, the beam effect can be utilized to cover just the horizontal angle desired, keeping the vertical divergence small. The sound can then be focussed to cover the auditors without projecting a large proportion toward the ceiling. When used in an auditorium there is some effect in reducing the reverberation as the total energy input into the room for a given loudness to the auditors is smaller than it would be if the sound were projected uniformly in all directions, and in addition the sound is projected toward a good absorbing surface, the audience.

A 96-section speaker was built on these principles to cover a horizontal angle of about 90 deg. It was found that the best frequency response was secured with $RC=60$.

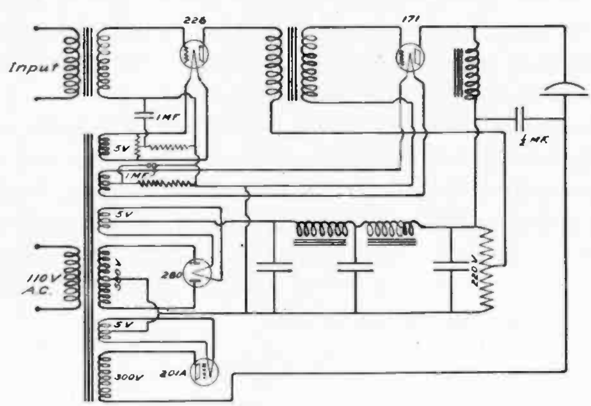

Fig. 7—Adaption of Amplifier and Power Back to Kyle Speaker.

In matching the speaker to an amplifier the characteristics of the amplifier, of course, have an important bearing. For example if the amplifier has a rising response characteristic toward the high frequencies it is possible to use a higher value of RC than if it were flat.

As shown above the force on the diaphragm at the desired frequencies is proportional to the product of the biasing potential and the alternating input voltage. This means that the energy output with constant input is proportional to the square of the biasing voltage. Practically this is only true within limits. If the biasing voltage is carried too high the diaphragm is drawn tightly against the back plate and placed under considerable tension. The result is a decrease in efficiency, rather than an increase, especially on the low frequencies. With the units constructed as at present a biasing voltage of 500-600 is as high as should be used.

Figs. 5 to 7 illustrate circuits applying the Kyle reproducer. Fig. 5 is the circuit of the biasing unit which is used with the individual speaker to be attached to any radio set. The 201A tube has proven a very satisfactory rectifier for this service as the current drain is practically nil. It will be noted that no filtering circuit is included. This is possible because no current is used in biasing the speaker. The charge on the speaker builds up until the voltage reaches that of the peak after which no current flows and no hum is perceptible.

Fig. 6 shows the simplest connection possible, no auxiliary apparatus whatsoever being used. If the connection to $-C$ is used the impedance between $+C$ and $-C$ should be small, otherwise a bypass condenser should be used from the speaker to $+B$ and a grid leak inserted between the speaker and $-C$.

Fig. 7 shows means for adapting the power pack of an amplifier to furnish biasing voltage in excess of that furnished in the plate voltage. These diagrams are not intended to show all the possibilities by any means but only to illustrate the requirements.

In cases where the speaker is to be built into the radio set the problem of installation is fairly simple. The speaker units may be made to cover practically the entire front area of the console, leaving narrow spaces for bringing through the set controls. Some very satisfactory models have been made up in which all controls were eliminated from the front of the console, the control knobs being placed at the end and the indicating dial appearing on top.

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DETECTION AT HIGH SIGNAL VOLTAGES

Part 1

Plate Rectification with the High-Vacuum Triode*

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I. INTRODUCTION

DURING the past five years an abundant literature has grown up dealing satisfactorily with the detection of *small signals* both from the theoretical and experimental viewpoints. A convenient theory can be formulated mathematically when the applied voltages and the higher tube parameters are small by means of the series method first employed by Carson in discussing the plate circuit. This has been done by Carson[1] for detection in the plate circuit, and by Lewellyn[2] and Ballantine[3] for rectification in the grid circuit.

The performance of the detector in the more complicated case in which the signal voltage and higher order tube parameters are high, however, does not seem to have been accorded much experimental attention, nor does the theory seem to have been satisfactorily worked out. It may be noted from the mathematical side that as the carrier voltage is increased the higher order terms in the Carson series formulation become increasingly important and the computations from it soon become laborious beyond the point of usefulness for ordinary purposes of investigation. Chaffee has devised an ingenious theory in terms of closed integrals over the usual d-c characteristics and certain differential parameters of the detector which offers some advantages in computation over the series method, but these are hardly sufficient to make it a practical tool of investigation.

In my own work in this field I have employed three methods of investigation:

(1) A descriptive theory which attains its greatest simplicity in the case of a purely resistive load in the plate circuit, when a graphical solution can be obtained;

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[1] J. R. Carson, PROC. I. R. E., 7, 187; April, 1919.

[2] F. B. Lewellyn, *Bell Sys. Tech. Jour.*, 5, 433; July, 1926.

[3] Stuart Ballantine, PROC. I. R. E., 16, 593; May, 1928.

(2) A mathematical theory, formulated as an infinite series in powers, not of the carrier voltage E_0, but of the product of the carrier voltage and the degree of modulation m. This formulation is based upon experimentally determined *rectification diagrams* in the same way that the old E_0 formulation rests upon the ordinary d-c characteristics. These rectification diagrams are as easily obtained experimentally as the d-c characteristics and by taking this step experimentally, instead of mathematically as is virtually done when the power series in E_0 is employed, the labor of calculation is considerably lightened;

(3) An experimental study of the whole process, including the generation of harmonics, i.e., non-linear distortion. This experimental program was begun in 1922 and although it is still far from complete the main facts have probably been discovered.

The object of the present series of papers, of which this is the first, is to outline the experimental results in certain typical cases of: (1) plate rectification, (2) grid rectification, (3) grid and plate rectification, (4) special arrangements for linear detection, (5) diode and simple rectifiers (e.g. crystals), and also to suggest a rational basis for engineering design and the prediction of performance from diagrams which can be readily obtained experimentally.

II. Classification of Signals

Standard Symmetrical Modulated Signal. Before embarking upon a discussion of detection we may as well state our point of view as to the signal to be detected. In Fig. 1 a group of modulated signals is represented in three different ways. At the top the actual variation of

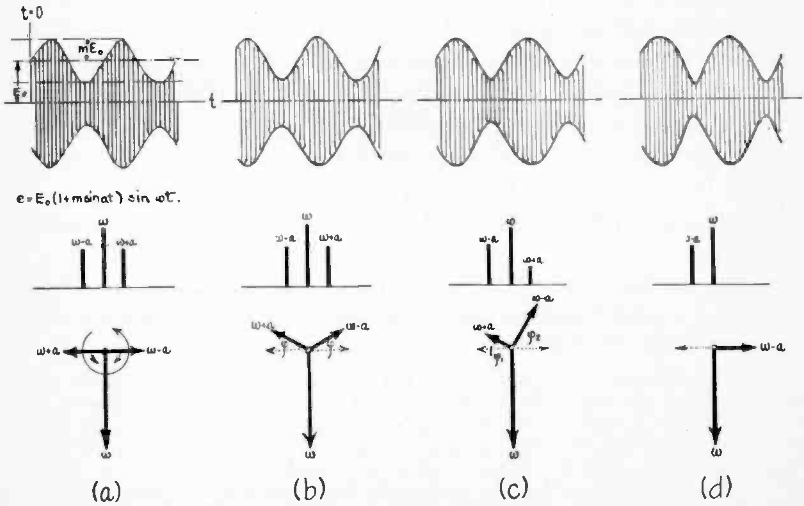

Fig. 1—Group of Modulated Signals. (a) standard symmetrical signal; (b) symmetrical phase shift in sidebands; (c) asymmetrical signal; (d) superior sideband suppressed.

voltage is represented against time; the middle diagram represents the amplitudes of the component frequencies in the Fourier-series resolution of the signal; the lower diagram shows how these components combine vectorially to form the signal.

We shall adopt as standard the symmetrical modulated signal shown at (a), Fig. 1, which is of the type used extensively in radiotelephony and radio broadcasting. This signal comprises a carrier E_0 and two sidebands, symmetrical in amplitude and phase. Unless the contrary is stated it will be supposed that the modulation of the standard signal is of a single audio frequency, the carrier being of radio frequency. A signal of this type may be represented by:

$$e = E_0(1 + m \sin at) \sin \omega t$$

$$= E_0\Big[\underbrace{\sin\omega t}_{\text{Carrier}} + \underbrace{\frac{m}{2}\cos(\omega - a)t}_{\text{Inferior sideband}} - \underbrace{\frac{m}{2}\cos(\omega + a)t}_{\text{Superior sideband}}\Big]$$

in which m is the modulation coefficient, which may vary from zero to unity, and a represents the audio and ω the radio angular velocities, respectively. In the vector diagram in Fig. 1a the carrier ω rotates anticlockwise at speed ω; at the same time the superior sideband $(\omega + a)$ rotates anticlockwise at rate a, and the inferior sideband $(\omega - a)$ rotates in the opposite direction at speed a, *both with respect to the carrier.*

A question may arise as to whether the results of investigation with such an ideal signal can be applied to other types of signal, especially signals which may have undergone some distortion in the processes of amplification and transmission, or which have not left the modulator in such standard form. Let us consider a few simple cases of distortion that are likely to arise in practice.

Symmetrical Sidebands Displaced in Phase. In passing through an amplifier employing simple resonant circuits the phases of the sidebands will be changed and their amplitudes diminished symmetrically as shown in Fig. 1b. It is assumed that the circuits are accurately tuned to the carrier frequency. The effect of this is two-fold: (1) a diminution of the effective degree of modulation m, and (2) a shift in phase of the audio-frequency envelope of the modulated signal. If m' is the altered degree of modulation and ϕ is the symmetrical phase-shift, then:

$$e = E_0[1 + m' \sin(at - \phi)] \sin \omega t. \tag{2}$$

The signal thus remains of our standard type (1) and the investigation will apply to it with the indicated modifications.

Sidebands Asymmetrical in Amplitude and Phase. In the more general case in which the r-f amplifier circuits are not precisely tuned to the carrier, the sidebands will be asymmetrical both in amplitude and phase, as shown in Fig. 1c. The mathematical expression for this signal is complicated and will not be written down since it will not be of further use; it is sufficient to say that this signal is not of type (1), that is, the modulation is not sinusoidal. The conclusions from the standard signal will not necessarily apply to a signal so distorted.

As a special case under this, consider that of equal sidebands with asymmetrical equal phase displacements. This might be brought about by a shift to the phase of the carrier by an amount ϕ. We then have:

$$e = E_0[1 + m^2 \sin^2 at + 2m \sin at \cos \phi]^{1/2} \sin(\omega t + \phi). \qquad (3)$$

This is not of form (1) when ϕ differs from 0 or π.

One Sideband Suppressed. This type of signal is frequently employed in practice (e.g., in transatlantic radiotelephony) and is expressed by:

$$\begin{aligned} e &= E_0\left[\sin \omega t + \frac{m}{2} \cos(\omega - a)t\right] \\ &= E_0\left[1 + \frac{m^2}{4} - m \sin at\right]^{1/2} \sin(\omega t + \psi). \end{aligned} \qquad (4)$$

The superior sideband is absent (Fig. 1d). This signal is not of the standard type (1).

It is interesting to note, in connection with this signal, that when it is detected by means of a curvature (square-law) detector there is no distortion due to beating between sidebands of opposite sign. However, in a practical signal each sideband contains several component frequencies so that there will still be some distortion produced by the beating of the components within the remaining sideband.

III. Ideal Linear Detectors and Small-Signal Detectors

Care must be exercised when using the term "ideal detector" to specify the type of signal for which it is ideal. In general a detector is ideal when the audio output is an exact replica of the original modulating wave *impressed upon the modulator.* Such a definition may be objected to on the ground that other processes, such as amplification, transmission, and modulation, take part in the process. This objection is only superficial, for even though the signal may be distorted from type 1, or any other standard type that might be adopted, the detector may be ideal to the distorted signal, that is, it may correct any distortion that has been introduced.

So far as the standard signal (1) is concerned an ideal detector is a *linear detector*, that is, one in which the instantaneous relation between audio output and r-f input is *linear*. It has long been recognized that such a linear detector may be found in a device the current-voltage characteristics of which are straight lines meeting at an angle as shown in Fig. 2. It is essential that the break occurs at the origin ($E=0$), and it can be brought there by suitable batteries.

Many unsuccessful attempts have been made to discover a practical device having these characteristics. Failing this the art has been content with small-signal (square-law) detection with devices which operate on continuously curved $e-i$ characteristics, at the point of

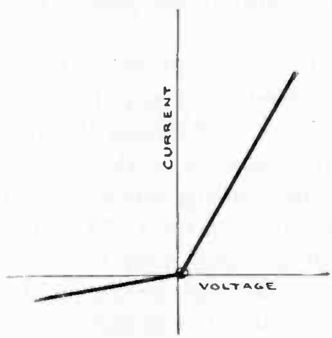

Fig. 2—E/I Characteristics of ideal linear detector for standard modulated signal.

greatest curvature. The inherent disadvantages of such curvature operation with a signal of the type $e=E_0[1+F(t)]$ sin at are well known.[3] The output of such a detector contains not only a term proportional to $F(t)$ as it should, but also a second-order $F^2(t)$ term which is superfluous and represents distortion. In order to limit this distortion the degree of modulation must be limited, that is $F(t)$ must be kept small compared with unity. This is uneconomical and wasteful of power in the carrier, and also limits the service area of a given broadcast transmitter for a fixed interference production by the carrier. I have been told that in the early days of radio broadcast transmission the transmitters were actually not capable of undistorted modulation of much more than 50 to 60 per cent. In English speech the "peak-factor" (the ratio of the maximum amplitude to the average amplitude) is stated by Sacia[4] to be about 5. This would mean that if in this case the maximum modulation were set at 50 per cent, the average modulation would be about 10 per cent. With such low modulation the non-

[4] Sacia, *Bell Sys. Tech. Jour.*, 4, 627; October, 1925.

linear distortion with curvature detectors might not be noticeable, and this probably accounts for the complacent way in which the process of detection has been viewed by experts in this art.[5]

Feeling that the detector had been too much neglected, and looking forward to the time (now at hand!) when 100 per cent modulation would be generally employed in broadcast and telephone transmitters and the consequent distortion in square-law detectors would probably become important, I began, in 1922, an investigation to see what might be done toward securing at least approximately linear detection with circuit elements which were practically available. This program rested upon the fundamental idea that by taking a practical rectifier which was perhaps not quite of the perfect type shown in Fig. 2, but which had for example two slightly curved branches connected by a small section of greater curvature near the origin rather than by a definite break, or a curved portion and a straight portion (as in the case of a thermionic tube), and raising the applied signal voltage the action would approach linearity as the average curvature over each half-cycle decreased. In reducing this idea to practice I was fortunate in securing the collaboration of Dr. L. M. Hull, who made a survey of crystal rectifiers with the object of finding a combination of the requisite linearity from the high-voltage point of view. The broad principle of operating a detector at high voltages and an account of the successful work of Hull may be found in a U. S. Patent issued to Ballantine and Hull.[6]

Paralleling Hull's investigation of crystals, I undertook, simultaneously, a study of the action of thermionic devices with high signal voltages. While the relation between the thermionic current and voltage is known to be non-linear, the device is nevertheless recondite for the reason that at least *one* branch of the curve (zero current for retarding fields) is linear; hence the response may be expected to continuously approach linearity as the voltage is increased. This approach is further facilitated by reducing the curvature of the curved portion by the connection of linear impedances in the external circuit.

The soundness of this fundamental idea, and the improvement in the performance of a tube detector that results from increasing the signal voltage, is fully verified by the experimental results to be given later.

[5] As an example of this attitude we may quote from an article by Harvey Fletcher entitled "High Quality Transmission of Speech and Music" (Midwinter Convention, A. I. E. E., 1925) in which he says, referring to the usual small signal operation, that "in general there is no distortion in the detector."

[6] No. 1, 698, 668; January 8, 1929.

IV. Descriptive Theory—Resistance Load

The action of the plate rectifying triode with high voltage signals of type (1) may be most simply exhibited when the external impedance is a pure resistance, for in this case a graphical construction may be employed. For simplicity the resistance load will be supposed to be by-passed for the carrier and neighboring frequencies, although a more nearly linear but less sensitive detection will be obtained if it is not by-passed. No inquiry will be made into the actual process of rectification, that is to say, no attempt will be made to derive the functional relation between the rectification current and the r-f grid voltage from d-c characteristics; this will be directly determined experimentally instead of the d-c curves. As the most fundamental relation we shall take that between the average plate current (as indicated by a d-c instrument), and the d-c plate voltage, for various r-f carrier voltages on the grid. This may be called the *rectification diagram for the tube,* and when, as in the case under consideration, the carrier is impressed

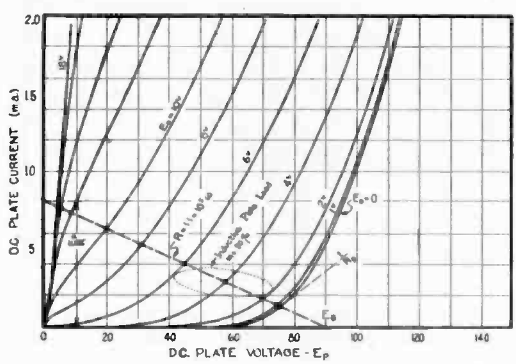

Fig. 3—Rectification diagram for triode. Relation between d-c plate current and d-c plate voltage with various r-f voltages on grid. 201A triode $E_c = -8$ volts.

upon the grid instead of being directly inserted in the plate circuit, we will call it the *transrectification diagram for the tube.* Such a diagram has been independently employed by Smith.[7] Fig. 3 is a typical experimental diagram for the 201A type of tube, $E_b = 90$ v, $E_c = -8$ v.

To determine the output we want the relation between the d-c voltage developed across the resistance load R in the plate circuit and the r-f voltage applied to the grid. In the case of the resistance load this may be determined graphically, as shown in Fig. 3. The voltage drop across R and the actual plate voltage are given by the inter-

[7] V. G. Smith, Proc. I. R. E., 15, 525; June, 1927.

sections of the straight line $I_p = (E_b - E_p)/R$ and the $I_p - E_p$ curves. We can now construct a diagram of E_r vs. E_0. This will be called a *detection diagram;* if desired the data for this diagram may be directly obtained experimentally. In Fig. 4 the curve marked "$E_c = -8$ v" corresponds to the graphical solution of Fig. 3. The other curves correspond to other values of grid bias, E_c. The dashed curve marked "grid current" indicates the voltages at which grid electron current begins to flow.

We see at once from Fig. 4 what happens when our standard signal (1) is impressed upon the grid. This signal is an r-f voltage of variable amplitude, the variation comprising two parts, a constant part and a sinusoidally variable part. It is helpful to compare the process with that of amplification. In this analogy the Fig. 4 detection characteristic is analogous to the $I_p - E_g$ characteristic of the amplifier, the carrier

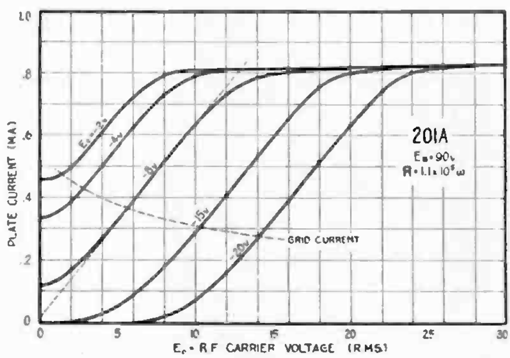

Fig. 4—Detection diagram for triode with 110,000-ohm resistor in plate circuit. Relation between plate current (d.c.) and r.f. voltage on grid.

voltage E_0 is analogous to the grid bias E_c of the amplifier and determines the "operating point," and the sinusoidal modulation $mE_0 \sin at$ is analogous to an alternating voltage of the same type applied to the amplifier grid. The curvature of the detection diagram will produce distortion in the same way that curvature of the amplifier characteristic produces it, and with a signal of type (1) the output will in general comprise a fundamental of modulation frequency and a group of harmonics.

With small signals the only part of the detection diagram of interest is that at the extreme left (E_0 small). The curvature of the characteristic in this region is compatible with the distortion calculated from the small-signal theory (Sect. III). We can obviously never hope to obtain demodulation free from distortion in this range of E_0.

As the carrier voltage is increased the curvature decreases and finally vanishes at a point of inflection. Obviously this is the best operating point. Here the detection is actually linear and the harmonics and distortion reach a minimum. This bears out the soundness of the idea of high-voltage operation as outlined in Sect. III. Experimental curves will be given later which actually show that the harmonics are minimum and that the relation between carrier voltage and fundamental output is of the first order at this point.

As the voltage E_0 is increased beyond the point of inflection the curvature increases rapidly and the distortion becomes even greater than in the region of small signals. The output also falls off due to the "saturation" course of the curve.

V. Mathematical Theory for Small Modulation and Large Carrier Voltage

Starting with the usual d-c characteristics of the tube we can build up a theory of detection by the Carson series method in which the output is expressed as an infinite series in powers of E_0 and m. Even in the most favorable case of small m, however, this formulation becomes exceedingly tedious for large carrier voltages. It is proposed here to abandon the d-c characteristics entirely and start with the experimentally determined rectification characteristic for the tube (see last section). A new theory can then be built up in a series in powers, not of E_0, but of mE_0, and the various differential parameters of the *rectification characteristic.* What we are virtually doing here is pursuing the amplifier analogy. In the case of the standard signal mE_0 corresponds to the amplitude of a sinusoidal voltage impressed on the grid of an amplifier. The practical usefulness of such a formulation is confined to small values of mE_0, but this restriction does not seriously limit its instructive value, for we can still find out what happens at large E_0 by appropriately diminishing m. It is especially valuable as a supplement to the descriptive theory when the plate load is not a pure resistance and the graphical method is no longer available. In particular it furnishes several new concepts of engineering value. Among these is that of an *effective plate resistance for detection,* which is useful in designing the output apparatus for maximum transfer and fidelity.

Let e represent the instantaneous amplitude of the r-f voltage impressed on the grid, exclusive of the steady biasing voltage E_c; let i_p represent the rectified current in the plate circuit and let e_p represent the instantaneous plate voltage. Let it be supposed that the set of rectification characteristics $I_p=f(E, E_p)$ has been experimentally determined. This functional relationship may presumably be expressed in a double Taylor's series.

$$I_p = P_1E + P_2E^2 + P_3E^3 + Q_1E_p + Q_2E_p^2 + \cdots + R_1E_pE + R_2E_p^2E + \cdots$$

where

$$P_1 = \partial I_p/\partial E; \qquad P_2 = \tfrac{1}{2}\partial^2 I_p/\partial E^2; \ + \cdots$$
$$Q_1 = \partial I_p/\partial E_p = g_p; \qquad Q_2 = \tfrac{1}{2}\partial^2 I_p/\partial E_p^2; \tag{6}$$
$$R_1 = \frac{\partial^2 I_p}{\partial E \partial E_p}; \ \text{etc.}$$

The parameter $P_1 = \partial I_p/\partial E$ is of the dimensions of a conductance and is analogous to the mutual conductance of the amplifier tube. It represents the rate of change of the rectified plate current with respect to the amplitude of an alternating sinusoidal voltage applied to the grid. In view of the fundamental nature of this parameter it will be convenient to have a special name for it and until a more felicitous term appears I shall call it the *transrectification factor*, or shortly, the *transrectification*. The parameter $1/Q_1 = 1/\partial I_p/\partial E_p$ corresponds to the plate resistance R_p of the amplifier theory, and there is no need to change the term. It is important to note, however, that R_p is now a function of the carrier voltage as well as of the plate and biasing voltages. This fact might be kept in mind by some such term as the *detection plate resistance.*

Following Carson we wish to express i_p finally in the form:

$$i_p = a_1e + a_2e^2 + a_3e^3 + \cdots . \tag{7}$$

Now the alternating part of the plate voltage $e_p = -i_pZ$, where Z is the external impedance in the plate circuit. For simplicity we shall confine ourselves to the case where e is a sinusoid of single frequency, that is

$$e = \tfrac{1}{2}(Ee^{i\omega t} + \overline{E}e^{-i\omega t}).$$

The bar denotes the conjugate of the unbarred symbol. Let

$$i_p = i_1 + i_2 + i_3 + \cdots \tag{8}$$
$$e_p = e_1 + e_2 + e_3 + \cdots \tag{9}$$

and substitute in (5). We have to deal here with a function of two unrelated variables and a double power series. The situation is the same as in Llewellyn's[2] extension of Carson's theory which removed the restriction of van der Bijl's relation (constant μ) between the variables E_g and E_p. Except for this the remaining work is virtually the same as that given by Carson[1] and need not be repeated. The results for the effects of the first two orders may be concisely stated as follows:

First Order Effect. Equivalent Circuit of the Detector. The first order output can be calculated by assuming a hypothetical voltage

$=P_1e/Q_1$ operating in a circuit comprising an external impedance Z and the detection plate resistance ($R_p=1/Q_1$) in series. The current will be given by

$$I_1=\frac{\partial I_p}{\partial E}\frac{R_p}{R_p+Z}e. \tag{10}$$

This is the equivalent circuit of the plate rectifying detector, and is analogous to the equivalent circuit theorem for the amplifier which was originally stated by Carson; the transrectification factor $\partial I_p/\partial E$ in this case replaces the mutual conductance of the amplifier theorem. The calculation of the detection for small mE_0 is thus reduced to a simplicity comparable with that of the fundamental amplifier circuit. One of the chief practical contributions of this theory is that it defines an "effective plate resistance for detection," and enables us to see what happens when the external circuit is not a pure resistance and the detection diagram of Fig. 4 cannot be used to predict the output. With an inductive load, for example, and a sinusoidal modulation, the voltage-current relation during a cycle of modulation no longer describes a straight line in the Fig. 3 diagram, but an ellipse.

In the case of the standard signal (1), e in (10) is to be replaced by $mE_0 \sin at$ giving

$$I_1=mE_0\frac{R_p}{R_p+Z(a)}\left[\frac{\partial I_p}{\partial E}\right]_{E=E_0} \tag{11}$$

$Z(a)$ being the impedance for the modulation frequency $a/2\pi$. The value of $\partial I_p/\partial E$ is to be taken at the carrier voltage E_0. This derivative may be determined graphically from the data of Fig. 3 for the tube, or may be measured experimentally.

For small signals

$$I_p(\text{rect.})=\frac{1}{2}\frac{\partial g_m}{\partial e_g}\frac{E^2}{2}; \tag{12}$$

so that

$$\frac{\partial I_p}{\partial E}=\frac{E}{2}\partial g_m/\partial e_g \tag{13}$$

and

$$I_1=\frac{1}{2}\frac{\partial g_m}{\partial e_g}\frac{R_p}{R_p+Z}E^2, \tag{14}$$

which is the result given by the small-signal theory.

Effective Plate Resistance for Detection. The quantity $R_p = 1/Q_1 = 1/\partial I_p/\partial E_p$, which has been referred to as the "detection plate resistance," can be evaluated graphically from the rectification $I_p - E_p$ diagram, Fig. 3. It is often preferable to measure it directly and a

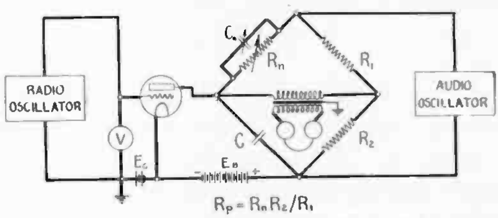

Fig. 5—Bridge arrangement for measuring effective plate resistance for detection.

convenient method for this is shown schematically in Fig. 5. This is an ordinary bridge arrangement already in use for measuring the amplifier R_p with the difference, however, that a r-f carrier voltage E_0 is connected to the grid during the measurement. C is a bypass condenser whose effect on the balance is compensated by C_n.

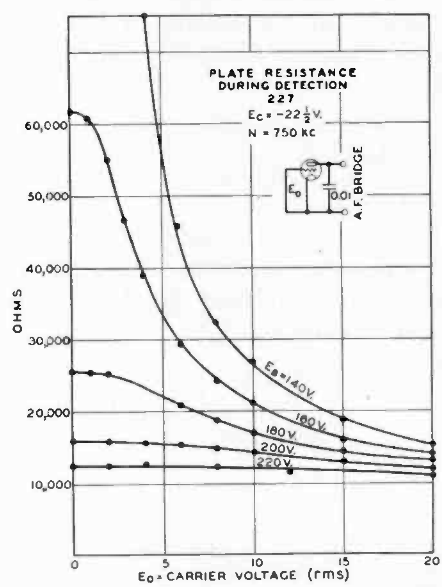

Fig. 6—Illustrating variation of effective plate resistance for detection with the variation of r-f voltage on grid. 227 triode; = −22.5 volts.

Typical results of such measurements are shown in Fig. 6. These data were taken with a 227-type triode with a grid bias of −22.5 volts. The different curves correspond to different plate battery voltages.

The values of R_p for $E_0=0$ are the quiescent values which are significant in the amplifier theory. Note the dependence of R_p on the carrier voltage, especially for the lower battery voltages. These curves will be further discussed in Sect. IX.

Second-order Terms. Distortion. The second term in our series formulation (8) is of the second order in e, and can be regarded as the result of a hypothetical voltage

$$-(P_2e^2+R_1ee_1+Q_2e_1^2)/Q_1, \tag{15}$$

acting in a simple circuit comprising the external impedance and R_p in series. Here e_1 is the voltage between plate and cathode due to the first-order current (10). The voltage (15) will generally comprise several frequencies.

As an illustrative case consider our standard signal (1) and a purely resistive plate load, R. The second-order current is

$$i_2=\frac{m^2E_0^2}{4}\,\frac{R_p}{R+R_p}\left[\frac{\partial^2 I_p}{\partial E^2}-r\frac{\partial}{\partial E_p}\left(\frac{\partial I_p}{\partial E}\right)^2\right.$$
$$\left.+r^2\left(\frac{\partial I_p}{\partial E^2}\right)^2\frac{\partial^2 I_p}{\partial E_p^2}\right](1-\cos 2at) \tag{16}$$

where $r=RR_p/(R+R_p)$. This contains a double-frequency term ($\cos 2at$) which represents distortion.

To make connections with the small-signal theory as expressed in terms of d-c characteristics, assume for simplicity, van der Bijl's relation (constant μ); then

$$i_p=\cdots\frac{1}{2}\left\{\frac{\partial^2 I_p}{\partial E_g^2}e_g^2+2\frac{\partial I_p}{\partial E_g\partial E_p}e_pe_g+\frac{\partial^2 I_p}{g E_p^2}e_p^2\right\} \tag{17}$$

$$I_p(\text{rect.})=\frac{1}{2}\,\frac{\partial g_m}{\partial e_g}\left[\frac{E^2}{2}+\frac{E_p^2}{\mu^2}\right]=f(E,E_p) \tag{18}$$

Substituting the values of the various derivatives of (18) in (16) we get:

$$i_2=\frac{m^2E_0^2}{8}\,\frac{\partial g_m}{\partial e_g}\,\frac{R_p}{R+R_p}\left\{1+\left(\frac{RR_p}{R+R_p}\right)\frac{E_0^2}{\mu^2}\right\}(1-\cos 2at). \tag{19}$$

The second term in the brackets is of the order of E_0^4 and will be disregarded for small E_0^2. Comparing (19) with I_1 as given by (10) we see that the distortion (I_2/I_1) approaches $m/4$ as E_0 approaches zero. This is the result given by the small-signal theory. Note that for small signals, to the order of quantities that have been retained, the external impedance is without effect upon the distortion. This is in contrast with the well known effect of an external impedance in an amplifier circuit in reducing the harmonics relative to the fundamental. With high-voltage signals, however, the external impedance does affect the distortion; this is already beginning to show up in the E_0^4 term in the brackets of (19).

VI. Definition of Distortion

With respect to the standard modulated signal (1) we shall have occasion to speak of two kinds of distortion: (1) *frequency distortion* as manifested by the departure of the output-modulation-frequency relation from uniformity, and (2) distortion arising from non-linearity whereby there appears in the output, in addition to the fundamental term of frequency, a, a series of harmonics of frequencies $2a, 3a, \cdots$ The latter distortion will be defined as the ratio of the r.m.s. value of the combined harmonics, as measured by an ordinary thermocouple meter, to the r.m.s. value of the fundamental. Denoting by E_1 the amplitude of the fundamental, and by E_n that of the nth harmonic, this definition may be expressed by:

$$\text{Distortion} = \left(\frac{E_2^2 + E_3^2 + \cdots E_n^2}{E_1^2} \right)^{1/2}$$

The convenience of this definition in experimental work resides in the fact that a thermocouple meter, responding according to the square law, indicates $(E_1 + E_2 \cdots)^{1/2}$ regardless of the relative phases of the components.

VII. Experimental Technique

The apparatus employed in the experimental study of detection is somewhat complicated, and to avoid interruption a detailed description of it will be postponed until the final paper of this series. For the present purposes a brief outline of the experimental method will suffice.

Standard Signal Generator. The first requisite for this work is a standard signal of type (1) of which the modulation can be varied up to 100 per cent, and the carrier voltage to about 100 volts. This signal is required to be of unusual purity, that is, the audio envelope should contain no harmonics, and the r-f carrier should also preferably be sinusoidal. None of the usual systems of modulation which were tried successfully met the requirements of range and purity, but after some investigation a satisfactory signal was secured from a new modulator which will be separately described. The modulation was performed at low voltages and the signal was brought to the desired level by means of a broadly tuned amplifier. Since the degree of modulation used was never less than 20 per cent, no trouble was experienced from the high shot-noise/signal ratio which this procedure might have been expected to produce.

Measurement of *m*. The degree of modulation *m* was measured at the grid terminals of the detector by means of a special meter, based upon the method of Posthumous and van der Pol. This meter will be described elsewhere. The method was found accurate, convenient, and decidedly superior to the more common methods. The modulation meter contained a buffer amplifier which was perfectly monodic, and did not affect the circuit across which it was connected.

A sensitive check on the purity of the signal and the accuracy of the measurement of *m* is afforded by the measurement of the percentage of distortion (ratio of second-harmonic to fundamental) in the

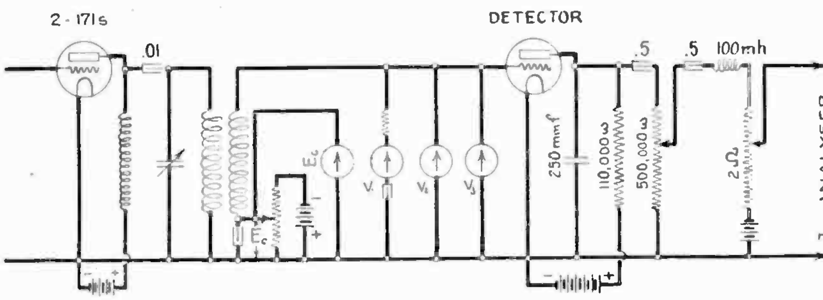

Fig. 7—Connections of triode for plate rectification as employed for experimental work. Resistance output.

detector at low signal-voltages. This ratio should approach $m/4$, and will be seen to do so in Fig. 8. This is evidence of the proper working of the apparatus, including the analyzer.

Connections for Plate Rectification. The actual circuit connections of the detector are shown in Fig. 7. The external impedance is shown as a pure resistance. The method of supplying the signal voltage to the detector grid is also shown. This is of importance when the grid takes current, since the load on the supply circuit occasioned thereby is non-linear. The effect of a non-linear load is to produce a distortion of the signal by lowering the peaks relative to the troughs in a non-sinusoidal fashion. The course of the curves for carrier voltages in the region of grid current depends, therefore, somewhat on the supply circuit. To reduce this effect two 171 tubes operating at 200 volts on the plate are used in parallel and the output transformer is designed to minimize the impedance change due to the grid current in the detector tube. No attempt has been made to eliminate it completely. This was done at first by using higher power tubes and more inefficient transformer design, but was later considered to be unnecessary in view of the fact that there is no standard method of supplying the detector tube and the practical value of the results would be no greater. In a practical test and in actual design the whole amplifier should be measured with the detector, or if the amplifier is known to be linear over the range of voltages to be used, the stage preceding the detector should at least be included.

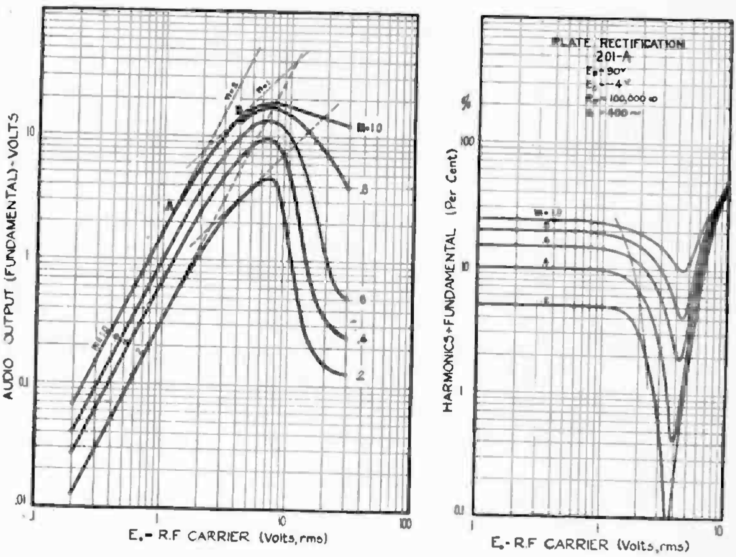

Fig. 8—Resistance Output. (left) Relation between fundamental output and carrier voltage in standard signal; (right) percentage of harmonics (distortion) versus carrier voltage. 201A triode, m = degree of modulation

Analysis of the Detector Output. The audio voltage across the output terminals of the detector was measured and analyzed with regard to the amplitudes of the fundamental and harmonics. The method of analysis was as follows: The fundamental and all harmonics, that is to say the quantity $(E_1^2+E_2^2+E_3^2+\cdots)^{1/2}$, was first measured. The fundamental E_1 was then eliminated in an early stage of the analyzer by means of a Wheatstone bridge having one tuned arm, the remaining arms being resistive. A second measurement then gave the quantity $(E_2^2+E_3^2+\cdots)^{1/2}$. The distortion as defined in Sect. VI can be directly computed from these data. If the harmonics are small $E_1^2 \gg \Sigma E_n^2$ and the first measurement can be taken as giving the amplitude of the fundamental with negligible error; otherwise a suitable correction is to be applied. The fundamental may also be measured by tuning a stage of the amplifier associated with the analyzer to this frequency. A further "microanalysis" of the amplitudes of the individual harmonics can be made, with the fundamental eliminated, by means of a selective amplifier and output system. In this work it was found sufficient to carry this only as far as the fourth harmonic, as this summation accounted for the total harmonic effect within a small error.

The use of the Wheatstone bridge for the elimination of the fundamental is exceedingly convenient and avoids errors which would arise from the generation of harmonics in the post-detection amplifier and selective analyzer if the fundamental were permitted to enter it. I have employed this scheme for several years in this and other investigations but find that it has been fully described by Belfils.[8] A full description of the analyzer apparatus and details of its manipulation will be given separately.

VIII. Typical Experimental Results—Resistance Load

In presenting the experimental picture we may profitably confine the discussion to a typical case; in order to make comparisons with the descriptive theory of Sect. IV and the experimental rectification data of Figs. 3 and 4, we shall take that of a resistance load of 100,000 ohms in the plate circuit of a 201A type triode with $E_b = 90$ v, E_c at first equal to -4 v, later variable.

The range of carrier voltage extended from 0.1 to 50 volts (r.m.s.). Logarithmic coordinates were used on account of the wide range of magnitudes. The frequency of modulation was 400 cycles; separate tests at 100 and 2000 cycles showed that with a resistance load no difference in the results was to be expected at other frequencies. The carrier frequency was 600 kc (500 m).

Fundamental Output. The relation between the carrier E_0 and the fundamental (400-cycle) output voltage across the R-load for various degrees of modulation (20, 40, 60, 80, 100 per cent) is shown in the left-hand curve of Fig. 8. For carrier voltages up to the point A the output varies as E_0^2 in agreement into the theory for small signals. Beyond this point the small-signal theory begins to fail and the response approaches linearity ($n = 1$), which it attains at point B. This is the value of E_0 at which the distortion is a minimum and corresponds to the point of inflection on the detection diagram, Fig. 4, $E_c = -4$ v.

[8] G. Belfils, *Rev. Gen. d'Elec.*, 19, 523; April 3, 1926. G. Chiodi, *Electrotecnica*, 15, 166, 1928. The Belfils paper has evidently escaped the attention of I. Wolff (*Jour.* Opt. Soc. Amer.)

Beyond B the output increases slightly and suddenly falls off; this will be referred to as "overloading." The overloading may be accounted for by the "saturation" character of the curve in Fig. 4. It occurs more suddenly the lower the modulation, being least marked for $m=100$ per cent.

Harmonics. Distortion. The variation of the combined harmonics, that is of the quantity $(E_2^2+E_3^2+E_4^2+\cdots)^{1/2}$, over the same range of E_0 is shown at the right of Fig. 8. The ordinates represent distortion as defined in Sect. VI. For low signal voltages the distortion approaches $m/4$ as predicted by the small-signal theory, and as noted previously, this furnishes a check on the performance of the apparatus. The distortion remains constant over the range of "small-signals", decreases as the carrier voltage is further increased, and finally reaches a minimum at a voltage corresponding to point B in the "fundamental" diagram. This has been predicted by the descriptive theory. Microanalysis of the harmonics shows that up to and a little beyond the point B (20 per cent modulation) the second harmonic predominates, vanishing at B, and reversing sign in going through this point. The residual distortion at the minimum is largely composed of third harmonic. This harmonic increases rapidly with E_0 and m.

The dotted curve represents the points at which electron current begins to flow in the grid circuit of the detector tube.

With regard to the practical interpretation of these curves of distortion it has been my experience that the ear cannot detect with certainty a distortion of less than 5 per cent, so that the upper part of this diagram is probably the only part of significance.

The rather sudden rise in distortion which accompanies overloading will be noticed, the values attained being even higher than those for small-signal operation.

The experimental results of Fig. 8 again testify to the soundness of the idea of operating the detector at high signal voltages, thereby taking advantage of linearity.

Effect of Grid Bias. The qualitative effect of changing the grid bias can be gleaned from the detection diagram, Fig. 4. Under the conditions of that diagram the best bias, for modulations ranging up to 100 per cent, appears to be about -8 volts. Smaller bias voltages give less output because of the limited range of E_r. Higher biases result in a "cut-off" on the $E_r=0$ axis which introduces distortion at the higher modulations. With $E_c=-20$ v, for example, and E_0 adjusted to the optimum value (point B) this cut-off effect would appear at about $m=60$ per cent. Notice, however, that with a *limited m* the bias may be increased above -8 v with correspondingly better output; the smaller *m* is, the higher the bias may safely go before introducing distortion. The upper bend of the curve must also be taken into consideration; as a matter of fact it is usually more important than the lower, or cut-off, bend because the saturation is more abrupt. The detection diagram (Fig. 4) is very instructive on all these points, and many other practical conclusions may be drawn from it.

The corresponding experimental picture is presented in Figs. 9, 10, 11. The variation of the fundamental output with carrier, for 20 per cent modulation, is shown in Fig. 9 for several grid bias voltages (−2, −8, −15, −20 volts). These curves verify the qualitative deduc-

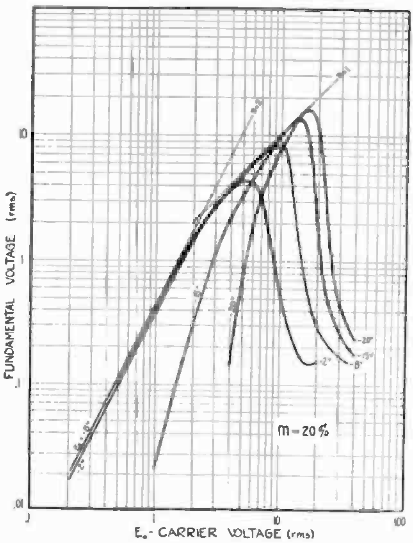

Fig 9—Resistance Output. Effect of grid bias. Relation between fundamental output and carrier Voltage. 201A triode; $E_b = 90$ v, $R = 110{,}000$ ohms, 20 per cent modulation.

tions from the descriptive theory. The maximum output for $E_c = -8$ v, for example, is about twice that for $E_c = -2$ volts. The small-signal behavior is normal for biases up to about −8 volts. The effect of the cut-off, that is obtained with biases of −15 and −20 volts, is to cause a variation of output more nearly as E_0^4 than as E_0^2. For this degree of modulation (20 per cent) an E_c greater than −8 v results in an ultimately greater output and the operation at the proper value of E_0 may be quite satisfactory and normal, even though unsatisfactory at small E_0.

The variation of distortion for the same changes of grid bias is shown in Fig. 10 for 20 per cent modulation, and in Fig. 11 for 100

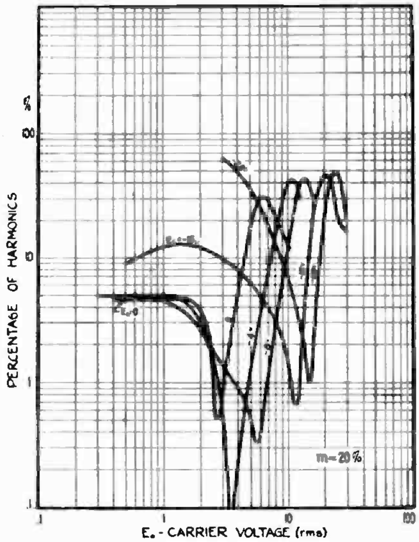

Fig. 10—Resistance output. Effect of grid bias. Relation between percentage of harmonics (distortion) and carrier voltage. Same conditions as in Fig. 9. Twenty per cent modulation.

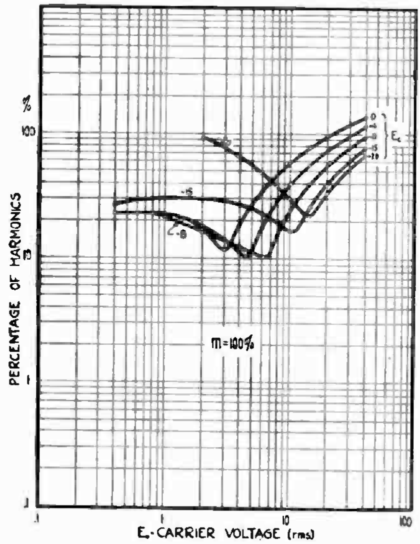

Fig. 11—Resistance output. Effect of grid bias. Same conditions as in Fig. 10 but with 100 per cent modulation.

per cent modulation. With reference to Fig. 10 it will be seen that the lowest average distortion for $m = 0.2$ is obtained with a bias of -8 v; this result checks the inference from Fig. 4. Note the abnormally large distortion for biases more negative than -8 v, i.e., in the cut-off range. The left-hand portions of these curves for $E_c = -15$ and -20 volts could not be followed further because the current became too small. The tendency toward the small-signal limit, $m/4$, shown by the -15 v curve, is probably only apparent.

The curves for 100 per cent modulation shown in Fig. 11 are generally similar to those for 20 per cent modulation. The value of -8 v as the best bias is further confirmed. By operating at the proper signal level the distortion is reduced from 25 per cent to 10 per cent. This improvement is readily perceived by the ear.

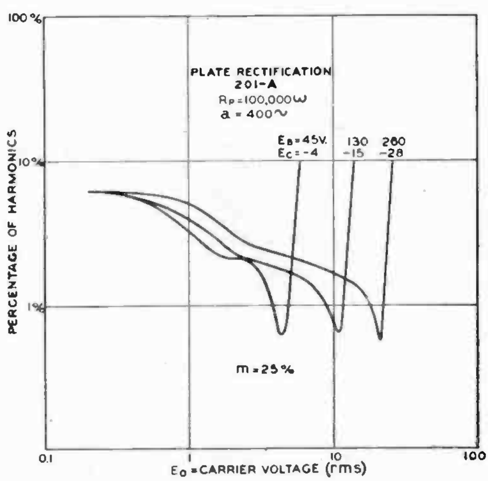

Fig. 12—Resistance output. Distortion versus carrier. Effect of changing plate and grid (bias) voltages simultaneously so as to preserve constant d-c plate current.

Effect of Plate Voltage. The effect of increasing the plate battery voltage is not particularly interesting, and if at the same time the grid bias is changed so as to preserve constant plate current, the curves just given are simply moved laterally toward higher E_0. This is illustrated by Fig. 12, which shows the distortion as measured with three combinations of plate and bias voltages selected on the basis of constant plate current. The harmonic curves in Fig. 12 do not agree exactly with those of Fig. 11 as the two sets of data were taken three years apart with entirely different apparatus, different tubes, and under different supply conditions. They illustrate, nevertheless, the shift of the phenomena toward higher E_0 which is characteristic of increasing E_b.

Relation between Fundamental Output and *m*. This relation is ultimately significant as an index of the fidelity of detection. The fundamental output should, of course, vary linearly with the degree of modulation, for a given carrier voltage. It should be noted, however, that this is not in itself a guarantee of the absence of distortion, for harmonics may still be present in the output. For example, with small signals the fundamental output varies linearly with m, but there is also present a double-frequency current which varies as m^2. With regard to the standard signal we may therefore make a further distinction between the kinds of distortion in detection due to non-linearity. We have: (1) a non-linearity in the relation between the fundamental and m, and (2) harmonics which are not present in the original signal. In

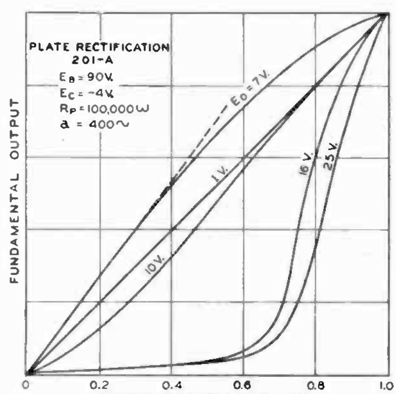

Fig. 13—Resistance output. Relation between fundamental output and degree of modulation for various carrier voltages.

the example cited above, of small-signal voltage and square-law detection, only the second kind of distortion is present.

The experimental relations between the fundamental output and the degree of modulation, obtained under the experimental conditions of the previous curves, are shown in Fig. 13. The grid bias is -4 v, and the several curves correspond to different carrier voltages. All curves have been reduced to equal output at $m = 100$ per cent. The curve for $E_0 = 1$ v may be taken as representative of small-signal operation (see Fig. 8), and the output is proportional to m. While no measurements were made with a carrier exactly equal to the optimum value (point B in Fig. 8) it may be inferred from the curves that the relation will be nearly, if not exactly, linear. Note the considerable departures from linearity when the detector is overloaded ($E_0 = 16$, 25 volts).

IX. Transformer Output Load

We have discussed the simple case of a resistive output impedance from both the descriptive and experimental viewpoints, have observed a satisfactory qualitative agreement between them, and have obtained a general idea of the way the detector operates at high signal levels. We may now turn to the consideration of other types of output impedance, for which the graphical method is not available. A case of practical interest is that of a transformer.

As previously remarked, the instantaneous relation between current and voltage now describes an ellipse on the rectification diagram in Fig. 3, and the detection diagram, Fig. 4, is multiple-valued and no longer significant. We may therefore turn to the mE_0 theory and particularly to the theorem expressed by equation (10) in order to obtain a starting point for design. According to this theorem the

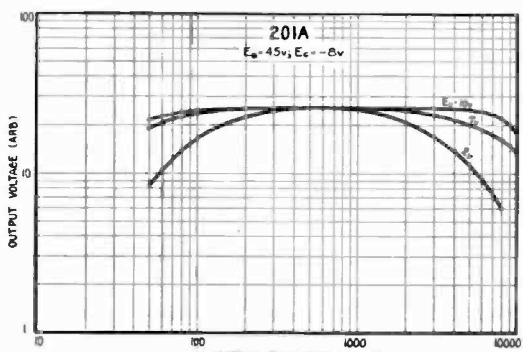

Fig. 14—Transformer Output. Effect of carrier voltage on fidelity; 201A triode; RFL 5B transformer.

problem of design for the detector is identical with that for an amplifier, provided the detection plate resistance, as defined in Sect. VII, is employed in place of the usual quiescent R_p. This is the gist of the whole matter and since amplifier design is well-known, no further discussion seems necessary.

The experimental relations between the fundamental output, distortion, and carrier voltage in the case of a transformer, at a definite modulation frequency, are very similar to those which have been shown in Figs. 8, 9, 10, 11, for a resistance. In view of this it does not seem justifiable to waste space reproducing the experimental curves, since they show nothing new. There is, however, one additional factor that does not appear in the resistance case, but which deserves discussion; this is the question of fidelity.

Fidelity. The term *fidelity* is employed here in its usual sense as designating the relation between the fundamental output and the modulation (audio) frequency. In an amplifier stage the fidelity is determined by the transformer impedance and R_p; in this case, R_p is a function of the carrier voltage, so the fidelity will in general depend upon the signal level. The change of fidelity with E_0 can be predicted from an experimental $R_p - E_0$ diagram such as Fig. 6. This is a matter of considerable practical importance. If the same fidelity is desired at low and high signal levels, the plate and bias voltages must be chosen so that R_p does not vary much with E_0 (compare curve for 220 v in Fig. 6). A case in which these voltages are so chosen, that R_p varies considerably with E_0, is illustrated by the experimental fidelity curves in Fig. 14. These were taken with a 201A-type triode, with $E_b = 45$ v and $E_c = -8$ v.

X. Practical Applications

The most promising practical application of detectors operating at signal voltages, high enough to give linear response, as described in this paper, is probably to receivers for broadcast (entertainment) and telephone reception with signals of the standard type (1). Plate and grid rectifying detectors of this type have been incorporated in broadcast receivers designed by the Radio Frequency Laboratories for its manufacturing licensees.

The idea of applying signal voltages of the order of 1 to 100 volts to a detector may have sounded fantastic and uneconomical when first proposed by us in 1923,[6] but this could hardly be urged today. Shielded tetrodes have lately become available in commercial quantities, and furnish the required amplification conveniently and at low cost. As a matter of fact in broadcast receivers for the range of 545 to 1500 kc a certain minimum number of tuned circuits are needed to provide the selectivity demanded by present conditions, and if these are cascaded between tetrodes yielding an amplification of the order of 100 per stage, the output voltages will be entirely adequate for this purpose. If desired, and the voltages are available, the detector may also replace the output tube and operate the electrophone load directly. This may properly be termed "power detection" and has been employed (*vide* also Fig. 5, Ballantine-Hull patent cited above). A less extreme step consists in eliminating but one audio stage, retaining the power tube and operating it by the output of the detector.

There is no special difficulty in maintaining the signal voltage at the optimum point B (Fig. 8) by a manual control; nevertheless it is desirable in receivers designed for commercial use to make the adjustment for linearity as easy and as obvious as possible. Two methods for accomplishing this have been employed. In the first the carrier is maintained at its optimum value over a wide range (10,000 to 1) of field strength variation by means of the automatic volume control which I have previously described.[9] In the second method manual control is employed and the adjustment is facilitated by extending the range of E_0 over which the detector is linear by means of special devices which will be described in the fourth paper of this series. The practical feasibility of both methods has been demonstrated in R. F. L. commercial broadcast receivers.

In conclusion I wish to acknowledge my indebtedness to Dr. K. C. Black, Messrs. H. A. Snow, P. O. Farnham, and Raymond Asserson for experimental assistance at various times.

[9] Meeting of the Philadelphia Section, Institute of Radio Engineers, May 21, 1926.

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TRANSMITTING ANTENNAS FOR BROADCASTING*

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FOR many more years broadcasting will be of increasing importance for the general public. We radio engineers must therefore recognize what the future problems of the broadcasting technique will be, what has to be improved or developed. The main thing will be that everyone in the world will be able to receive broadcast performances without being bothered by technical deficiencies.

I do not intend to discuss these problems as far as receivers are concerned; I shall only refer to the future development of transmitters and transmitting antennas. The ways and means for the development of broadcasting transmitters and the possibilities of improvement are already more or less known and the technical development will certainly continue the way it has thus far pursued. Future improvements in this field will concern an enlargment of the frequency range on either side—in the future we shall probably have frequencies from 20 to 20,000 kc; also the modulation will have to be enlarged, and ratios of amplitudes of 1:1000 will probably be broadcast by the transmitters. Therefore we shall have to use transmitters of higher power. The increased transmitting power will result in increasing the range of interference. Therefore it may become necessary to couple many transmitters in groups and broadcast on the same wavelength. The broadcasting system will be such that all transmitters working on the same wavelength will have to transmit the same program. This will probably result in control of these transmitters by means of talking films running synchronously. Later on still higher demands must be satisfied with regard to the reproduction of music; that is, this will bring the broadcasting transmission to the following point: control of the transmitter without transmission cable between studio and transmitter, and use of sound records on films operated in the high-power transmitting station. This pertains more to broadcasting conditions in Germany.

In this way the radio engineer may foresee the future possibilities of development in the design of transmitters. The principles of this development are generally clear, but this is not the case with regard to the transmitting aerial.

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Which is the best broadcast aerial? Fundamental conditions for such an aerial are: greatest economy; largest service area of the transmitter, that is, no fading within a very large area around the transmitter; smallest interference area. By simply increasing the intensity of the transmitting energy we would not increase the service range but only the range of interference.

I wish to report to you how we have pursued these problems in Europe, particularly in Germany. Our intention was to modify the ratio between surface waves and space waves in favor of the surface waves. The radiation emitted from the aerial upwards at a certain angle must be reduced as far as possible. The aerials which are com-

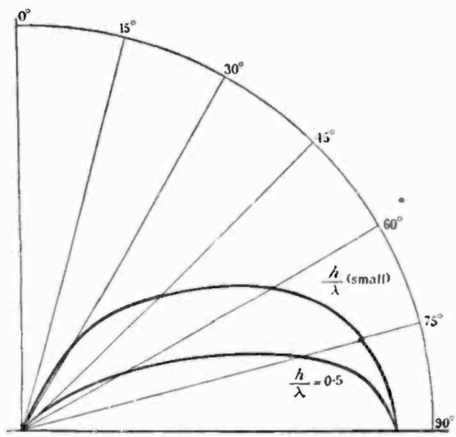


Fig. 1—Vertical Polar Diagram of Radiation for $\frac{1}{2}\lambda$ and $\frac{1}{4}\lambda$ (or less) aerials. Drawn for the same maximum radiation intensity in the horizontal plane.

monly used in broadcasting oscillate in a quarter wavelength. They might be considered as one half grounded dipole (half-dipole). Such aerials usually show fading at wavelengths between 400–500 m in a distance of 100–120 km due to the influence of the reflected space waves. In order to improve the ratio of the surface waves to the space waves, we use for transmission instead of the half-dipole a complete dipole suspended as high as possible. Thus instead of a quarter wavelength, the length of the aerial is now a half wavelength.

While the usual aerials for broadcasting have a current loop at the grounded point of the aerial, there is now a current node at said point, and hence a loop of potential. Such an aerial has an increased radiation horizontally parallel to the surface of the earth. Fig. 1 is taken from Eckersley's[1] recently published paper demonstrating the difference between these two aerials. In order to avoid possibility that the hori-

[1] P. P. a. T. L. Eckersley a H. L. Kirke, *Jour.* I.E.E., April, 1928.

zontally emitted radiation from such an aerial be disturbed, it is necessary that the high supporting masts be insulated at the base. When iron masts are used care has to be taken that their natural wavelength does not coincide with the wavelength of the transmitter. Since the natural wavelength of the insulated metal mast is approximately equal to twice the height, one is obliged to accept the following compromise regarding the height of the mast: the height of the mast must be smaller than half the emitted wavelength and the antenna must be designed so that the center of capacity of the upper half of the dipole is still situated (approximately) at the same height it would be in the case of an aerial wire stretched vertically, and the length

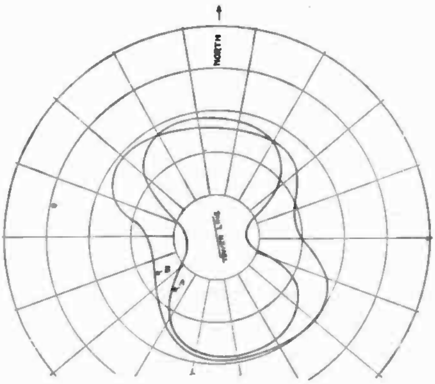


Fig. 2—Field Patterns of Vertical Antenna in Span B–F.
Pattern A—with towers resonant
Pattern B—with towers detuned

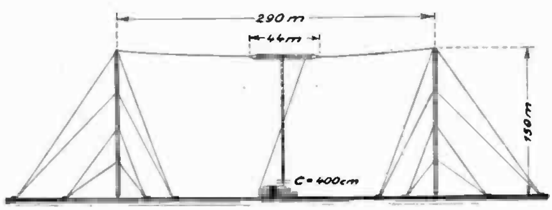
of the wire has to be $\lambda/2$. If the natural wavelength of the masts is of the order of the transmitted wavelength, the field distribution loses its symmetry. Fig. 2 shows such a distortion of the field with a $\lambda/4$ aerial from tests carried out by H. M. O'Neill[2] of the General Electric Company, Schenectady. In this case the distance between the masts and the aerial is larger than $\lambda/4$. The masts are 100 m high and are grounded at the base. The wavelength was 380 m. If the tuning of the masts is within the range of resonance, the field intensity in the direction of the masts is essentially higher than in the plane normal to said direction.

[2] H. M. O'Neill, Proc. I. R. E. 16, 880; July, 1928. According to R. Beckmann the influence of the mast may be calculated by the following formula:

$$E = K \cdot \frac{J_a}{r} \sqrt{\left[1 + 2\frac{J_m}{J_a}\cos\left(\frac{\pi}{\lambda} d \cos\varphi\right)\right]^2 - 2\frac{J_m}{J_a}\cos\left(\frac{\pi}{\lambda} d \cos\varphi\right) \cdot \left(2 \sin\frac{\psi}{2}\right)^2}$$

In this formula J_a is the current in the aerial, J_m the current in the mast, ψ the azimuth angle, ϕ the phase of the current in the mast is a function of its natural vibration and the distance d/λ.

Experiments carried out by Telefunken in order to improve broadcasting aerials by using total dipoles were started early in 1926. Later on they were continued in cooperation with the German Telegraph Technical general-postoffice (Telegraphen-Techn.). Before 1926 it was not possible to use such aerials with a potential loop at the grounding point due to the fact that broadcasting transmitters with independent drive had not yet come into use. At that time it was recognized that although an ammeter in the earth connection indicated scarcely any current, aerials could nevertheless be energized if the transmitter was separately controlled by an auxiliary generator. From the intermediate circuit current and the plate current of the last amplifier stage the amount of energy transferred to the aerial could be estimated.



$\lambda = 545\ m$

$\lambda_0 = 930\ m$

Fig. 3—Broadcasting Transmitter—Budapest.

This principle of using $\lambda/2$ aerials instead of $\lambda/4$ aerials formerly developed by Telefunken has proved to be correct and has been verified by tests recently made by Mr. Eckersley, the technical manager of the British Broadcasting Co. In order to avoid interference from the radiation effect of the aerial by the masts, these tests have been carried out with aerials supported by balloons. It was found that such an aerial of $\lambda/2$ height radiated an increased field intensity of 1:1.26 compared with an aerial of $\lambda/4$ height. But the most important fact, he found, was that with the $\lambda/2$ aerial, compared with the $\lambda/4$ aerial, fading could be reduced and that due to this reduction of fading the service area of the antenna was enlarged.[3]

I wish to explain to you the results that may be obtained in practice with such aerials, and for this purpose I would refer to the broadcast transmitter at Budapest which has been designed according to these

[3] For the German broadcasting transmitters having self-supporting masts of 100 m height the Telegraph-technical-office (Mr. W. Schäffer) since 1927 has also introduced the principle that the transmitted wave shall be 0.6 times the natural wavelength of the aerial.

principles and has been operating now for about one year. This transmitter is especially known all over Europe for its wide range of transmission. It was built by the Telefunken Company under the supervision of the Hungarian Post and Telegraph Administration. The antenna (Fig. 3) is supported by two 150-m masts 290 m apart. The vertical aerial has a flat top extending horizontally about 22 m in both directions. The service wavelength is 545 m, the natural wavelength of the aerial being 930 m. The antenna is shortened at its grounding point by a capacity of 400 cm. By means of this capacity

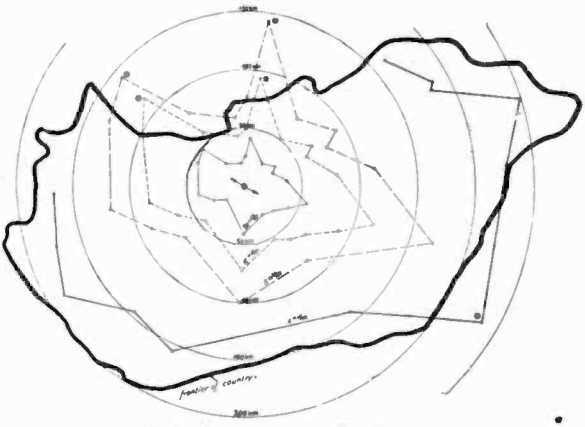


Fig. 4—Field Intensities—Budapest. 15 kw.

the aerial is at the same time coupled to the transmitter. The current loop lies approximately at half the height of the mast and the potential loop at the grounding point. Accordingly only few grounding wires are used. The earth resistance is not of great importance.

Fig. 4 shows the field intensities around the aerial with a transmitter output of 15 kw when not being modulated; these intensities have been measured by the officials of the Hungarian Post and Telegraph Administration.[4] The field intensities at different distances and in the two preferred directions were as follows:

at	50 km	about	30	mv	per m.
"	100 "	"	11	"	"
"	150 "	"	5	"	"

The distortion of the field intensity curve in the direction of the plane of the masts (indicated by the arrow) is caused by the influence of the masts. The insulator which serves to separate the mast from the rope supporting the aerial has by mistake been inserted in the

[4] S. Baczynski, *Telefunkenzeitung*, June, 1929.

middle of this supporting rope so that by a rope of 61 m length the natural vibration of the mast was increased to about 450 m and approached that of the transmitted wave, thus causing a distortion of the field intensity in the direction of the plane of the masts. For the transmitter at Budapest, however, this distortion effect was very desirable since the Hungarian country is a narrow but long area, and because it had been required that this one transmitter at Budapest should provide, if possible, a field intensity which could be efficiently picked up at any place in the country.[5]

The following table shows the field intensities at various distances, i.e., 50, 100, and 150 km, measured around Budapest, Motala, the strongest broadcasting transmitter in Sweden, reduced to 15 kw,

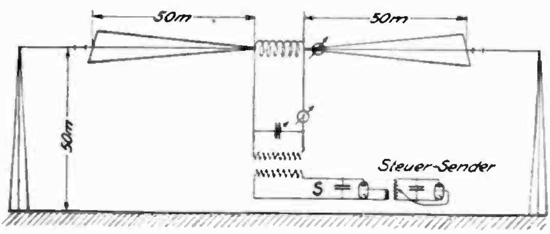


Fig. 5—Horizontal Antenna for Broadcasting.

and around an English high-power transmitter, according to P. P. Eckersley's[6] statement, which is also reduced to 15 kw.

TABLE I

	50 km	100 km	150 km
BUDAPEST 15 kw			
Favorable direction	30 mv/m	11 mv/m	5 mv/m
Average	19 "	5 "	1.4 "
MOTALA 15 kw			
Maximum	21 "	4.95 "	2.1 "
Average	12 "	3.2 "	1.2 "
ENGLISH STATION			
Average	13 "	4.22 "	1.5 "

But what has made the new antenna at Budapest particularly valuable and useful is the remarkable improvement with regard to fading. The observations made by the Hungarian Post and Telegraph Administration have shown that slight fading begins only at distances beyond 150 km, and in the direction of the plane of the masts fading will occur at greater distances. For normal aerials the limit for fading with this wavelength is from 100 to 120 km.

Another aerial similar to that at Budapest has just been completed at Oslo (Norway) by the Telefunken Company under the super-

[5] The disturbance of the field strength in Fig. 4 can be described by the formula in footnote 3, substituting in this formula the ratio of current in the masts to that in the antenna $= \frac{1}{6}$.

[6] P. P. Eckersley, *Jour.* I.E.E., **65**, 600; 1927.

vision of the Norwegian Post and Telegraph Administration. In this case an aerial 150 m high has been provided for working a wavelength of 496.7 m.

Though the problem of broadcasting aerials seems to have been considerably advanced, yet another question must be cleared: Is a horizontal aerial which is fed at its center by a feeder line better than a vertical aerial? During the tests carried out in 1926 (Fig. 5) in cooperation with the German General Post Office it appeared that the horizontal aerials were superior to the vertical ones within the broadcasting wave range up to 300 m if they were suspended at a height of about $\lambda/4$ above the ground, and this applies to the direction of the plane of the aerial as well as to the direction at right angles to it.

In the experiments self-supporting grounded masts were used. For waves beyond 300 m and under the conditions prevailing at that time (100-m grounded masts), the vertical aerial seemed to be superior to the horizontal one. Owing to the complicated construction of such aerials these experiments were not continued. But I hope that they will be taken up within a short time and that we shall then be thoroughly informed about all the different types of broadcasting antennas.

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CORRELATION OF DIRECTIONAL OBSERVATIONS OF ATMOSPHERICS WITH WEATHER PHENOMENA*

By
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Introduction

SINCE March, 1928, observations of the direction of arrival of atmospherics have been made by the American Telephone and Telegraph Company at Houlton, Maine, U. S. A. using a cathode ray direction finder.[1] This apparatus as used at Houlton has been described by Mr. A. E. Harper[2] in a paper in which the results of the observations are analyzed by means of long-period averages, and compared with data on the distribution of thunderstorms over the earth. It is the purpose of the present paper to point out the relation of individual observations to the weather conditions existing at the time, and to indicate the possible usefulness of such observations in weather forecasting.

Attempts have been made to correlate these observations with weather phenomena using the daily weather maps of the U. S. Weather Bureau and of the British Air Ministry, together with daily reports of thunderstorms in the United States, the latter kindly furnished by Dr. Kimball of the New York Office of the U. S. Weather Bureau. No detailed analysis of the results is presented in this paper, but our general conclusions are stated and illustrative examples given.

This work had as its inspiration similar observations made during the summer of 1927 by R. A. Watson Watt[3] and his associates in England and Scotland, with the assistance of the British General Post Office. In the case of the British observations, the use of two observing stations (one at Cupar, Scotland, the other at Slough, near London) connected by a telephone line made possible the identification of individual disturbances and the location of their origins by

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[1] R. A. Watson Watt and J. F. Herd, "An Instantaneous Direct-Reading Radiogoniometer," *Jour.* I.E.E., 64, No. 353; May, 1926.

[2] A. E. Harper, "Some Measurements of the Directional Distribution of Static," presented at the meeting of the American Section of the U.R.S.I., Washington, D. C., May 15, 1929.

[3] Reported by Appleton at the Washington meeting of the U.R.S.I. in 1927.

triangulation. It was found that in the vast majority of cases the locations coincided with those where thunderstorms were known to have occurred or where conditions were such that thunderstorms would be expected. The southeasterly edges of low-pressure areas were found to be the most common sources of disturbances.

The work at Houlton has been handicapped by the fact that only a single observing station was available, making triangulation impossible. Another difficulty which we encountered was due to the bidirectional ambiguity of the device, but this was removed by the installation of a unidirectional feature.

Correlation With Weather Conditions

In spite of these handicaps, it has been possible to correlate the observations with weather conditions in the vast majority of cases, excepting, of course, those occasions when the sources of atmospherics were in regions not covered by available weather data. In many cases the directions from which atmospherics came coincided with the bearings from Houlton of places where thunderstorms were reported. In many others the sources of atmospherics were apparently low-pressure areas where thunderstorms may have occurred, though none was observed at Weather Bureau stations. We are inclined to believe from these results, as well as from the work of others, that most atmospherics are due to lightning discharges, although, of course, the evidence is too incomplete to permit us to draw positive conclusions.

A low-pressure area seems to produce more atmospherics when it is moving rapidly. When it is more or less stationary and quiescent it produces few atmospherics. In the summer, lows produce many more atmospherics when over land than after they pass out to sea, but in cool weather the reverse is sometimes true. In the winter, sources as far away as Texas, the West Indies, South America, and Africa can be observed, but in the summer the effects of nearby disturbances usually overshadow these distant sources. On days when there is nearly a complete absence of thunderstorms in the United States, the atmospherics are generally light, unless there is a source due to a low not far out in the Atlantic.

Another interesting phase of the work has been that in which it has been possible to detect the approach of storms from areas not covered by available weather data. In one case, a distinct source of atmospherics gave evidence of a disturbance in the Caribbean beyond the southern limit of the U. S. Weather maps two days before this storm, moving northward, began to be indicated on the maps. In another case, a strong disturbance was indicated to the northwest of

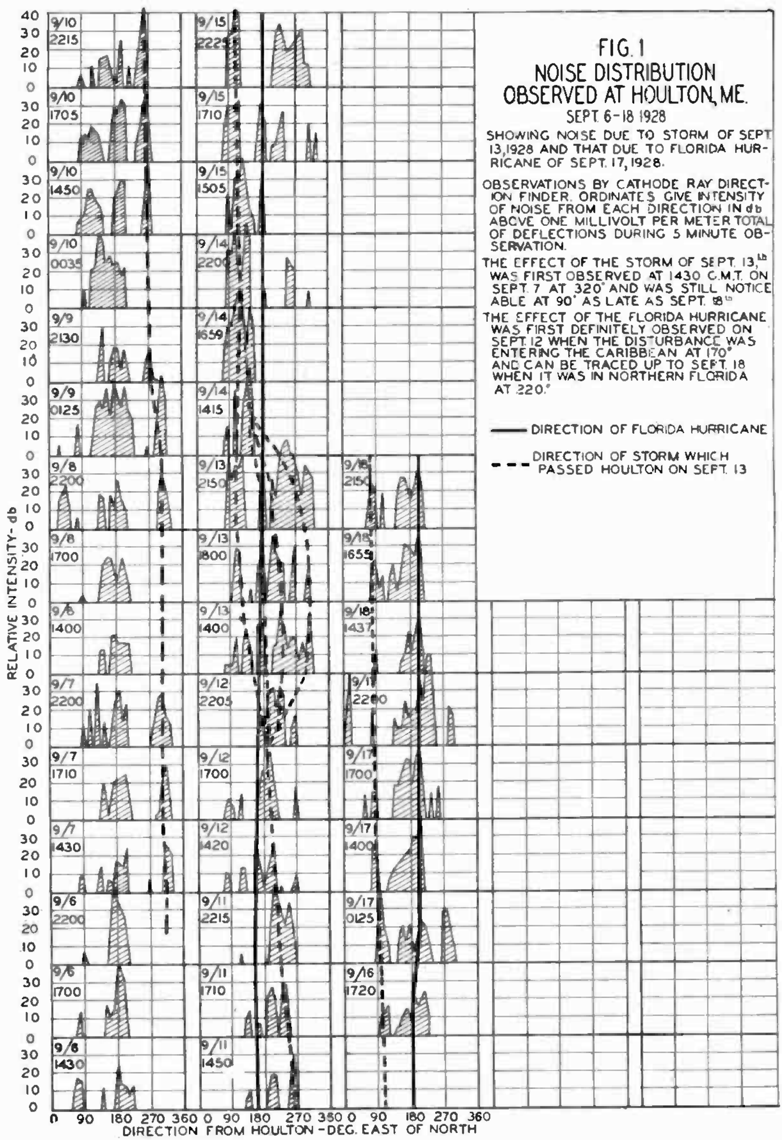

Fig. 1—Noise Distribution Observed at Houlton, Maine, September 6–18 1928.

Houlton, the origin of which remained a mystery to us until the British Air Ministry weather maps were received some ten days later, which showed a low-pressure area over the Hudson Bay region.

We often have evidences of disturbances out to sea in the direction southeast from Houlton, which may be due to storms at sea which are not reported to the Weather Bureau.

To give an example of the way in which storms may be followed, by means of the directional observation of atmospherics, Fig. 1 has been prepared. This figure shows the directional distribution of atmospherics as observed at Houlton from September 6 to September 18,

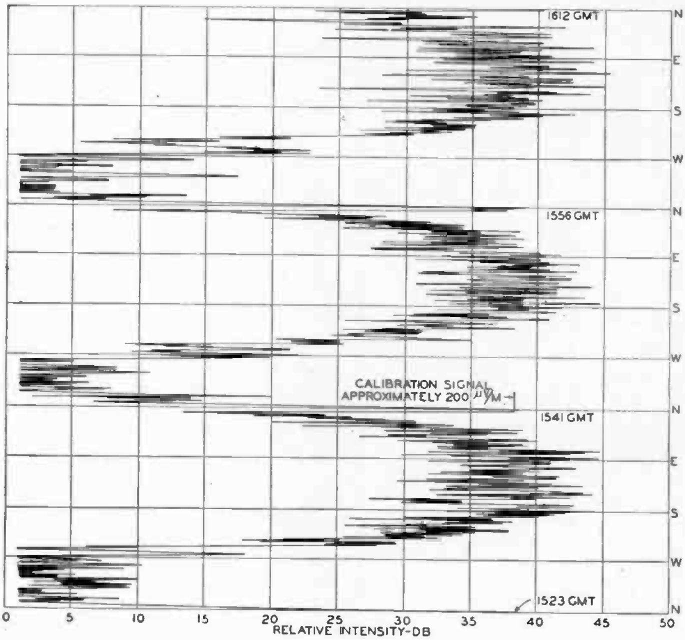

Fig. 2—Record of Rotating Recorder Taken from 1523 to 1612 G.M.T., September 14, 1928.

1928. During this period there were, of course, several storm centers causing disturbances, of which two have been selected for discussion. One is a storm which first gave us evidence of its existence on September 7, 1928, when it was somewhere northwest of the Great Lakes, bearing 320 degrees from Houlton. Starting at the lower end of the left-hand column and proceeding upward to the top of the drawing, thence up the second and third columns, the dashed line indicates the progress of the storm in terms of its bearing from Houlton. In nearly every observation, distinct evidence of the storm is seen in the form of a peak on the atmospheric direction curve in the direction of the storm. High winds and severe electrical disturbances accompanied the storm at several points along its course. It passed the vicinity of Houlton on September 13, 1928, being accompanied by unusually frequent lightning. The observations of that day showed the disturbance apparently surrounding Houlton, with atmospherics coming from several directions. On the next day (September 14) the disturbance was out to sea to the southeast of Houlton. Evidence of the storm at sea persisted for several days thereafter.

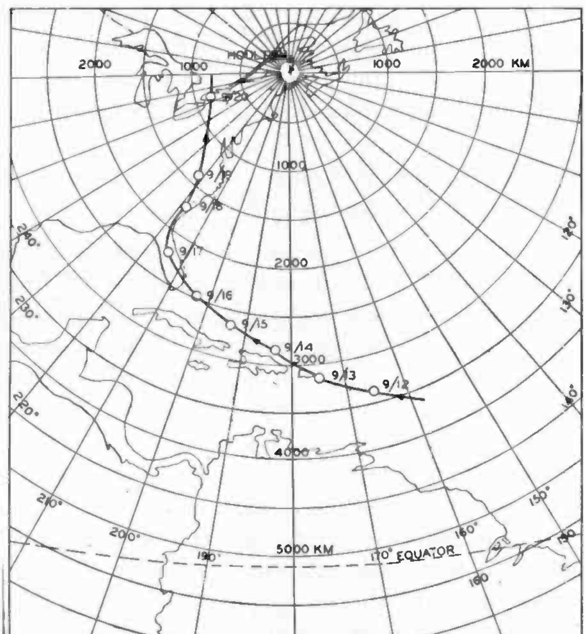

Fig. 3—Polar Map About Houlton, Maine, Showing Path of Hurricane September 12–20, 1928.

As an example of the results obtained from another method of atmospheric direction-finding, there is shown in Fig. 2 the record of an automatic recorder,[2] which shows evidence of this storm when it was southeast of Houlton on September 14, 1928.

The other storm selected for discussion is the Florida hurricane of September 10-20, 1928. The first definite indication of this storm from weather data seems to be on September 10, 1928, when it was reported southeast of Porto Rico, bearing about 150 degrees from Houlton. While there are some evidences of it in the atmospheric records prior to that date, one cannot establish a definite correlation due to the meagerness of the available weather data. The track of this hurricane is shown in Fig. 3, the data for which was obtained from the U. S. Weather Bureau.[4]

Starting from the bottom of the second column on Fig. 1, the solid line shows the progress of the hurricane, in terms of its bearing from Houlton, from September 11 till September 18, 1928. Although many other stronger disturbances are indicated, due to sources nearer Houlton, in most of the observations there is a definite peak in the direction of the hurricane. On September 14, the absence of evidence of the hurricane in the observations at 1400 and 1700 G. M. T. is probably due to the extremely strong nearby source, which made it necessary to reduce the amplification of the cathode ray device until the atmospherics due to the hurricane were not observable.

Advantages of Cathode Ray Apparatus over Rotating Loop

The use of radio direction finders as a means of locating storms is by no means new. In this country, however, previous workers have used automatic recorders associated with continuously rotating loop or loop-and-vertical antenna systems.[5] Such apparatus is subject to the limitation that it records only the integrated effect of all sources of atmospherics. In case two or more equally strong sources are present it is usually impossible to determine the direction of any of them, and weak sources cannot be detected when a strong source is present. This is quite a disadvantage from the point of view of weather forecasting, since atmospherics from a storm receding from an observing station will often mask those from an approaching storm concerning which information is desired. A comparison of Figs. 1 and 2 will illustrate this point by showing how impossible it would be to detect the atmospherics due to the Florida hurricane on the record of Fig. 2. The cathode ray direction finder, on the contrary, permits the determination of the directions of a large number of sources simultaneously, since the effect of each atmospheric is to produce a discrete deflection of the spot on the tube. Truly simultaneous atmospherics are so infrequent that they offer only slight hindrance in observing each source by itself.

[4] C. L. Mitchell, "The West Indian Hurricane of September 10–20, 1928." *Monthly Weather Review*, **56**, No. 9; September, 1928.

[5] E. H. Kincaid, U.S.N. "Two Contrasting Examples Wherein Radio Reception was Affected by a Meteorological Condition," Proc. I.R.E. **15**, No. 10; October, 1927. Includes summary of previous publications on this subject.

The cathode ray apparatus is also very well adapted to triangulation. If two or more stations are connected by telephone, the observers can identify the deflections produced by each atmospheric, thus obtaining simultaneous bearings which can be used to plot the locations of the several sources. The results of Watson Watt's work in Great Britain using a telephone connection between observation points have demonstrated beyond doubt that triangulation is practicable.

Application to Weather Forecasting

To one who is without a detailed knowledge of the meteorology of weather forecasting this work raises a question as to whether a system of observing stations with cathode ray direction finders connected by telephone and telegraph would be of assistance in tracing the movements of storms. This question arises particularly in the case of storms out at sea or in areas where there are few or no weather observation stations.

It would seem that as few as three stations, one on the north Atlantic coast, one on the south Atlantic coast, and one in the middle west, would cover the eastern part of North America and the western part of the Atlantic Ocean fairly well. Our experience indicates that such a system might be helpful in the location of storms in Northern Canada, the Atlantic, the Gulf of Mexico, and the West Indies, as well as those in the eastern half of the United States. A similar system on the Pacific coast might permit the location of storms in the Pacific Ocean and possibly the forecasting of their arrival at the coast.

Conclusions

Our work at Houlton with the cathode ray direction finder has confirmed the results of Watson Watt and others in Europe in establishing a close connection between atmospherics and weather conditions. It has been possible in many cases to follow the movements of storms as far as 2000 miles from Houlton. Sources of atmospherics usually seem to be associated with the advancing edges of low-pressure areas. In the case of lows in the Northern Hemisphere moving from west to east, the southeastern part of the low produces the most atmospherics.

The cathode ray direction finder is particularly suitable for such work, since it permits the directions of several simultaneously active sources to be determined. By triangulation the locations of the sources can be established.

The question is raised as to whether a system of stations for the directional observation of static would be of assistance in weather forecasting, especially in following the progress of storms in regions where there are no stations for weather observations.

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EXPERIMENTS IN RECORDING RADIO SIGNAL INTENSITY*

By

L. W. Austin

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Summary—*The paper describes briefly the method of recording the strength of long-wave radio signals used at the Bureau of Standards and gives some of the results obtained. The curves shown indicate the great variability of the wave propagation both in regard to strength and the angle of incidence of the downcoming wave. This variability appears to be greater for transmission distances below 1000 km than for greater distances. An apparent connection is shown in certain cases between the night signal variations and magnetic storms. The observations seem to indicate that the downcoming waves are reflected (or refracted) from rapidly changing masses of ionized gas.*

It was originally thought that daylight observations represented normal radio transmission, while night observations showed the normal transmission disturbed by reflection effects, the study of which might be properly neglected until the simpler daylight conditions were better understood. In recent years, however, it has become increasingly evident that daylight and night transmission phenomena are so interconnected that there can be no clear understanding of the first without considering the second. Therefore, as our laboratory personnel was too limited to permit night watches, it was decided to try automatic recording. Our apparatus has been described by my assistant, Mr. Judson, in another place.[1] It consisted briefly of an autodyne detector such as we have long used for daylight measurements by the telephone comparator method,[2] and several stages of audio-frequency amplification. The last audio-freqeuncy stage is coupled inductively to a tube rectifier circuit containing the Cambridge recorder, which prints the deflections on a revolving drum every half minute. By means of a clock relay, described in Mr. Judson's article, different stations can be tuned in or the circuit can be connected to different signal collector systems as may be necessary for the different records desired.

Automatic recording has some bad as well as good features. While it gives easily a vast number of series of observations, it is somewhat

* Dewey decimal classification: R 270. Original manuscript received by the Institute, April 13, 1929. Read at Brussels meeting of the U. R. S. I., September, 1928. Publication Approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] Proc. I. R. E., 16, 666; May, 1928.

[2] Proc. I. R. E., 12, 521; October, 1924.

limited in its accuracy and dependability as compared with the work of personal observers. For example, unknown disturbances may at times intrude themselves and not be detected, and accidents may happen to the apparatus rendering a whole night's work useless.

Until the time comes when special transmitting stations are operated purely for experimental purposes, continuous records, continued day after day for months at a time, can evidently be made only on regular traffic from commercial transmitting stations. This, of course, rules out all extended experiments depending on special signals. Commercial stations are more or less irregular, seldom sending much on Saturday nights or on Sundays, and sometimes closing down entirely for considerable periods.

The particular system of recording which we have adopted has certain good points which deserve mention. By using only audio-frequency amplification a very good degree of constancy of calibration can be obtained over periods of many months. If the filament currents of the amplifier are kept constant within ± 1.5 per cent and the plate voltages within about ± 10 per cent, the changes in sensitivity will not be greater than ± 10 per cent, which is about the limit of accuracy in measuring absolute signal intensity from commercial sending.

Another convenient fact is found to be that it is quite possible with this type of recorder to get a nearly linear relationship between the antenna voltage and the recorder deflection over most of the scale.

It is also found that when an interfering signal is weaker than the signal being measured the two effects do not appear to superpose on the recorder within the limits of accuracy assumed above, i. e., the resulting deflection seems to correspond closely to that of the stronger signal alone. It is only when two signals are nearly equal in intensity that superposition becomes evident.

Some of the work which is being done by means of automatic recording is described below.

Reception Variation

The recorder was first used for registering the general changes in long-wave signal intensity during the day and night. In the beginning an attempt was made to measure a large number of stations, observing each station for five minutes in every hour. Curves of this kind were shown in Mr. Judson's paper already cited. While this method was fairly satisfactory, at least with distant stations, it was soon decided that, on account of the rapid changes in intensity, more frequent observations on each station were desirable. In recording the transoceanic long-wave stations, with which our work largely deals, it was found, especially in the cases of stations at distances of less than 1000 km, that the sequences of change in intensity showed very great variability on different nights. The degree of this variability may be seen in the collection of curves in Fig. 1. In this figure the curves are made up from series of ten recorder points taken each half minute with five-minute intervals after each series. In considering the variability of the curves without going into the possible causes of variations, we see at once that curves taken on single nights, or even on a considerable number of nights, would have very little value for purposes of generalization. It was thought at first that there were more or less

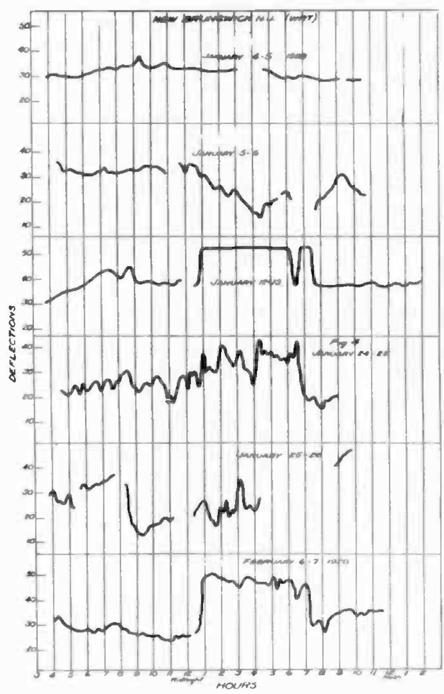

Fig. 1

periodic cycles of night change, the same patterns of change repeating themselves every two or three weeks, but we are now doubtful as to the existence of such cycles, apart from the possible effects of magnetic and solar disturbances.

Fig. 2 shows the differences which may exist in the night changes in signals of somewhat different wavelengths coming along the same path at the same time. The two stations, WCI ($\lambda = 16350$ m, $f = 18.35$ kc) and WGG, ($\lambda = 13500$ m, $f = 22.22$ kc), are both at Tuckerton, N. J., 251 m from Washington, WCI transmitting from an umbrella antenna while WGG makes use of a flat top antenna. It is not believed, however, that the differences observed are produced by the antenna forms, as similar differences are also found in other cases where the antennas are of the same type.

In the case of transmission over distances short enough to make the ground wave comparable in intensity with the downcoming wave, it must be remembered that the phase relation between the two, due to the difference in length of their paths, is probably the chief factor in determining whether the signal intensities at night rise above or fall below their daylight values. This fact must be remembered in making

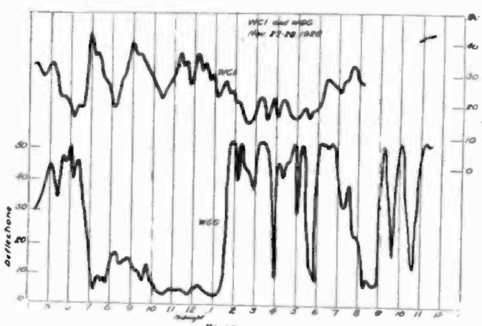

Fig. 2

use of the night signals from stations with strong ground waves for the study of the correlation of radio transmission with other natural phenomena.

It is generally believed that below the Kennelly-Heaviside layer there is a region of sufficiently great ionization to produce absorption in the downcoming wave, certainly in the day time and perhaps, in a lesser degree, at night. The relative importance of reflection or refraction in the Kennelly-Heaviside layer, and absorption in the absorbing layer in affecting signal intensity is not yet by any means clear, the absorption perhaps being more important in the day time, and the changes in reflection at night.

Measurement of Downcoming Wave Angle

Another use for the automatic recorder is the continuous determination of the angle with the horizontal at which the downcoming wave reaches the receiving station. A method for calculating this from observations made on a vertical antenna and on a loop antenna has been given by Appleton and Barnett.[3]

[3] *Proc.* Royal Soc., (A), 109, 621, 1925.

In the following explanation, for the sake of the clearness of the physical picture, the electric field is considered both in the case of the antenna and of the loop, instead of considering the electric field in the case of the antenna and the magnetic field in the case of the loop, as in the paper by Appleton and Barnett.

Suppose the case of a radio wave passing along the ground with its electric force E_G vertical and a reflected or refracted wave from the same source coming down from the Kennelly-Heaviside layer at an angle ϕ with the horizontal and with its electric force E_R at right angles to the direction of propagation and in the propagation plane. E_R on account of the difference in length of the two paths will, in general, be out of phase with E_G.

From Fig. 3A, it is seen that the downcoming wave E_R before and after reflection from the earth will have its vertical components $E_R \cos\phi$ and $E_{R1} \cos\phi$ in phase but its horizontal components $E_R \sin\phi$ and $E_{R1} \sin\phi$ in opposite phase, so as to neutralize each other, if the earth is a perfect conductor, which is generally approximately the case for

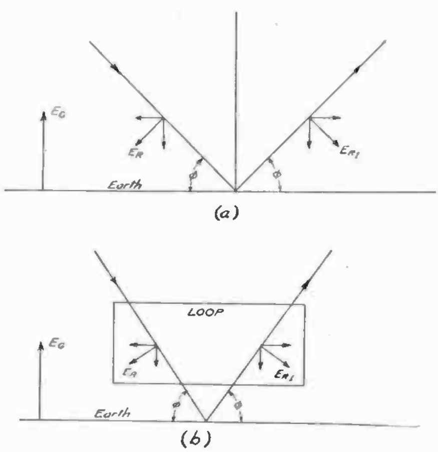

Fig. 3

very long waves. The resultant e. m. f., therefore, as measured on an antenna will be practically vertical and will be $2E_R h \cos\phi$ when h is the effective height of the antenna.

Different conditions prevail in the case of reception on a vertical loop with its plane in the plane of propagation, as has been shown by Appleton and Barnett in the paper cited. The loop current may be looked upon as due to the difference in phase of the wave where it enters the loop and where it leaves it, the resultant electromotive force being independent of the angle at which it strikes the loop and equal to $(E_R 2\pi nh')(l/\lambda)$ where E_R is the field strength; l, the distance from the front to the back of the loop in the direction of propagation; $nh'l$, the area turns of the loop; and $2\pi(l/\lambda)$, the difference in phase of the wave at the points of entering and leaving the loop. As the phase of the horizontal component will be shifted 180 deg. by reflection and as the reflected wave now passes the loop from below, (see Fig. 3B) the resulting e.m.f. produced in the loop by the reflected wave will be in the same direction as that due to the direct wave and the sum of the two e.m.f.'s will be $4\pi E_R nh'(l/\lambda)$. If we assume no abnormal polarization in the downcoming wave, and that the field due to the downcoming wave is negligible in comparison with the ground wave in the daytime, and that the latter remains of the same intensity by night as by day, we may determine the angle of the downcoming wave as follows: having observed the average day field intensity (ground wave alone) E_G, which will be the same for the antenna and loop, and then the average night field intensities on the antenna and loop, which will, in general, be different, we have, calling the resultant antenna field intensity E and the loop field intensity E'

Antenna	Loop
E_D (day) $= E_G$	E_D' (day) $= E_G$
E_N (night) $= E_G + 2KE_R \cos\phi$	E_N' (night) $= E_G + 2KE_R$

The difference in night and day field intensities is then

$$E_N - E_G = 2KE_R \cos\phi \qquad\qquad E_N' - E_D = 2KE_R$$

The ratio of the night and day difference of the field intensities of the antenna and loop is

$$\frac{2KE_R \cos\phi}{2KE_R} = \cos\phi$$

where ϕ is the angle which the direction of the downcoming wave makes with the horizontal, and K a factor depending on the integral phase difference between E_G and E_R.

The accuracy of this result will be vitiated to the extent that reflection takes part in day transmission and to the extent that the ground wave varies between night and day.

Fig. 4 shows the great differences which are found in the loop and antenna reception patterns from long-wave stations at night, corresponding to differences in the angle of the downcoming wave. The reception shown in the figure is from WSS at Rocky Point, L. I., the distance from Washington being 435 km, and the wavelength 16100 m. Since the curves of the individual days are so varied in form, an attempt has been made to use averages covering a month for determining the mean values of the downcoming wave angles at the various times of the night. It has not been found possible to determine the angle of the downcoming waves in the middle of the day, although these waves almost certainly exist, at least in winter, as is shown by the fact that the signals sometimes reach two or three times their calculated values. Their presence has also been indicated by the work of Hollingworth.[4]

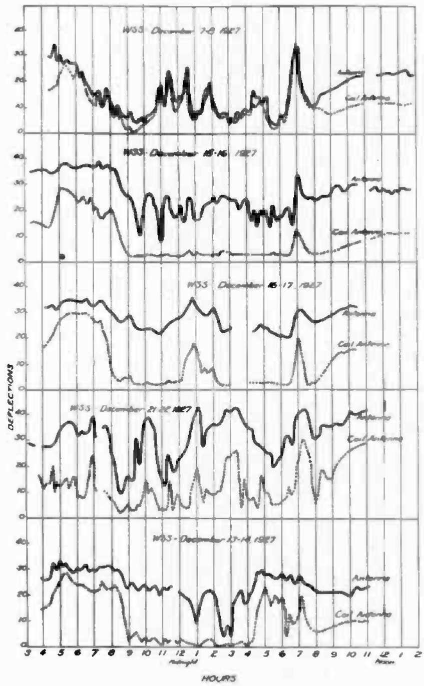

Fig. 4

Fig. 5 shows the curves of the mean values of the angle for the hours between 4 P. M. and 10 A. M. for the station WSS in the months of December 1927 and February 1928. The two curves show a rapid rise in angle about sunset, an irregular course during the night, a fall followed by a rise about sunrise, and a rapid fall to low values an hour or two later.

Attempted Determination of the Height of the Kennelly-Heaviside Layer

If it were possible to assume that the downcoming wave is the result of regular reflection from a plane surface we could at once cal-

[4] *Jour.* I. E. E., London, 64, 579, 1926.

culate the height of the reflecting layer since the distance between the sending and receiving stations is known. Fig. 6 shows the average

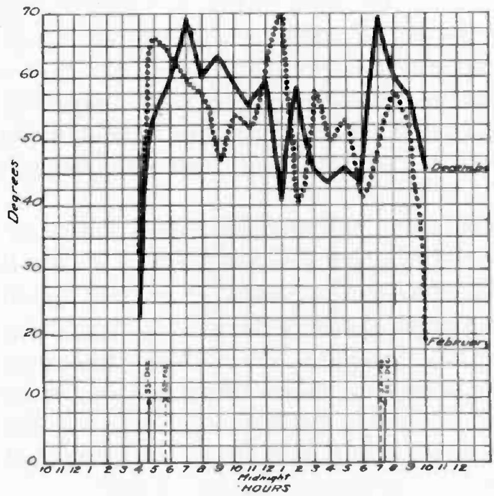

Fig. 5

heights for the various hours of the night, for the station WSS during the month of February 1928, as calculated from the downcoming wave

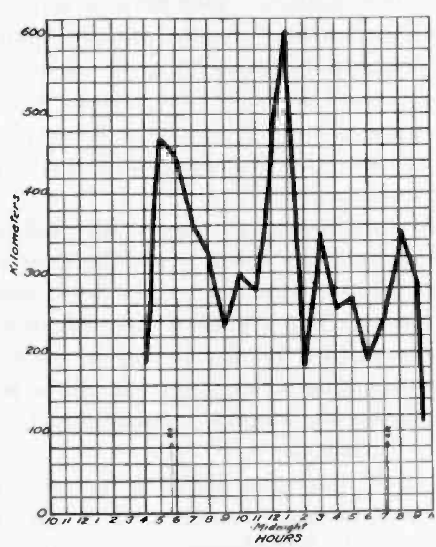

Fig. 6

angles in Fig. 5. Fig. 6 indicates a rapid rise in the height of the layer near the time of sunset, with irregular changes during the night and a fall after sunrise, corresponding to the changes of angle in Fig. 5. This is probably qualitatively correct, but an actual change in height from 50 to 500 km, as indicated in Fig. 6, would necessarily result in the intensity of the signal passing through a number of maxima and minima due to the interference of the ground and downcoming waves. These maxima and minima do not appear on the records of the recorder. If we consider the indicated height records of the individual nights, the heights calculated are seemingly preposterous, sometimes exceeding 2000 km.

In the examination of the individual daily curves of the loop and antenna reception from which Fig. 5 is derived, we find that the calculated angles of the downcoming waves are not only nearly always very large but in many cases appear to be greater than 90 deg., that is, the wave comes down from the back. These observations may be explained either by supposing that the downcoming wave is produced by reflection from a rough surface or perhaps from irregular ionized cloudlike masses, or by refraction in a medium of very irregularly distributed ionization.

Nature of the Fields

It may be of interest to study briefly the variations in the downcoming wave which would produce the changes on the antenna and loop which the observations indicate. This may be done with the help of the diagrams of Fig. 7. In these the antenna and loop are shown with the vertical and horizontal components of the electric fields acting on them. Here E_G represents the field of the ground wave assumed to be constant day and night, $E_R \cos \phi$ the vertical component of the field of the downcoming wave, and $E_R \sin \phi$ the horizontal component of the field of the downcoming wave.

We assume that the vertical antenna is affected only by the vertical electric fields, E_G and $E_R \cos \phi$, while the loop with its plane in the plane of propagation is affected by the total field of each wave of its angle of incidence. The effects of the reflection from the earth have been already explained in the discussion of the calculation of the angle of the downcoming wave, and it should be remembered that two waves passing across the loop in opposite directions produce loop currents in opposite directions.

For simplicity, in the diagrams of Fig. 7 E_R and E_G are considered either to be in phase or in opposite phase. The legends placed beside the diagrams will probably furnish sufficient explanations of the combinations of electric fields and the resulting changes in the antenna and loop signal intensity. All of the cases of change in antenna and loop signal intensities given have been identified in our records.

Long-Wave Night Signals and Magnetic Storms

The continuous records of the long-wave signals promise more complete information concerning the relation of magnetic storms to the variations in radio transmission at these wavelengths than it has been possible to obtain from the daylight observations, which were the only ones taken regularly at the Bureau of Standards before the introduction of the recorder.

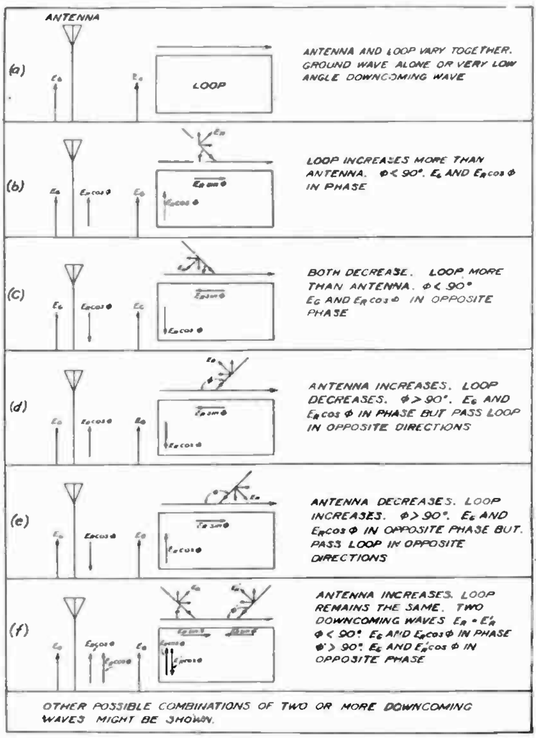

Fig. 7

Some records taken on signals from the R.C.A. station WCI at Tuckerton, N. J., wavelength 16750 m, (frequency 17.91 kc) in July 1928, are shown in Fig. 8. These include the period of the unusually severe magnetic storm of the night of July 7–8 and show apparently unmistakable evidence of the effects of this storm on the transmission. As no record was obtained at the Bureau of Standards on the night of the storm, G. W. Pickard has kindly permitted me to use one taken by him at Newton Center, Mass., where the curves of WCI generally agree closely in behavior with those taken in Washington. This curve is shown as a dotted line in the figure. It will be noted that if we compare the average curve of the three days before the storm, which we believe represents normal comparatively undisturbed summer conditions, with the curve of the night of the storm and those of the nights which follow, the storm appears to have caused an inversion of the general night trend, changing the slight normal drop during the night to a considerable rise. During the hours of the continuation of the storm, from 6:30 P.M. on the 7th to 6 A.M. on the 8th, the night curve is not only in general much higher than usual but very much disturbed. On the succeeding nights the irregularities of propagation gradually became less until on the night of the 12th–13th almost normal conditions had

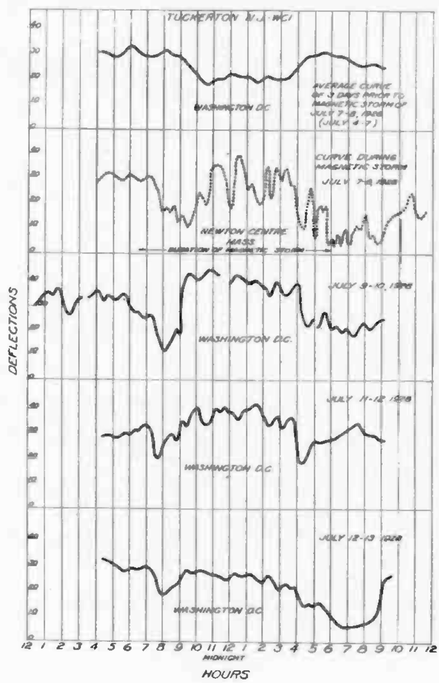

Fig. 8

returned. Similar effects have been observed in the case of two other major magnetic storms on the signals of WCI, and irregularities have often been detected due to the minor storms noted as No. 1 days in the magnetic reports.

WCI appears to be particularly suited in wavelength and in distance from Washington for showing the effects of magnetic disturbances on the night signals. Some of the other R.C.A. stations in New Jersey and on Long Island show these effects much less. These differences in behavior are perhaps to be expected when we remember that the increase or decrease of the night signal depends so much on the phase relations of the ground and downcoming waves.

Unidirectional System

Automatic recording is also applicable to a method of reception which was first introduced by Appleton and Ratcliffe,[5] for the study of downcoming waves and which was independently used for the same purpose a little later at the Bureau of Standards.

In this method the well known combination of a loop with a vertical antenna for the elimination of signals from a given direction in the horizontal plane takes the form of a cardioid.

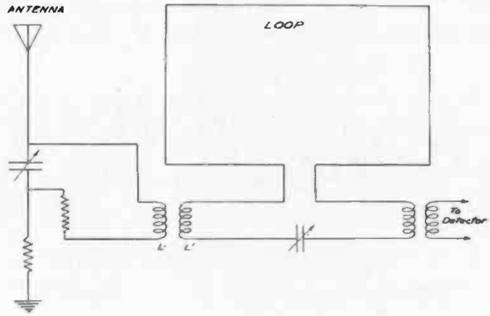

Fig. 9

This circuit, often called the barrage circuit in America, has long been used for the elimination of undesired signals and for the reduction of atmospherics. The circuit arrangement is shown in Fig. 9. Here the loop is turned on its vertical axis so that its plane is in the plane of propagation, but is so coupled to the antenna that the reception from the given direction on the loop opposes that on the antenna. Then the strength of coupling LL' is adjusted so that in the middle of the day, when it is assumed that only the vertical ground wave is present, the two receptions balance and no deflection is shown on the recorder. If these conditions are fulfilled, the system is balanced for all vertical fields of the given frequency from the given direction for which the adjustment was made. If, however, as sunset approaches, or during the night, downcoming waves appear, their horizontal components of field will destroy the balance and deflections will be produced.

Calling E_G the electric component of the field due to the ground wave and E_R that due to the downcoming wave, the effect of the an-

[5] *Proc.* Roy. Soc., (A), 115, 291, 1927.

tenna on the receiver is proportional to $E_G + KE_R \cos\phi$, and of the loop $E_G + KE_R$ as was shown in the discussion of the angle of the downcoming wave. Since the loop and antenna are adjusted so as to produce equal and opposite effects on the receiver in the case of the reception of the ground wave, the resultant effect on the receiver when downcoming waves occur is

$$E = A(E_G + KE_R - E_G - KE_R \cos\phi)$$
$$= AKE_R(1 - \cos\phi) = 2AKE_R \sin^2 \frac{\phi}{2}$$

where A is a constant.

The advantage of this system over that in which the antenna and loop are used separately is that here we are able to study the downcoming wave free from the ground wave although modified by K, the factor due to the phase difference between E_G and E_R.

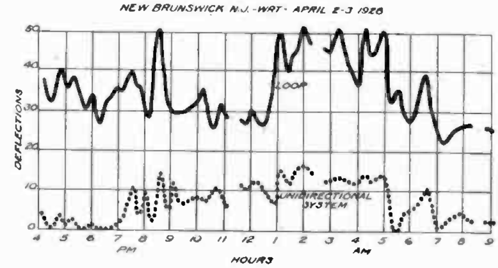

Fig. 10

Fig. 10 shows two curves of reception of the R.C.A. station WRT ($\lambda = 13200$ m, $f = 22.73$ kc) at New Brunswick, N. J., as recorded in Washington on the night of April 2–3, 1928. The solid curve represents reception on the loop and the dotted curve that on the unidirectional system. The sensitivity of the recorder when used with the unidirectional system was four times as great as when used with the loop. It will be noticed that the variations in the two curves generally, but not always, follow each other.

Our knowledge of the conditions in the upper atmosphere which affect the radio waves as they pass through it to the receiving station is still very fragmentary.

The impression which is gathered from the large number of records of reception at wavelengths above 10,000 m, taken on the automatic recorder, does not by any means support the view that the bending of the waves in the upper regions is due to any approximately regular reflection or refraction.

The somewhat confused picture which we have gained is rather that of rapidly changing masses of ionized gas forming an irregular and shifting lower surface and possibly at times thinning out or forming openings so that the rays may then pass to higher levels before being turned back toward the earth.

There is, however, a difficulty in accepting this conception of reflection from an irregular changing surface, as it would seem to imply rays striking the receiving system at times from the side that is not in the great circle plane joining the sending and receiving stations. Such rays would produce deviations in direction finding of a type which according to the experiments of Smith-Rose[6] with the Adcock direction finder should not exist.

[6] Proc. I. R. E., 17, 467; March, 1929.

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THE RELATION OF RADIO PROPAGATION TO DISTURBANCES IN TERRESTRIAL MAGNETISM*

By
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Summary—*This paper presents the results of a study of an apparent inter-relationship between radio reception and changes in the earth's magnetism. The results show that for long-wave daylight reception over great distances 4,000 to 7,100 km) there is in general a variable but definite increase in the intensity of the received signal following the height of severe magnetic disturbance. This increase reaches its maximum in from one to two days and disappears in from four to five days. For moderate distances (250 to 450 km) there is an increase in the intensity of the received signal noticeable before as well as after the magnetic storm reaches a maximum. These changes in intensity cover periods from two to four days both before and after the magnetic storm reaches its height.*

In a paper presented before the Institute of Radio Engineers in May, 1925, Espenschied, Anderson, and Bailey[1] pointed out that at times of severe magnetic storms abnormal radio transmission was likely to occur, night field intensities being greatly reduced and daylight intensities slightly increased. These conclusions were based upon hourly observations (for one day a week) of low-frequency transmission (17, 25, and 57 kc) across the Atlantic covering a period of about two years. From a more exhaustive analysis of this same material with the addition of later observations Anderson[2] in 1928 concludes "High daylight radio field strengths (at 57 kc) obtain during periods of marked magnetic activity. In most cases, the magnetic disturbances precede the high values, but there is evidence of an abrupt rise to high values preceding the magnetic disturbance and at times a gradual rise to high values independent of the magnetic activity . . . . . It is seen that the high radio fields do not occur particularly on days of high magnetic character but rather during periods when magnetic storms occur. Because the radio data are available for one day a week only, no detailed conclusions can be drawn. For the most part,

* Dewey decimal classification: R 113.5. Original manuscript received by the Institute, February 5, 1929. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce. To be published in forthcoming issue of the Bureau of Standards Journal of Research.

[1] Espenschied, Anderson and Bailey, *Bell Sys. Tech. Jour.*, 13, No. 3, 1925. Proc. I. R. E., 14, 7; February, 1926.

[2] C. N. Anderson, Proc. I. R. E., 16, 297; March, 1928.

however, the high fields follow the magnetic disturbance and then gradually fall off."

Pickard[3] from a series of observations on broadcast reception taken at Newton Center, Mass., on the Chicago station WBBM (800–900 kc) concludes that the "depression of night reception accompanying magnetic storms is very striking. Day reception from Nauen, AGS, (24 kc) shows an inverse effect, an increase of field accompanying and following the storm."

In a paper[4] presented before a meeting of the International Union of Scientific Radio Telegraphy in Washington, October, 1927, it was pointed out that the field intensity of the American station WSS (18.5 kc) for the duration of 8 months when averaged in periods of

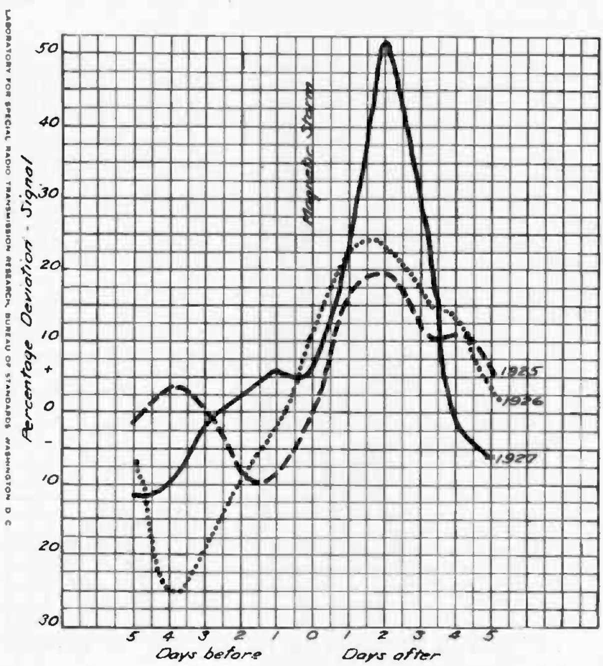

Fig. 1—Average daily deviation from the monthly mean of daylight field strength of signal from stations in Europe (LY, FU, AGW, GBR) during the progress of magnetic storms; 1925, 1926, 1927.

five days, exhibited a marked tendency to vary with the diurnal range of horizontal intensity of the earth's magnitic field. This indicated the possibility of a day by day relationship between magnetic disturbances and variations in signal strength. The present study was, therefore,

[3] G. W. Pickard, Proc. I. R. E., 15, 83, February, 1927; also 749, September, 1927; and 1004, December, 1927.

[4] L. W. Austin and I. J. Wymore, Proc. I. R. E., 16, 166; February, 1928.

undertaken to determine whether such a correlation existed. A long series of reception data consisting of daily observations on low-frequency stations (15 to 23.4 kc) was available, which was particularly suitable for this investigation. These measurements had been made at the Bureau of Standards by the telephone current comparator method.[5] Field intensity measurements from two groups of stations were examined; those made on signals from long distances, (4000–7100 km), and those on signals from moderate distances (less than 500 km). For the former, observations taken from 10 to 11 A. M. on Lafayette (LY), Ste. Assise (FU and FT), Nauen (AGSandAGW), Rugby(GBR), Coltano (ICC), and Bolinas (KET) were utilized and for the latter, observations at 10 A.M. and 3 P.M. on the Radio Corporation stations

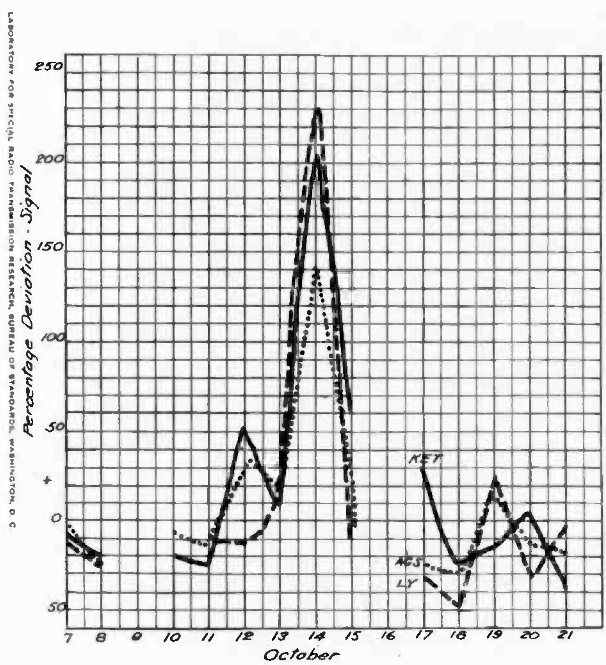

Fig. 2—Deviations in signal strength from the monthly average during the progress of the magnetic storm of October 12, 1927.

at Tuckerton, N. J. (WGG), New Brunswick, N. J. (WRT and WII), and Rocky Point, L. I. (WSS). In order to eliminate as much as possible any variations due to conditions not generally effective, stations of approximately the same wavelength were grouped and the data were averaged. Thus, in Fig. 1, LY (15.9 kc), FU (15.0 kc), AGW (16.5 kc)

[5] L. W. Austin and E. B. Judson, PROC. I. R. E., 12, 521; October, 1924.

and GBR (16.1 kc) are grouped together; in Fig. 3, AGS (23.4 kc), FT (20.8 kc), Bolinas KET (22.9 kc), and ICC (19.9 kc); and in Fig. 4, the Radio Corporation stations WII (21.8 kc), WGG (18.9 kc), WRT (22.7 kc), and WSS (18.7 kc).

The field intensity of low-frequency signals is believed to be less influenced by magnetic storms than that of the broadcast range. For this reason, only the most severe disturbances were considered in the calculations. Since practically all severe magnetic storms occur simultaneously over the earth the observations taken at the Cheltenham Magnetic Observatory of the U. S. Coast and Geodetic Survey were considered sufficiently indicative of changes in magnetic activity. As a qualitative measure of daily magnetic activity "magnetic character of day" numbers[6] were used to determine the occurrence of and to locate the central day of the magnetic storms which were selected in preparing the data in Figs. 1, 3, and 4 and the diurnal range of horizontal intensity of the earth's magnetic field was used for comparison in Figs. 5 and 6.

Days for which the magnetic character number was reported as 2 at Cheltenham, Md., were considered days of maximum magnetic activity and are represented by the zero point of the abscissas in Figs. 1, 3, and 4; i. e., they are the central days of eleven-day periods extending from five days before to five days after each magnetic storm. Averages were made of the radio field intensity of the stations on the corresponding days of these eleven-day periods.

The following table gives the dates of the magnetic storms considered in the calculations:

1925	1926	1927
Jan. 19–20	Jan. 26–27	March 28
May 4	Feb. 23–24	April 14
June 13	March 5	May 5
June 24	Apr. 14–16	July 21–22
July 26	May 4–5	Aug. 20–21
Aug. 22–23	June 1–2	Oct. 10
Sept. 1–2	Sept. 9	Oct. 12
Sept. 14–15	Sept. 15	Oct. 22–23
Sept. 21	Sept. 20–21	
Oct. 23–24	Oct. 14–16	
Nov. 9		

In Fig. 1 are given the daylight values of the percentage deviations from the corresponding monthly averages of signal intensity of the long-wave European stations (LY, FU, AGW, and GBR) during the time of greatly increased activity of the sun in the years 1925, 1926, and 1927. While the values for the curves are smoothed, they approximate closely the actual deviations obtained. The trend of the curves

[6] For a qualitative estimate of magnetic conditions days are commonly divided into three classes and designated as follows: 0 denotes days which are magnetically quiet; 1, moderately disturbed days; and 2, severely disturbed days.

before the maximum of the magnetic storms varies somewhat in the three years although in general it tends to fall below the average. The most striking similarity is the high value on all the curves on the second day after the peaks of the storms. In connection with this, the behavior of signals at the time of one extremely severe disturbance, that of Oct. 12, 1927, is interesting. In Fig. 2 the percentage deviations from the monthly averages of field intensity for the stations, Lafayette (LY), Nauen (AGS), and Bolinas (KET), at the time of this storm are given. Intensities well above average were observed on October 12, the day of the maximum disturbance, but on October 14, two days

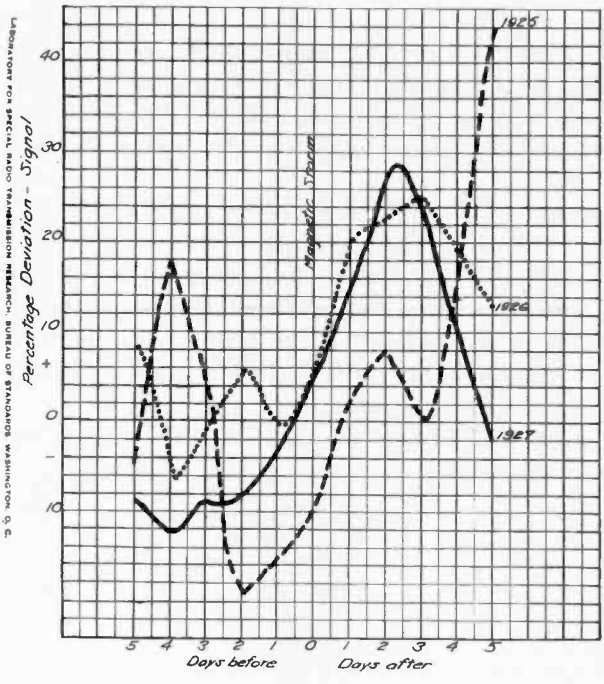

Fig. 3—Average daily deviation from the monthly mean of daylight field strength of signal from stations in Europe and California (FT, AGS, KET, ICC) during the progress of magnetic storms; 1925, 1926, 1927.

following, the intensity had increased so greatly that in some cases it was more than 200 per cent above the average value for the month. This increase in signal strength is too great to be a recovery from an abnormal condition before the storm and so probably represents some real effect of the condition productive of the magnetic disturbance.

In order to obtain some idea of the variation of signal strength on magnetically quiet days an average for each of three years was made for twelve days which were reported as magnetically quiet (magnetic character number = 0) and which were removed by five or more days from any reported disturbance. For 1925 these results gave an average signal deviation from the monthly average of two tenths of one per cent for quiet days; for 1926, six tenths of one per cent; and for 1927 one tenth of one per cent, the mean for the three years being three tenths of one per cent. Such an average, of course, represents merely the normal variations. Individual variations of field intensity on undisturbed days at times are much larger, and may occasionally reach or exceed 10 per cent.

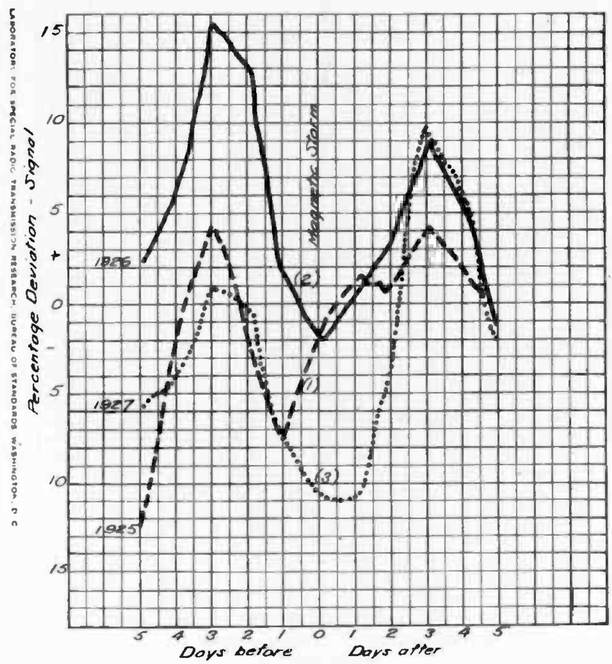

Fig. 4—Average daily deviation from the monthly mean of daylight field strength of signal from stations in New Jersey and Long Island during the progress of magnetic storms: (1) WII and WGG, 1925; (2) WII, WGG, and WSS, 1926; (3) WII, WGG, WSS, and WRT, 1927.

In Fig. 3 the average deviations from the monthly means for Nauen (AGS), Ste. Assise (FT), Bolinas (KET), and Coltano (ICC) for the same three years are given. The same general tendency is noted in these curves as in those of Fig. 1 with the exception that the curve for 1925 shows high values on both the fourth and fifth days after the maximum magnetic disturbance.

The observations of field intensities of American stations (WII, WGG, WRT, and WSS) at moderate distances gave somewhat different results. In general they show, for the same three years, a depression of signal strength below normal on the day of the storm, preceded three days before the storm by a considerable rise in intensity and followed three days after by another increase. The daily average deviations from the monthly averages during the periods of magnetic storms for 1925, 1926, and 1927 for these stations are shown in Fig. 4. Curve 1 gives the average of WII and WGG at 10 A.M. and 3 P.M., 1925; curve 2 of WII, WGG and WSS, at 10 A.M. and 3 P.M., 1926; and curve 3 an average of WII, WGG, WRT and WSS, at 10 A.M. for 1927.

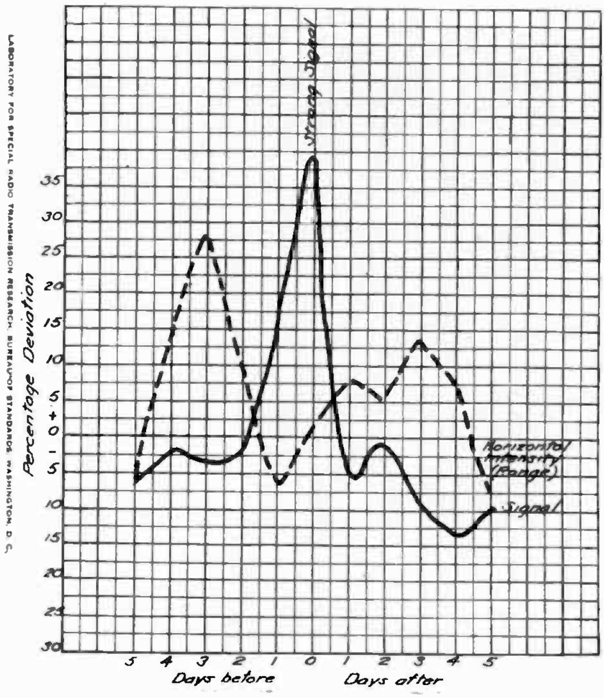

Fig. 5—Average daily deviation from the monthly mean of daylight field strength of signal (Rocky Point, WSS) and of horizontal intensity (range) of the earth's magnetic field, 1926.

A signal whose intensity is 25 per cent or more above the average for the month is considered well above normal and due to some unusual conditions effective along its path. In Fig. 5 a comparison is made between the variations in field intensities before and after these days of unusually strong signals and the diurnal range of the horizontal intensity of the earth's magnetic field. The center or zero day is taken as the day on which the observed field intensity was 25 per cent or more above the monthly average. In Fig. 5 the station observed was WSS, at 10 A. M., 1926; in Fig. 6, WII at 10 A.M., 1927. High values of the diurnal range occurred three days before and from two to three days after the signal peak. All data were smoothed by the formula

$$\frac{a+2b+c}{4}$$

From the foregoing curves it is evident that during periods of magnetic storms the behavior of low-frequency (15 to 24 kc) daylight

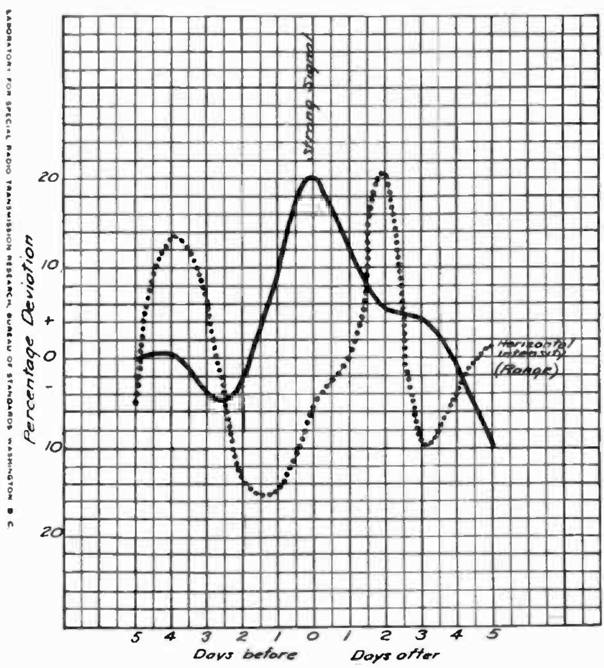

Fig. 6—Average daily deviation from the monthly mean of daylight field strength of signal (New Brunswick, WII) and of horizontal intensity (range) of the earth's magnetic field, January to July, 1927.

signals tends to be as follows:

(1) *Over Long Distances (4000-7100 km).*

The intensity of signal falls below normal for several days before the maximum magnetic disturbance which is followed by a definite increase in strength from one to four days after the storm.

(2) *Over Moderate Distances (250-400 km).*

There is an increase in signal strength above the average from two to four days before the disturbance with values below normal during the height of the storm followed by a strong increase in intensity from two to four days after the storm.

This work was done under the direction of L. W. Austin at the Laboratory for Special Radio Transmission Research, Bureau of Standards. The observations were made by E. B. Judson at that laboratory.

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SOME MEASUREMENTS ON THE DIRECTIONAL DISTRIBUTION OF STATIC*

By
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Summary—*The utility of directional data on static is shown, and two types of apparatus devised for such a directional investigation are compared. It is shown that a method which gives the direction of individual crashes is superior to integrating methods. The distribution of thunderstorms over the world is discussed, and comparisons are drawn between this distribution and the observed directional distribution of static. Probable geographical locations are assigned to the sources, based upon thunderstorm data and directional observations.*

THE object of this study was primarily to determine the directional distribution of the sources of static observed at our transatlantic radio telephone receiving station located at Houlton, Maine, for the purpose of investigating the performance of the present directional receiving antennas in the reduction of static, and of furnishing basic data for the design of improved systems. It also was hoped that data might be obtained which would locate the geographical positions of these sources and thus indicate the possibility of a more favorable site for a receiving station.

Since our interest in the problem was confined to its immediate bearing upon the transoceanic radiotelephone channel, only matters of practical interest were investigated. For this reason our work was confined to the operating hours of the channel and a band of frequencies between 55 and 65 kc. We believed that local daylight observations would be the more important, not only because the greater portion of the circuit operating time is daylight, but also because night readings are subject to directional shifts and other phenomena of a more or less irregular nature.

The distribution at other frequencies probably would be modified only by non-uniform attenuation. The effect of daylight attenuates the high frequencies to a greater extent than the low frequencies, and due to the advancing shadow wall from east to west magnifies the effect of high-frequency static or signals arriving from the dark portion. Probably a wide departure in frequency from 60 kc would show a somewhat modified distribution for this reason.

* Dewey decimal classification: R114. Original manuscript received by the Institute, March 26, 1929. Presented before joint meeting of the Institute and the International Union of Scientific Radiotelegraphy, American Section, at Fourth Annual Convention of the Institute, Washington, D. C., May 15, 1929.

At the outset of our investigation the ideal apparatus for our purpose seemed to be a recorder which would draw a continuous graph of the strength and direction of static. Accordingly we built an apparatus consisting of a recorder with a scale range of 40 db, an adjustible gain radio receiver, a combination of loop and vertical antenna to produce a revolving cardioidal reception diagram, and the necessary calibrating and auxiliary apparatus. The loop was turned by a motor at a rate of one revolution per fifteen minutes, and when passing through north, a contact operated a comparison oscillator for one minute. By this means the north was indicated on the record, and at

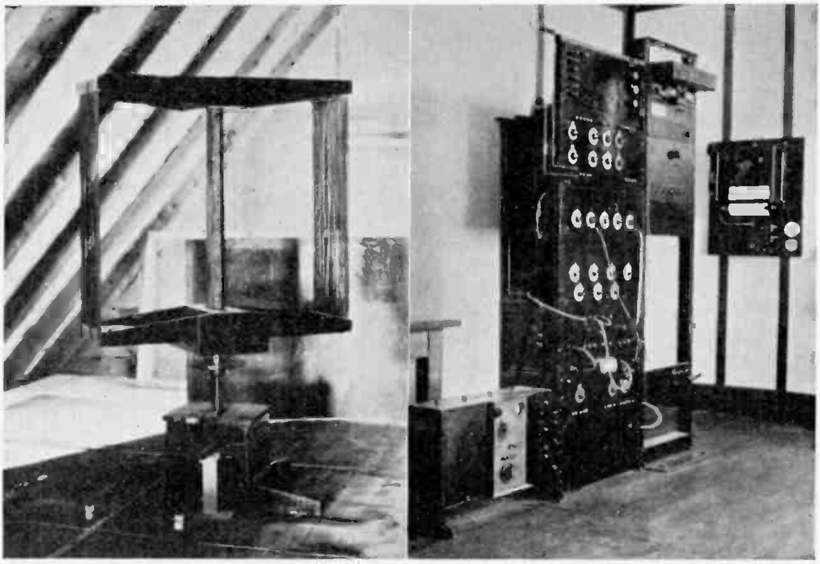


Fig. 1—Recording Direction-Finding Apparatus at Houlton, Maine.

the same time the sensitivity of the apparatus was checked. The record, by interpolation between the north marks, showed the angular relation between the minimum of the revolving cardioid and the true north.

Tests were made on distant transmitters of known location, and it was found that the apparatus traced a satisfactory curve, indicating the direction to a nice degree of precision. When applied to static, however, the device was not satisfactory, because two or more sources gave a diagram requiring mathematical analysis with many asssumptions. The time required for such an analysis was longer than that required to take the records, and the results were open to question on account of the necessary assumptions. Multiple sources were present during a very large percentage of the time.

When we discovered that trouble would be experienced with the recorder we cast about for some other tool for the purpose. An apparatus devised in England by Mr. Watson Watt[1] offered possibilities and this apparatus with certain modifications was used. In its original form it consisted of two crossed loops, one receptive in a N-S plane, while the other received best in an E-W plane. These loops were connected to two receivers of equal gain, whose outputs were in

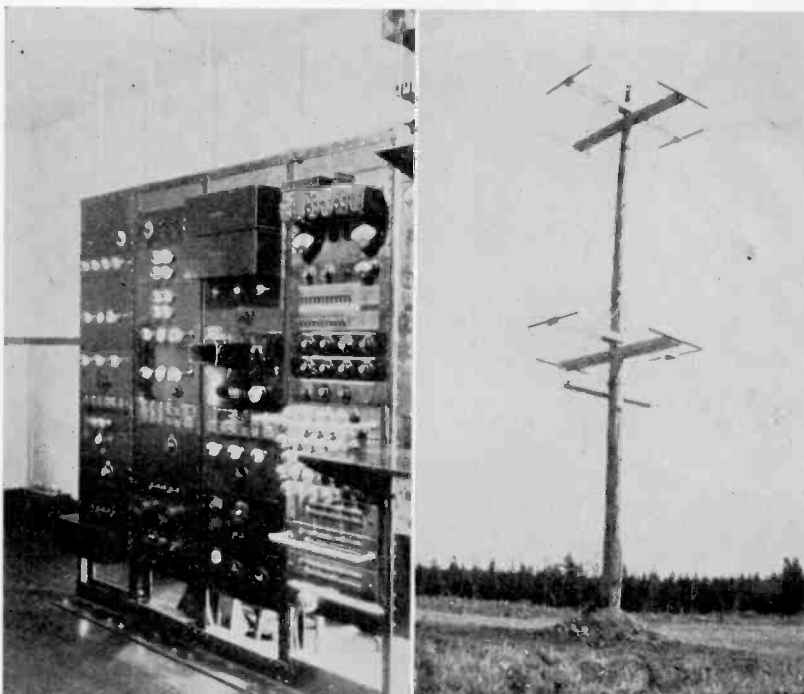


Fig. 2—Visual Direction-Finding Apparatus at Houlton, Maine.

turn connected to the vertical and horizontal deflecting elements of a low-voltage cathode-ray oscillograph tube. The potentials induced in the N-S and E-W loops, respectively, are proportional to the components of the arriving wave in these planes and after passing through their associated amplifiers produce vertical and horizontal deflecting forces on the beam. The composition of these forces causes the beam to oscillate in a plane corresponding to the angle of the arriving signal.

[1] R. A. Watson Watt and J. F. Herd, "An Instantaneous Direct Reading Goniometer," *Jour.* I.E.E., 64, No. 353, p. 611.

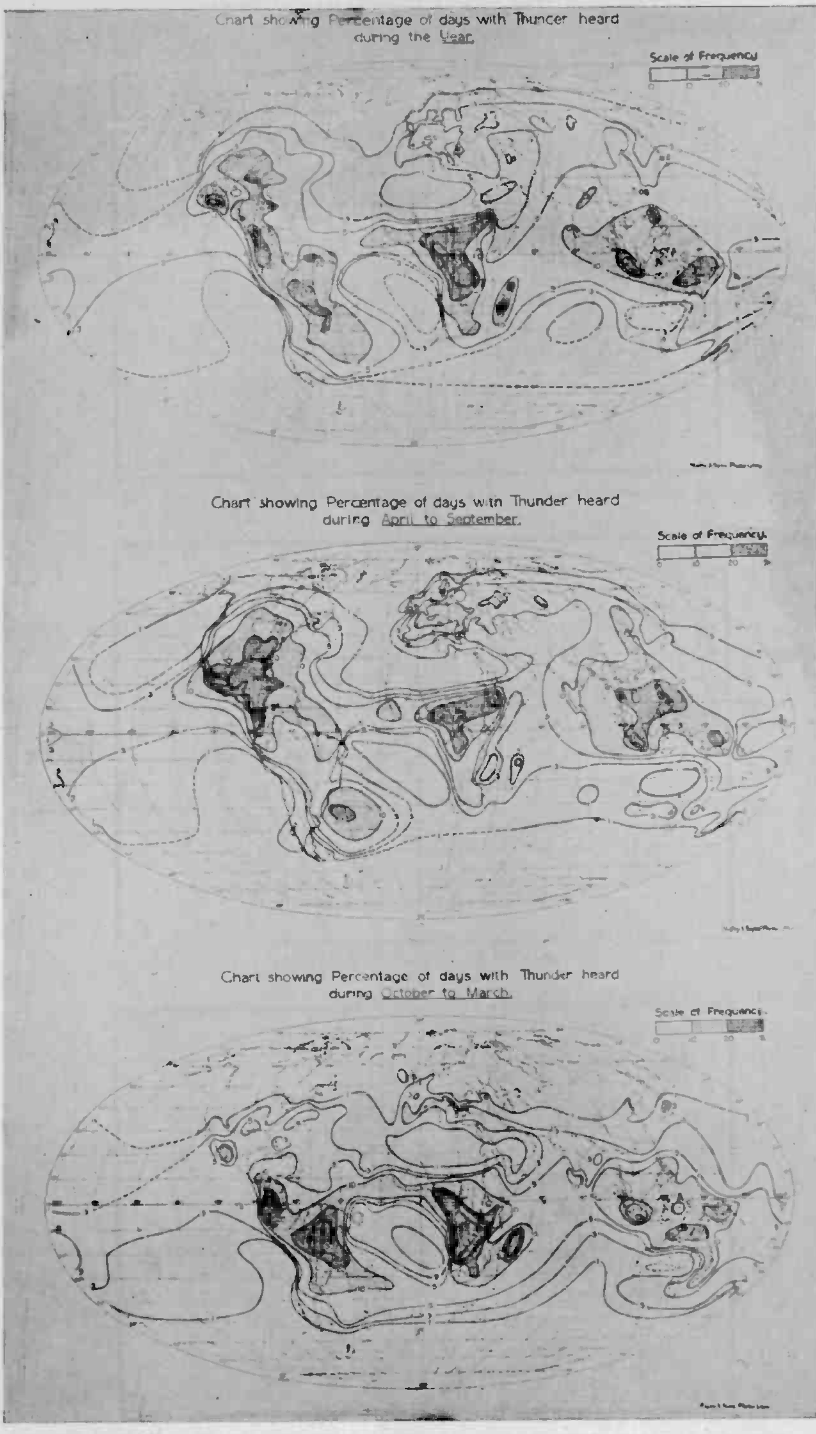
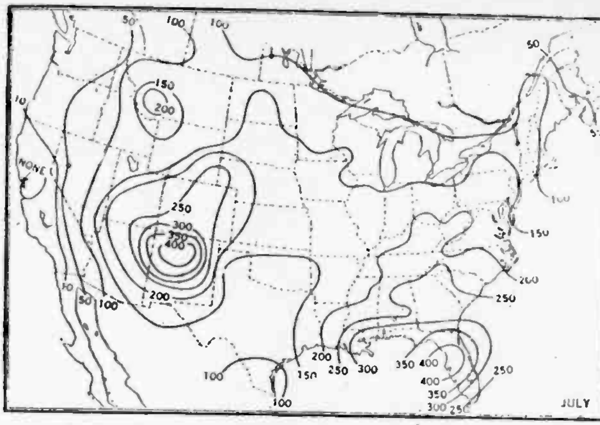
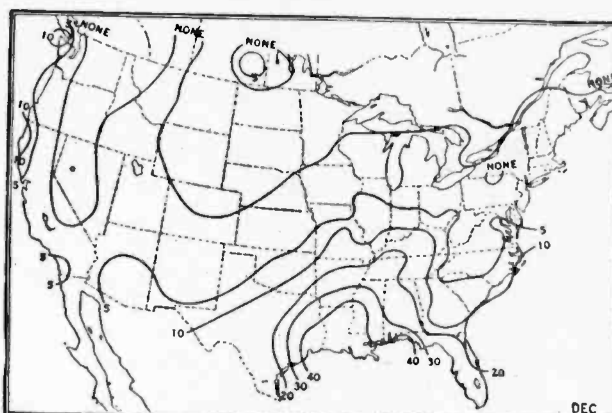


Fig. 3—World Distribution of Thunderstorms. (Reproduced from British Air Ministry Memoir No. 24, by C. E. P. Brooks.



Isoceraunics, July, based upon total number of thunderstorm days, 20 years, 1904–1923



Isoceraunics, December, based upon total number of thunderstorm days, 20 years, 1904–1923

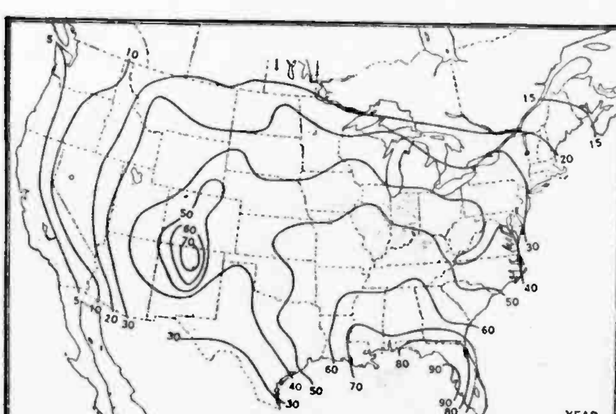


Fig. 4—Average Distribution of Thunderstorms in the United States. (Reproduced from U.S.W.B. Monthly Weather Review, 52, 337–343; July, 1925, paper by William H. Alexander).

The screen of the tube is marked off with points of the compass and 10-deg. graduations, in a clockwise direction so that a crash of static would make the beam in the tube vibrate in a plane whose intersection with the screen produced a fluorescent trace, the direction of which indicated the azimuth of arrival of the disturbance. This apparatus therefore can give the direction but not the sense of the incident wave. Information obtained regarding the location of thunderstorms, etc., and records taken on the recording apparatus served to help us decide which end of the line was the index.

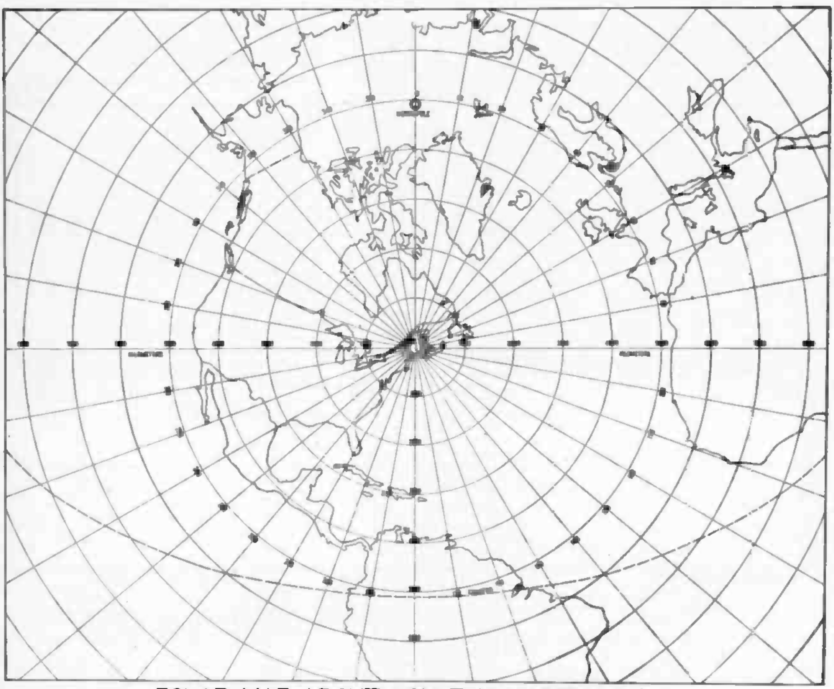
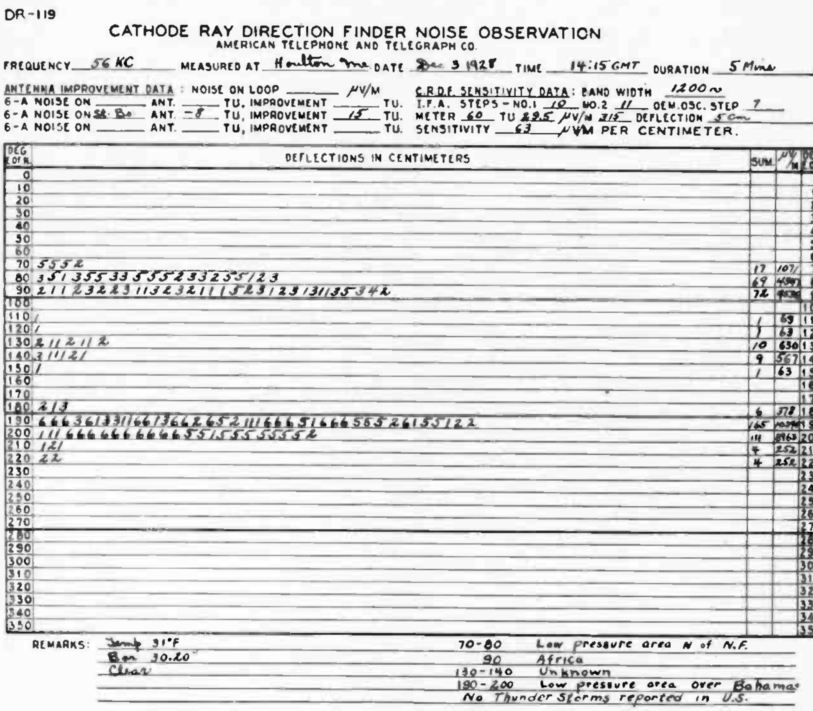


Fig. 5—Polar Map about Houlton, Maine.

This apparatus seecmed very satisfactory in its operation so modifications were made to make it unidirectional and to increase its ease of operation. In its final form it is shown in Fig. 2.

The method of taking observations by means of the cathode-ray tube is as follows. Each crash or grinder of static produces a momentary fluorescent line on the screen of the tube, pointing in the direction of arrival. It occurred to us that photographic recording might be of assistance, but a trial gave us unsatisfactory results, so a method of visual observation had to be used. Two men are required, one to note the readings made by the other. At the beginning of the observation the apparatus is adjusted to give a nearly full scale deflection on the static. The sensitivity of the apparatus in microvolts per meter per centimeter of deflection is then measured and noted on the form. The observer, after a minute in which his eyes become accustomed to the light, begins a 5-minute run timed by his assistant. At each crash of



DR-119

CATHODE RAY DIRECTION FINDER NOISE OBSERVATION
AMERICAN TELEPHONE AND TELEGRAPH CO.

FREQUENCY 56 KC MEASURED AT Houlton Me DATE Dec 3 1928 TIME 14:15 GMT DURATION 5 Mins

ANTENNA IMPROVEMENT DATA: NOISE ON LOOP ______ μV/M
6-A NOISE ON ______ ANT. ______ TU, IMPROVEMENT ______ TU.
6-A NOISE ON St. Bo ANT. −8 TU, IMPROVEMENT 15 TU.
6-A NOISE ON ______ ANT. ______ TU, IMPROVEMENT ______ TU.

C.R.D.F. SENSITIVITY DATA: BAND WIDTH 1200 ~
I.F.A. STEPS—NO. 1 10 NO. 2 11 OEM. OSC. STEP 7
METER 60 TU 29.5 μV/M 315 DEFLECTION 5 cm
SENSITIVITY 63 μV/M PER CENTIMETER.

DEG. E OF N.	DEFLECTIONS IN CENTIMETERS	SUM	μV/M	DEG. E OF N.
0				0
10				10
20				20
30				30
40				40
50				50
60				60
70	5552	17	1071	70
80	351355335552332355123	69	[illegible]	80
90	211232231132321115231231311353 42	72	[illegible]	90
100				100
110	1	1	63	110
120	1	1	63	120
130	2112112	10	630	130
140	311121	9	567	140
150	1	1	63	150
160				160
170				170
180	213	6	378	180
190	666361331166136626521116665166656526155122	165	[illegible]	190
200	111666666666655155555552	111	6963	200
210	121	4	252	210
220	22	4	252	220
230				230
240				240
250				250
260				260
270				270
280				280
290				290
300				300
310				310
320				320
330				330
340				340
350				350

REMARKS: Temp 31°F
Bar 30.20″
Clear

70-80 Low pressure area N of N.F.
90 Africa
130-140 Unknown
190-200 Low pressure area over Bahamas
No Thunder Storms reported in U.S.

Fig. 6—Sample of Record of a Visual Observation.

static he calls off the intensity as estimated in centimeters, six being the maximum, and the direction to the nearest 10-deg. graduation on the tube. These data are recorded by the assistant on the form shown in Fig. 6. At the end of the 5-minute run the deflections observed in each 10-deg. sector are totalled and multiplied by a conversion factor to obtain the relative noise, the units of which are 1 μv per meter per 5 minutes. The conversion factor is obtained by a measurement of the output of a comparison oscillator required to give a 5-cm deflection. This oscillator output is then related to the field strength by use of the ordinary methods.

Daily measurements are made at 9 A.M., 12 noon, and 5 P.M. EST, and the results are averaged and analyzed in the form of monthly reports. In order to prevent this paper from becoming too voluminous, we have not included our monthly averages, but have made one set of curves covering the closely related period of April to September, and since complete winter data are not available at this time, we have taken December as representative of the winter months.

The fact that static may come from great distances has been proved by means of simultaneous records made of static crashes in Hawaii, New York, and Germany.[2] We believe that for receiving in Maine the most important source of static is thunderstorms in the United States and Canada, after which we put thunderstorms in other portions of the globe. In addition to actual thunderstorms we find static accompanying weather disturbances such as electrified clouds, etc., which have not reached the point of producing audible thunder. As a working hypothesis it may be assumed that such static is produced on the southeast edge of an advancing low-pressure area, especially if precipitation occurs. This condition when accompanied by uprushing winds according to Humphreys[3] tends to produce a thunderstorm. Therefore in the absence of other data, thunderstorm charts would be the most logical index of the location of static sources. The above theory seems to be strengthened by our Houlton measurements.

According to available information on the subject of thunderstorms, they are much more frequent on land than over the oceans. The period of highest frequency is given as 2 to 4 P.M. on land in summer and about 4 A.M. over the oceans. Ocean thunderstorms are said to be more frequent in winter than summer. Basing our prediction of the distribution of static on average thunderstorm data alone, the principal disturbed areas are shown in Table I, compiled from Figs. 3 and 4. These concentrated sources have been arranged in order of their distances from Houlton, which would be expected to be a measure of their importance. The season has been designated by the representative month to avoid ambiguity of northern and southern hemisphere seasons.

The directional distribution of received atmospherics is also a function of the radio attenuation. When the transmission path is over land the static is weaker, due to land attenuation, than if it had traveled only over water. A diurnal variation must be expected

[2] M. Baumler, "Simultaneous Atmospheric Disturbances in Radio Telegraphy," PROC. I.R.E., 14, 765–771; December, 1926.
[3] Prof. William J. Humphreys, "Physics of the Air."

because day and night attenuation differ considerably. Static arriving from the dark side of the shadow wall being attenuated to a smaller extent than that arriving from the illuminated portion of the globe produces a distortion of the distribution curve which would be expected if this phenomenon were disregarded.

Data analyzed but not given in this paper, based on circuit time lost on the transatlantic radio channel, and on monthly values of relative noise, show a fairly good connection between thunderstorm

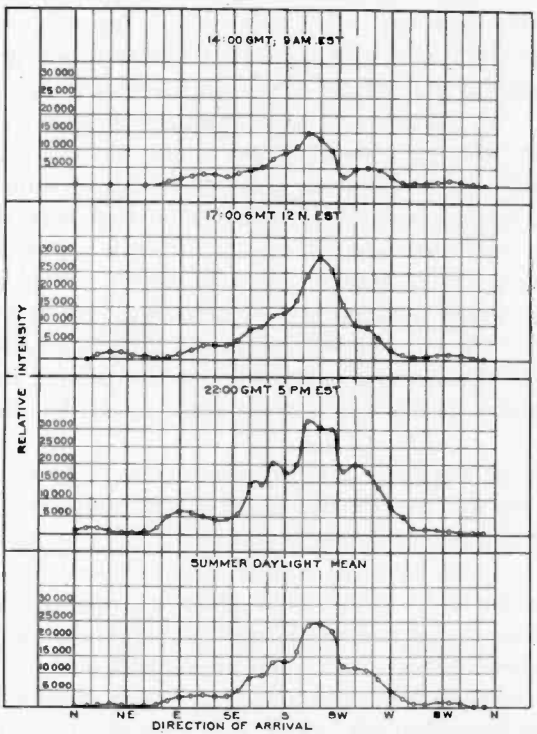


Fig. 7—Observed Directional Distribution of Static from Houlton, Maine, April–September, 1928.

frequency in the United States and these values. It is fortunate that it is only the very strong summer static that causes our circuit troubles. The weak winter variety from long distances is further reduced by directional reception and is overridden by strong signal fields, causing little lost time.

Examining the curves of Fig. 7 we note maximum noise from 210 deg. increasing as the hour becomes later. Due to the magnitude of the separate crashes observed, we have ascribed this source to Florida and the southern Atlantic coast states. A submaximum at 250 deg. at 1400 GMT probably is due to Mexico and disturbances in the United States in this direction. This sector shows somewhat less markedly at 1700 and 2200 GMT. At 2200 GMT a rather pronounced submaximum appears at 90-100 deg. which may be African static taking advantage of the lower attenuation due to approaching darkness from the east. A bump on the curve is also evident at this time which might be charged against the area at sea off Argentina, although

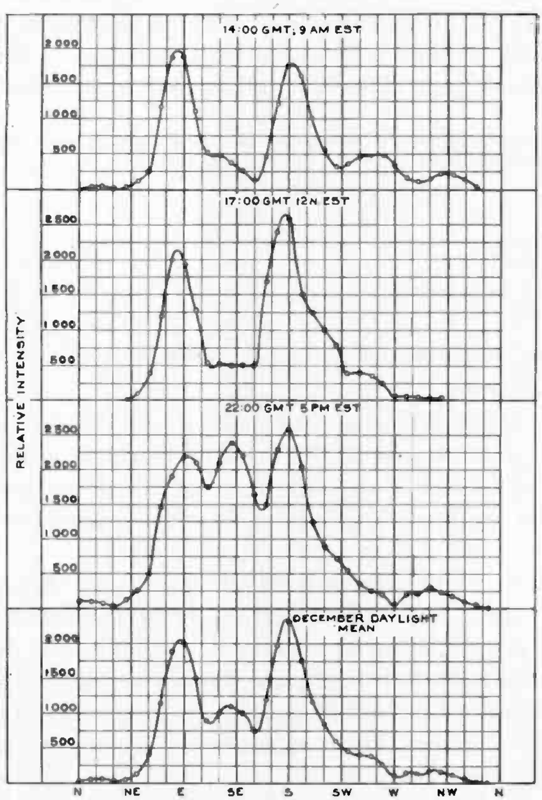


Fig. 8—Observed Directional Distribution of Static from Houlton, Maine December, 1928.

this is purely conjecture. There is a very noticeable blanketing effect due to North American static which makes all these long distance phenomena stand out less sharply than desirable.

The winter curves of Fig. 8 show a very important maximum at 90 deg. which probably is due to Africa. Another slightly higher maximum is at 180 deg. which we feel justified in ascribing to South

America. A maximum at 130 deg. is observed at 2200 GMT which may be due to equatorial static in midatlantic.

Besides these principal maxima, we have at 1400 GMT several submaxima, for example one at 250 deg. which may be due to Texas thunderstorms. A very poorly defined maximum at about 300 deg. has not yet been explained. Static from this sector is also recorded at 2200 GMT.

Table I seems to fit the observational data astonishingly well, leaving only two points uncovered. The thunderstorm areas in Louisiana and Mexico do not distinguish themselves on our winter curves. This fact may be due to high overland attenuation and to the blanketing effects of other sources. The East Indian area, which seems extremely

TABLE I

Directions of Principal Thunderstorm Areas from Houlton, Maine

Geographic Location	Approximate Bearing	Season
Florida	N210E	July
Mexico	N240E	"
New Mexico	N260E	"
Africa	N90E	"
At Sea off Argentina	N160E	"
Sumatra and East Indies	N5E	"
		December
Louisiana and Western Florida	N225E	"
Southern Mexico	N225E	"
Ecuador	N190E	"
Brazil	N165E	"
Central Atlantic near Equator	N115–140E	"
Africa	N90E	"
Sumatra and East Indies	N5E	"

important on the charts, does not make its appearance at all on the curves. This may be due to the extreme length of the transmission path, or to the fact that on account of its almost antipodal position it arrives from an unexpected direction and is blanketed by stronger sources.

At the start of our observations we expected to note evidence of disturbances from the neighborhood of the Icelandic semipermanent low-pressure area. However, none of our monthly curves shows any sign of trouble from this source. From this we are forced to conclude that low-pressure area in general do not necessarily have the electrical characteristics which at times accompany moving cyclonic depressions of steep gradient.

Our summer data show that July is the worst month for static at Houlton, and that this month also has the largest number of United States thunderstorms. The summer average curve indicates 200-220 deg. as the sector of maximum static with large quantities arriving at Houlton from the whole sector between 140 deg. and 270 deg. Minimum static at this season is received from the northern sector bounded by 290 deg. and 70 deg.

The author is indebted to Mr. F. H. Willis and staff at Houlton for the directional observations used in the preparation of this paper.

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THE ROUTINE MEASUREMENT OF THE OPERATING FREQUENCIES OF BROADCAST STATIONS*

By
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(Radio Division, Department of Commerce, Office of Supervisor of Radio, New York)

Summary—*The method of making "zero beat" measurements of the operating frequencies of broadcast stations in the Second Radio District is described, showing the method of comparing the received signal from a broadcasting station with a signal of known frequency, obtained from a 10-kc multivibrator controlled by a 90-kc quartz crystal. There is also given a description of the method used in reducing the measurement to a flexible routine procedure while still maintaining an accuracy well within the 500-cycle limit established by the Federal Radio Commission.*

FOR sixteen years the Radio Division of the Department of Commerce has concerned itself, as required by law, with the measurement of the radiated waves from all classes of commercial and amateur radio transmitters. Measurements of the operating frequencies of stations were made by means of a wavemeter at the transmitting station, which method was sufficiently accurate to insure freedom from interference between the relatively few stations operating prior to 1920. However, the rapid development of broadcasting, and a separation of ten kc between stations, soon demonstrated the futility of attempts to make a sufficiently accurate check of the operating frequencies of such stations by the use of an ordinary wavemeter at the station. Special wavemeters covering only the broadcast band, even when calibrated immediately before and after a visit to a station, were found entirely inadequate for checking frequencies within five hundred cycles.[1] It was therefore decided to make use of the so-called "zero beat" method, checking all stations at a given location where equipment better adapted for accurate measurement work could be installed and maintained under reasonably constant temperature conditions.

The office of the U. S. Supervisor of Radio at New York first made use of the zero beat method of measurement of the operating frequencies of distant radio transmitting stations early in 1923 at which time the measurements were confined principally to checks

* Dewey decimal classification: R210. Original manuscript received by the Institute, January 17, 1929. Presented before New York meeting of the Institute, April 3, 1929.

[1] Federal Radio Commission General Order No. 7, April 28, 1927.

on the waves emitted by coastal telegraph stations working with ships. The method as used at that time consisted, briefly, in tuning in the signal to be measured on a non-oscillating receiver, resonating a local driver or oscillator with the incoming frequency as determined by a pair of telephones and then measuring the locally generated frequency by means of a Kolster Type "D" Decremeter. This method was successfully employed in reducing interference between coastal marine stations, and was employed with some success in checking broadcasting stations when broadcasting was conducted on only two wavelengths, namely 360 and 400 meters.

There are many sources of error inherent to the measurement method indicated above, and while these errors were not of great importance when there were few broadcast stations widely separated, numerous changes and refinements were necessary to adapt the "zero beat" method of measurement to the accurate checking of stations operating on channels 10 kc apart.

It is therefore the purpose of this paper to describe the method of frequency measurement which has been successfully employed at the office of the U. S. Supervisor of Radio at New York during the past year, and to show how the measurement of the operating frequencies of broadcast stations in the Second Radio District has been reduced to a practical routine procedure while maintaining an accuracy of measurement well within 500 cycles.

Outline of Method of Making Frequency Measurements

The method at present employed for the measurement of the operating frequencies of broadcast stations consists of seven distinct operations:

(1) The desired signal is tuned in on a selective, non-oscillating receiver used in conjunction with a large cone loud speaker;

(2) A local oscillator (hereinafter called the auxiliary generator) is resonated with the incoming signal by a combination aural and visual method;

(3) The frequency meter is then adjusted to resonance with the auxiliary generator and the dial reading recorded as the "station setting";

(4) The antenna is disconnected from the receiver and a signal of known frequency corresponding to the frequency assignment of the station under measurement is substituted in the receiver for the station signal picked up by the antenna;

(5) The auxiliary generator is adjusted to resonance (zero beat) with the signal of known frequency as determined by aural and visual methods;

(6) The frequency meter is then readjusted and dial setting noted at the point which corresponds to this frequency, this reading being called the "crystal setting";

(7) From the two dial settings obtained, namely, the "station setting," the corresponding frequency of which is to be determined, and the "crystal setting" corresponding to the assigned frequency of the station, the deviation of the station from its assigned frequency may be readily determined provided the shape of the calibration curve of the frequency meter and the kilocycle equivalent of one degree of the frequency meter scale at this setting are known.

In order to obtain accurate results from the procedure indicated above, it is apparent that, first, an accurate method must be provided for obtaining zero beat or resonance between the incoming signal and the auxiliary generator, also between the standard known frequency calibration point and the auxiliary generator; second, a source of accurate known frequencies must be available which provides frequencies every 10 kc throughout the broadcast band; third, a frequency meter must be employed which will readily indicate changes in frequency of considerably less than 0.01 per cent. The manner in which these requirements are satisfied will be shown in the following paragraphs where each part of the equipment is described.

The equipment is installed in the Office of the Supervisor of Radio on the third floor of the Subtreasury Building at Wall, Nassau and Pine Streets, New York City. While this location is bounded by thirty-story office buildings on three sides and a 65,000-volt smoke precipitator on the fourth side, reception at night is satisfactory for our purposes. Ninety-five per cent of the Second District broadcast stations can be received with sufficient signal strength to be measured without difficulty.

Fig. 1 shows the arrangement of the measurement apparatus.

The Receiver

The receiver has two stages of tuned radio-frequency amplification, detector, and two stages of audio-frequency amplification storage battery operated, and is used in conjunction with a long single wire antenna on the roof. A switching device is used to short out turns on the higher frequencies so as to give greater selectivity on the higher frequencies in the broadcast band.

The audio-frequency transformers employed in the set were selected as most suitable for the very low frequencies obtained in adjusting to zero beat. A Western Electric type 560 AW cone loudspeaker is used with the receiver.

An output coil from the 10-kc oscillator is coupled to the input of the first radio-frequency tube in the receiver so that when the antenna is disconnected from the receiver the station signal may be replaced by the standard signal of known frequency. The receiver is shown at the extreme right of Fig. 1.

Fig. 1—View of Measurement Apparatus Employed for Checking the Operating Frequency of Broadcast Stations.

The Visual Beat Indicator

The plate circuit of the detector tube of the receiver is coupled by means of an air core auto transformer to the visual beat indicator, which consists of an ammeter having a full scale reading of one milliampere, in series with an adjustable crystal detector and switch connected across the winding of the auto transformer. The visual beat indicator and coupling coil are shown at the right of Fig. 2, and also Fig. 3.

The Auxiliary Generator

The auxiliary generator used is the type O designed by the Bureau of Standards and operates with a UX201A tube as an oscillator in a conventional circuit. Plate current is supplied by a 100-volt storage battery and the filament is heated by a six-volt storage battery. Plug-in coils are provided for quick changes in frequency range. A slow motion dial and a long bakelite rod permit accurate adjustment of the oscillator frequency without disturbing capacity effects. Sufficient energy is developed at all frequencies in the broadcast band employing a UX201A tube as oscillator to actuate the frequency

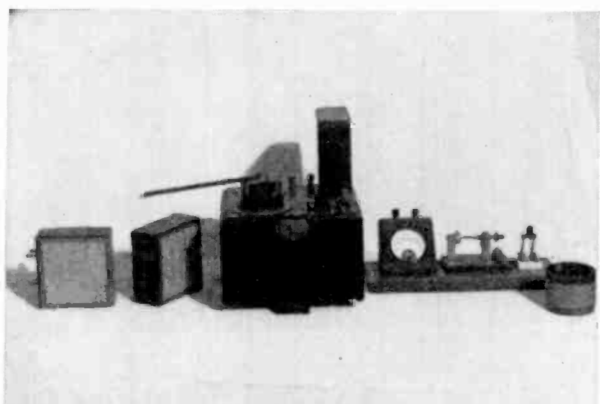

Fig. 2—Auxiliary Generator with Plug-In Coils; Visual Beat Indicator.

meter with a coupling of more than three feet, and sufficient energy at all broadcast frequencies is obtained in the receiver so that no coupling coil is necessary to feed energy from the auxiliary generator to the receiver. Each plug-in coil of the auxiliary generator has a calibration curve secured on its side which assists in identifying dial settings. The auxiliary generator and plug-in coils are shown in Fig. 2 and Fig. 7.

The 10-kc Oscillator

The 10-kc oscillator is of the multivibrator type[2] consisting of two UX201A tubes arranged in a push-pull circuit, the frequency of which is determined by the resistances and capacities used. In order

[2] J. K. Clapp, "Universal Frequency Standardization from a Single Frequency Standard," *Jour.* Opt. Soc. Amer. and Rev. Scien. Instr., **15**, 33; July 1927.

TABLE I

CALIBRATION OF FREQUENCY METER WITH 90 μh COIL

Frequency of Channel	10-kc Oscillator Harmonic	No.	Oscillator Settings	Oscillator Coil	Frequency Meter Setting	Frequency Meter Condenser Position	kc per Degree
550	550.24	55	106.0	3	121.7	A	1.10
560	560.25	56	100.0	3	130.7	A	1.12
570	570.25	57	96.5	3	139.3	A	1.10
580	580.26	58	93.0	3	147.9	A	1.17
590	590.26	59	90.0	3	156.4	A	1.12
600	600.27	60	87.0	3	164.8	A	1.23
610	610.27	61	84.0	3	172.7	A	1.26
620	620.28	62	81.5	3	0.7	B	1.27
630	630.28	63	79.0	3	8.4	B	1.29
640	640.28	64	76.5	3	16.2	B	1.31
650	650.29	65	74.0	3	23.7	B	1.34
660	660.29	66	71.5	3	31.1	B	1.36
670	670.30	67	69.5	3	38.4	B	1.39
680	680.30	68	67.0	3	45.5	B	1.40
690	690.31	69	65.0	3	52.7	B	1.42
700	700.31	70	63.0	3	59.6	B	1.44
710	710.32	71	61.5	3	66.6	B	1.46
720	720.32	72	59.5	3	73.3	B	1.48
730	730.32	73	58.0	3	80.1	B	1.50
740	740.33	74	56.5	3	86.6	B	1.54
750	750.33	75	55.0	3	93.1	B	1.56
760	760.34	76	53.5	3	99.4	B	1.59
770	770.34	77	52.0	3	105.7	B	1.61
780	780.35	78	50.5	3	111.8	B	1.61
790	790.35	79	49.0	3	118.1	B	1.61
800	800.36	80	48.0	3	124.2	B	1.65
810	810.36	81	46.5	3	130.2	B	1.67
820	820.36	82	45.5	3	136.2	B	1.71
830	830.37	83	44.0	3	141.9	B	1.77
840	840.37	84	43.0	3	147.5	B	1.72
850	850.38	85	42.0	3	153.5	B	1.72
860	860.38	86	41.0	3	159.1	B	1.80
870	870.39	87	40.0	3	164.6	B	1.85
880	880.39	88	39.0	3	169.9	B	1.83
890	890.40	89	38.0	3	175.5	B	1.83
900	900.40	90	37.0	3	0.8	C	1.94
910	910.40	91	36.5	3	5.8	C	1.92
920	920.41	92	35.5	3	11.2	C	1.92
930	930.41	93	34.5	3	16.2	C	1.98
940	940.42	94	34.0	3	21.3	C	1.96
950	950.42	95	33.0	3	26.4	C	2.00
960	960.43	96	32.5	3	31.3	C	2.02
970	970.43	97	31.7	3	36.3	C	2.04
980	980.44	98	31.0	3	41.1	C	2.08
990	990.44	99	30.0	3	45.9	C	2.11
1000	1000.44	100	29.5	3	50.5	C	2.11
1010	1010.45	101	29.0	3	55.4	C	2.11
1020	1020.45	102	28.5	3	60.0	C	2.15
1030	1030.46	103	27.5	3	64.7	C	2.11
1040	1040.46	104	27.2	3	69.5	C	2.16
1050	1050.47	105	26.5	3	73.95	C	2.17
1060	1060.47	106	26.2	3	78.7	C	2.16
1070	1070.48	107	25.7	3	83.2	C	2.22
1080	1080.48	108	25.	3	87.7	C	2.20

to maintain the frequency of the multivibrator exactly, the output of a 90-kc piezo-crystal oscillator is coupled to the multivibrator, as indicated in Fig. 3, so that the 90-kc crystal controls the ninth harmonic of the multivibrator, thus maintaining the fundamental of the multivibrator at exactly 10 kc. This is very easily accomplished since the multivibrator is fundamentally a very unstable oscillator and will respond readily to crystal control. Once adjusted, no further adjustment of the multivibrator is necessary. The multivibrator circuit is very rich in harmonics and from the 10-kc fundamental we have readily identified all harmonics lying within the broadcast band, that is, from the 55th to the 150th.

The frequency of the ninth harmonic of the mulivibrator is known with the same accuracy as the frequency of the 90-kc crystal, which in this case is better than one part in 10,000 (Bureau of Standards calibration) at a temperature of 29.2 deg. C. A thermostat is employed to maintain the temperature of the crystal within two-tenths of one degree of 29.2 deg. C thus reducing the change in frequency due to temperature variations to a negligible quantity.

The circuit in which the 90-kc crystal oscillates is a Bureau of Standards type piezo-crystal oscillator employing a UX201A tube utilizing 80 volts of storage battery for plate supply and a 6-volt

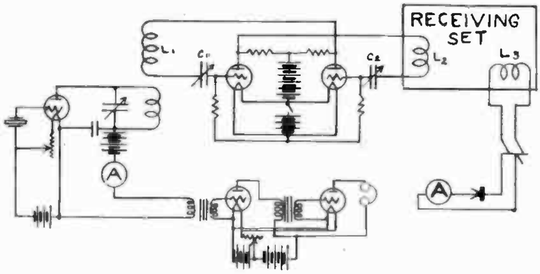

Fig. 3—Circuit Diagram of Crystal-Controlled 10-kc Oscillator.

storage battery for filament heating. A two-step audio-frequency amplifier is coupled in the plate circuit of the piezo-crystal oscillator for observing and checking the adjustment of the multivibrator.

The adjustment of the 10-kc oscillator is checked by noting the number of intermediate points at which beats are heard with the multivibrator in operation, lying between two successive beats from the crystal oscillator alone, beating with the auxiliary generator, which are separated by the fundamental frequency of the crystal oscillator, in this case 90 kc. For example, beats are obtained between the 90-kc crystal oscillator and the auxiliary generator with the auxiliary generator set at 540 kc and at 630 kc. If the multivibrator is now placed in operation and eight intermediate beat notes are obtained between 540 kc and 630 kc with the ninth point coinciding with the crystal point, it is then apparent that the 90-kc interval between 540 kc and 630 kc has been divided into nine equal parts, hence the beats are ten kc apart and must originate from a 10-kc fundamental. If there are nine intermediates from the multivibrator, then the fundamental frequency is 90/10, or 9 kc. Fractional harmonics are disregarded throughout. J. K. Clapp describes in detail the method of checking the adjustment of the multivibrator in the paper to which we have already referred.

In actual practice, the 90-kc crystal-controlled 10-kc oscillator functions in a manner similar to that of a crystal oscillator provided with a crystal ground for 10 kc. The method is superior to utilizing the fractional harmonics of the 90-kc crystal oscillator directly, as these fractional harmonics vary greatly in strength and are not spaced 10 kc apart. The multivibrator could be controlled at 10 kc by means

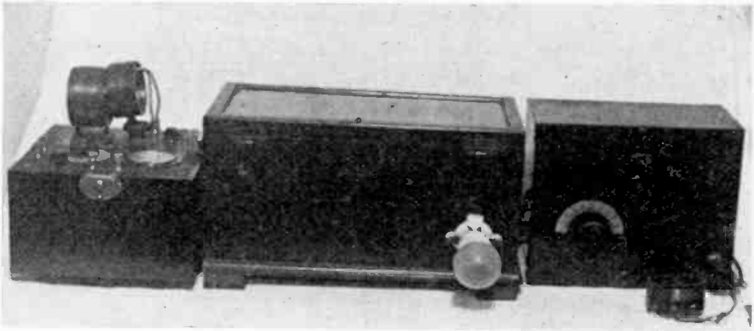

Fig. 4—90-kc Crystal Oscillator with Temperature Control Crystal Chamber and 10-kc Oscillator.

of other crystals which are exact multiples of ten merely controlling a different harmonic of the multivibrator; for example, a 150-kc crystal can be made to control the 15th harmonic of the 10-kc oscillator. A device of this kind might be of use in the calibration of broadcast receivers for the various channels. Fig. 4 shows the 10-kc oscillator at the right, and next to it the heat controlled chamber for the piezo crystal which operates in the oscillator at the left. The coupling coil of the 10-kc oscillator is seen at the left coupled closely to the coil of the crystal oscillator, and the output coil which feeds harmonics to the receiver is in front of the 10-kc oscillator at the right.

The Frequency Meter

The frequency meter consists of two coils, of 90 μh and 30 μh inductance, respectively, either of which may be connected across the variable condenser which has a maximum capacity of 1000 $\mu\mu$f.

The coils are wound with litzendraht wire (composed of 96 strands of No. 38 wire) spaced on 6-in. Pyrex forms with a diameter to length ratio of 2 to 1, which is nearly the ideal ratio for maximum inductance with a given length of wire. The wire is secured to the form with pure varnish applied to the under side of the wire while winding. Coils wound in this manner do not loosen as a result of temperature changes. With coils of this type as shown by E. L. Hall of the Bureau of Standards, it is possible to detect a change of 30 cycles at a frequency of 1000 kc.[3] The resonance indicator consists of a microammeter in series with a crystal detector coupled to the condenser by means of a coil and an aluminum plate.[4] A combination of capacity and inductive coupling is employed to give uniform response over the frequency range of the meter. The microammeter has a maximum scale reading of 200 microamperes and will show full scale deflection when the frequency meter is coupled to the coil in the auxiliary generator at a distance of three feet. A six to one geared vernier dial expands the condenser scale and reduces the kilocycles per degree to permit accurate reading of the dial settings. The resonance peaks on the frequency meter are so pronounced that settings may be duplicated to 0.05 of one degree on the condenser vernier dial. The frequency meter is shielded and grounded and adjusted by means of a long bakelite rod to eliminate entirely the effect of body capacity. We have found that the microammeter connected to the frequency meter, as shown in Fig. 6, produces much sharper resonance indications than can be obtained with a milliammeter connected in the grid circuit of the auxiliary generator (the latter method of indicacating resonance commonly known as the "grid dip" method).

As a result of the loose coupling enployed, the change in frequency produced in the auxiliary generator when the frequency meter is brought into resonance is less than one cycle per second at the lower frequencies in the broadcast band, and at the higher freqnencies does not exceed five cycles per second. With such small frequency change, it is impracticable to employ the method[5,6] of noting the point of zero reaction between the two detuning points when the frequency meter is resonated with the auxiliary generator, since the latter

[3] E. L. Hall, Technological Papers of the Bureau of Standards, No. 330, page 118.

[4] M. S. Strock, Scientific Papers of the Bureau of Standards, No. 502, page 116.

[5] C. B. Aiken, "A Precision Method for the Measurement of High Frequencies," Proc. I.R.E., **16**, 126; February, 1928.

[6] August Hund, "Uses and Possibilities of Piezo-electric Oscillators," Proc. I.R.E., **14**, 461 (footnote); August, 1926.

method of indicating resonance is inoperative without considerable reaction between the two circuits. Fig. 5 shows the frequency meter, and Table I lists the approximate settings of the frequency meter for the broadcasting frequencies between 550 and 1100 kc. The last column of Table I indicates the kilocycles per degree on the condenser dial of the frequency meter for each broadcast channel.

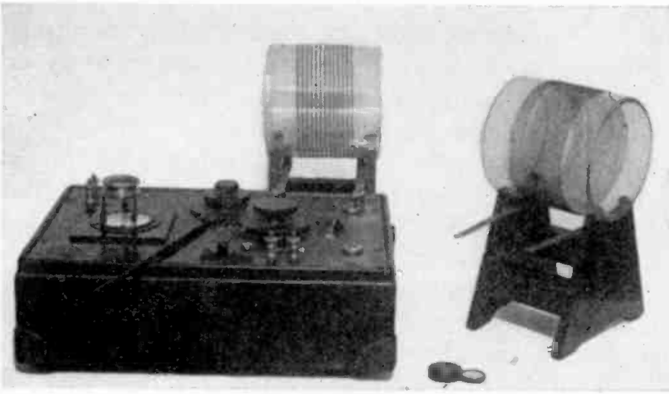

Fig. 5—Frequency Meter.

Fig. 6 shows the circuit used in the frequency meter, while Fig. 8 indicates the shape of the calibration curve of the frequency meter. Fig. 9 shows resonance curves of the frequency meter using the 30-μh and 90-μh coils, respectively.

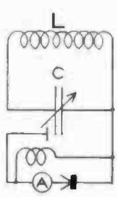

Fig. 6—Circuit Diagram of Frequency Meter.

Practical Operation and Results Obtained

In the outline of method given above, we have indicated the procedure followed in making a measurement of the operating frequency of a broadcast station. It will be noted from a study of Table I that the kilocycles per degree on the frequency meter condenser scale range from 2.20 kc per degree at 1080 kc to 1.10 kc per degree at

550 kc, which indicates that the calibration curve of frequency plotted against condenser degrees is not quite a straight line for the type of condenser used. However, unless the frequency of the station under measurement is actually one or more kc removed from the assigned frequency, the "station setting" on the frequency meter will differ from the "crystal setting" by a matter of only a few tenths of one degree of the condenser scale. For this extremely small portion of its length, the calibration curve of the frequency meter may be assumed to be a straight line, and in fact, since the "station setting" can never be more than 5 kc from some "crystal point" (the 10-kc oscillator furnishes harmonics at 10-kc intervals), the error introduced by assuming the curve to be a straight line, does not, under any condition of use, reach a value as great as 25 cycles. The possible

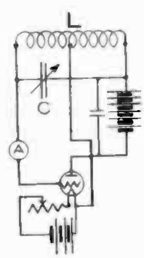

Fig. 7—Circuit Diagram of Auxiliary Generator.

error from this source is reduced as the "station setting" approaches the "crystal setting".

Curve I of Fig. 8 shows the portion of the calibration curve for the 90-μh coil of the frequency meter between 690 kc and 830 kc, and curve II of Fig. 8 shows the portion of the calibration curve of the 30-μh coil of the frequency meter between 1300 and 1450 kc. Using the 30-μh coil of the frequency meter between 1100 and 1500 kc, it is found that the kilocycles per degree range from 2.20 kc per degree at 1100 kc to 3.13 kc per degree at 1500 kc. The kilocycles per degree, using the 30-μh coil, are therefore slightly greater on the higher frequencies than the kilocycles per degree on the 90-μh coil using the latter coil for the lower frequencies in the broadcast band.

It is therefore an advantage to measure the frequencies of the broadcasting stations in the region of 1500 kc by employing the second harmonic of the auxiliary generator, rather than the fundamental frequency. For example, a 1500-kc station could be more accurately measured by adjusting the auxiliary generator to 750 kc. The difficulties inherent in the usual methods of obtaining zero beat adjustments have been overcome by the combination aural and visual beat method employed, which utilizes a large cone loud speaker for following the beat note down to the point where the visual beat indicator commences to function, which is in the neighborhood of 15 cycles. From this point to actual synchronism, the visual beat indicator

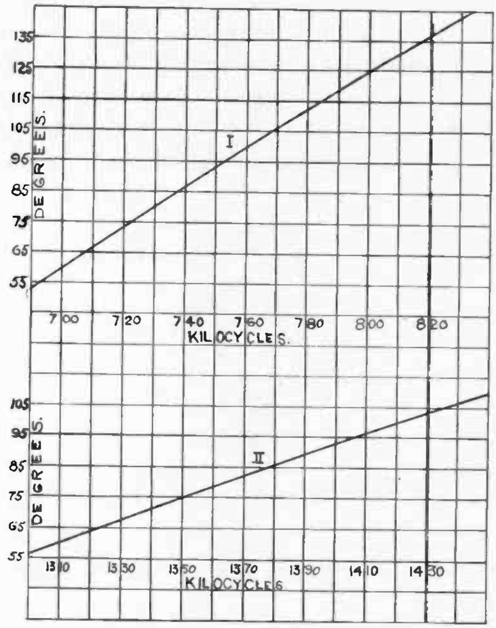

Fig. 8—Frequency Meter Calibration Curve.

produces visual indications of the beat frequency. The visual beat indicator has been successfully employed in resonating the auxiliary generator with the carrier frequencies of many of the more stable carriers of stations in the Second Radio District, and in fact, visual beats have been obtained on stations located as far distant as Denver, Colorado. In resonating the auxiliary generator with the harmonics of the 10-kc oscillator, the visual beat indicator is again utilized.

On account of interference conditions in the vicinity of the Subtreasury Building, measurements of the operating frequencies of broadcast stations are not regularly commenced until after 4:00 P.M., and from that time until approximately midnight it is customary

TABLE II

TYPICAL LOG OF MEASUREMENTS
DEPARTMENT OF COMMERCE
Radio Division
New York City

Room Temp. 74 deg., 5 P.M.

Barometer 29.96, 5 P.M.

Weather Clear, light N. W. wind

Zero Beat Measurements
Thursday, September 20th, 1928.

Zone No. 1
Dist. No. 2

Station*	Time	kc Deviation	High Low	Operating Frequency	Assigned Frequency	Remarks
1	2:29 P.M.	0.1	High	610.1	610	Visual beats
2	2:33 "	0.0	—	660.0	660	Visual beats O.K.
3	3:15 "	0.3	Low	1019.7	1020	Carrier slightly unsteady
4	3:24 "	0.0	—	760.0	760	Slight swinging
5	3:58 "	Carrier too unsteady to be measured				
6	4:26 "	2.2	Low	1217.8	1220	Fluttery carrier
7	4:47 "	0.1	Low	1119.9	1120	
8	5:52 "	1.9	High	1501.9	1500	Swinging
9	5:55 "	Station not on the air as advertised in program for this date				
10	5:57 "	0.2	Low	1369.8	1370	Swinging
11	6:15 "	0.8	High	1170.8	1170	Swinging
12	6:19 "	0.5	High	860.5	860	Slight swinging
13	6:28 "	0.9	Low	809.1	810	Visual beats
14	6:32 "	0.3	High	920.3	920	Visual beats
15	6:37 "	0.2	Low	969.8	970	Heterodyne
16	6:43 "	4.9	High	1474.9	1470	
17	6:53 "	0.1	Low	1499.9	1500	Heterodyne
18	6:57 "	0.2	Low	1119.8	1120	Carrier swinging
19	7:03 "	0.2	High	1220.2	1220	Carrier swinging
20	7:10 "	0.8	Low	1369.2	1370	
21	7:15 "	0.2	Low	1409.8	1410	Heterodyne
22	7:19 "	0.2	High	1270.2	1270	
23	7:25 "	0.0	—	1250.0	1250	Heterodyne
24	7:30 "	0.1	High	1320.1	1320	Very bad generator hum
25	7:41 "	0.1	High	1470.1	1470	Bad QRM from CW telegraph station
26	7:47 "	0.3	High	1170.3	1170	Visual beats
27	7:52 "	0.2	High	710.2	710	Visual beats
28	8:00 "	0.0	—	660.0	660	Visual beats O.K.
29	8:03 "	0.1	High	610.1	610	Visual beats
30	8:07 "	0.0	—	570.0	570	Visual beats O.K.
31	8:17 "	0.0	—	760.0	760	Visual beats; heterodyne
32	8:22 "	0.1	Low	809.9	810	Visual beats
33	8:31 "	0.2	Low	789.8	790	Visual beats
34	8:40 "	0.4	High	1500.4	1500	Heterodyne
35	8:46 "	0.0	—	1370.0	1370	Heterodyne; fading badly
36	8:54 "	0.8	Low	1389.2	1390	Heterodyne; fading
37	9:18 "	0.5	Low	1269.5	1270	Heterodyne
38	9:31 "	0.4	Low	1019.6	1020	Heterodyne very strong Fading
39	10:18 "	0.2	Low	1119.8	1120	Two bad heterodynes; bad hum on station
40	10:27 "	0.2	Low	1319.8	1320	Bad heterodyne; fading
41	11:05 "	Station not on the air as specified in station application				

*Numbers have been substituted for the actual call letters of stations.

to log about 35 Second District stations, and from 5 to 20 stations outside the district, depending upon prevailing receiving conditions.

The sample log sheet (Table II) for September 20, 1928 is typical of measurements made three times weekly of the operating frequencies of stations in the Second Radio District. Stations found to be deviating (more than 500 cycles) are immediately notified by letter of their deviations, and subsequently checked to ascertain whether such deviations have been corrected.

A study of Table II indicates that the carriers of many stations are unstable, preventing accurate zero beat adjustment, and therefore the frequencies cannot be accurately determined. In other cases it will be noted from the "Remarks" column that visual beats have been obtained on both the carrier wave of the station and the harmonic from which the frequency of that particular station was determined. Where two or more stations are operating simultaneously on nearly the same frequency, heterodyne beat notes occur which may seriously interfere with the adjustment of the auxiliary generator to resonance with the carrier it is desired to measure. In

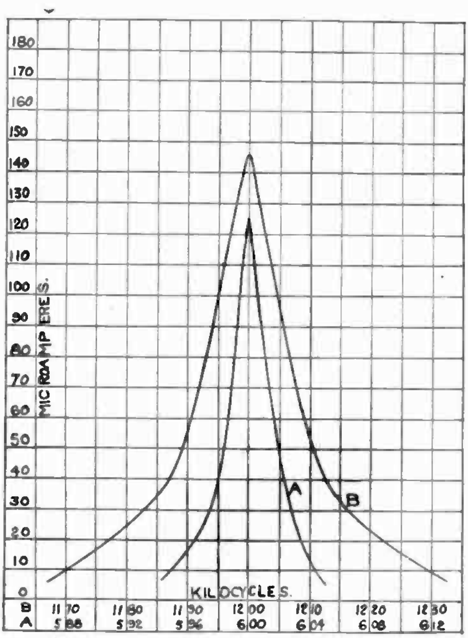

Fig. 9—Resonance Curves of Frequency Meter at 600 kc and 1200 kc.

such cases, no measurement is made unless the carrier can be identified and the desired signal separated from other stations.

It will be noted from Table I that the frequencies of the harmonics obtained from the 10-kc oscillator do not fall exactly on the channels assigned to broadcasting stations. This is due to the fact that the quartz crystal which controls the multivibrator has a fundamental frequency slightly in excess of 90 kc.

The fact that the 10-kc crystal harmonic points do not exactly coincide with the assigned frequencies does not in any way affect the procedure, nor the accuracy of the results obtained, provided the actual frequency of the harmonics is known with accuracy. While the system, as at present employed, uses a frequency meter to interpolate between the calibrating point and the station setting on the frequency meter, it is planned to use a calibrated audio-frequency oscillator to measure the beat note obtained when the signal to be measured is beating with the appropriate harmonic of the 10-kc oscillator.

As indicated in our early paragraphs, the problem was to devise quickly, with the apparatus then available, an accurate method of checking broadcasting stations on their assigned frequencies. The results obtained with the apparatus described have proved the method of comparison with the harmonics of a 10-kc source to be vastly superior to the previous method of measurement using a wavemeter. The results of simultaneous measurements by the use of the equipment described and several laboratories equipped to make frequency measurements with precision have indicated in most cases an agreement within 100 cycles.

In closing this paper, the authors wish to express their appreciation of the assistance rendered by the Radio Division of the Bureau of Standards, and particularly to E. L. Hall of that organization, who made several calibrations of the piezo-crystal oscillator used in connection with the apparatus described.

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EAST-WEST AND NORTH-SOUTH ATTENUATIONS OF LONG RADIO WAVES ON THE PACIFIC*

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Summary—*A comparative study of low-frequency signals of high power stations in the Pacific area has been made, with particular reference to relative attenuation in north and south directions as compared with attenuations in east and west directions. A comparison of observed field strengths in microvolts per meter with the results calculated by various proposed formulas has been made. While the agreement is none too good with any of the formulas, the results indicate that east and west attenuation is decidedly greater than north and south during the daylight hours in the fairly high latitudes. They also indicate that in comparing observed results with different transmission formulas due account must be taken of the type of experiments upon which the formulas in question were based. It is suggested that by the inclusion of terms in the formulas, depending upon both direction and latitude, it might be possible to construct or modify some of the existing formulas to fit the general case.*

IT has been theoretically shown by Nagaoka,[1] Pickard,[2] Appleton,[3] and Nichols and Schelleng,[4] that the east-west attenuation of radio waves ought to be greater than the north-south attenuation. Nagaoka and Pickard dealt with the problem by discussing the ionized state in the upper atmosphere, whereas Appleton, and Nichols and Schelleng attributed it to the effect of the terrestrial magnetism. However, as very little quantitative experimental information has been heretofore given to verify the above-mentioned theories, the results recently obtained by the authors will be given in the present paper.

Throughout the entire year of 1927, the measurements were made at a station near Tokyo at certain specified times of a day on the field intensities of radio signals received from several long-distance, long-

* Dewey decimal classification: R113. Original manuscript received by the Institute, March 2, 1929.

[1] H. Nagaoka, "On the propagation of electric waves on the earth's surface and the ionized layer of the atmosphere," *Proc.* Tokyo Math. Phys. Soc., p. 403, 1914.

[2] G. W. Pickard, "Static elimination by directional reception," PROC. I. R. E., **8**, 358; October, 1920.

[3] E. V. Appleton, "Geophysical influences on the transmission of wireless waves." The Phys. Soc. of London, and Royal Meteorological Society, a discussion on "Ionization in the atmosphere and its influence on the propagation of wireless signals." 16D, Nov. 28, 1924.

[4] H. W. Nichols and J. C. Schelleng, "Propagation of electric waves over the earth," *Bell Sys. Tech. Jour.* **4**, 215, 1925.

wave, high power stations. The method of measurement and results obtained by it were already published.[5] Among the observed stations were included Bolinas, Kahuku, Malabar, Palao and Saigon, which are compared in this paper.

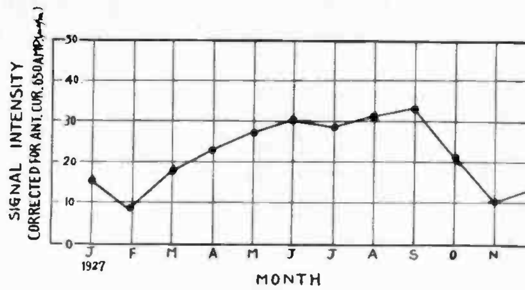

Fig. 1—Monthly Average Variations of Field Intensities, Bolinas.

As shown in Table I, Bolinas and Kahuku are situated nearly to the east, and Palao nearly to the south, while Malabar and Saigon are located almost to the southwest of the receiving station.

TABLE I

Observed Station	Direction* (deg)	Great Circle Distance (km)	Percentage of the Sea on the Path.
Bolinas	89° 7′	8,145	100
Kahuku	103 43	6,095	100
Malabar	217 46	5,920	75
Palao	191 13	3,280	96
Saigon	233 39	4,340	90

* Measured clockwise from the true north.

According to the theory advanced by Nichols[6], the greater attenuation of waves in the direction of east and west is due to that of a component of electric vector of the waves parallel to the terrestrial magnetic field, the waves being considered as composed of electric vectors parallel and perpendicular to the earth's magnetic field. The amount of the east and west attenuation thus depends on the inclination of the earth's magnetic field in a particular locality considered; that is, at a place where the magnetic inclination is small, the attenuation will not be great even in the direction of east and west. Therefore, there will be no appreciable difference between the attenuation in the direction of east and west and that of north and south. From

[5] T. Nakai, "Long distance radio receiving measurements." Researches of the Electrotech. Lab., No. 217, 1927. E. Yokoyama and T. Nakai: "The measurements of the field intensities of some high-power long-distance radio stations." Researches of the Electrotech. Lab., No. 229, June, 1928; No. 233, July, 1928; No. 238, Sept., 1928.

[6] Same reference as in 4.

the above reasoning, it follows that the southwest propagation either from Malabar or Saigon where the magnetic inclination is small, can be considered to be of the nature of north and south propagation as that from Palao.

As shown in Table I, the great circles passing through the receiving point and the observed stations do not cross a large extent of land

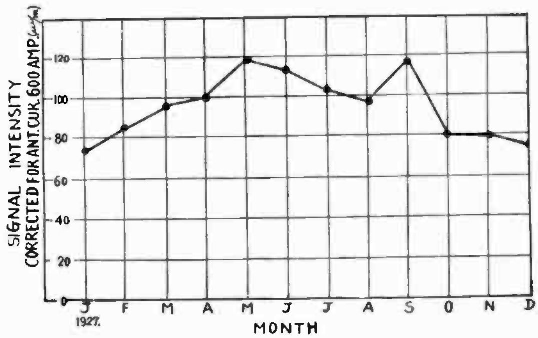

Fig. 2—Monthly Average Variations of Field Intensities, Kahuku.

which is apt to complicate the attenuation of waves, but lie almost entirely over the sea. Under such relative positions of stations, the transmission in the direction of east and west may be satisfactorily compared with that in the direction of north and south.

In Table II are given the wavelengths, radiation heights of antennas and antenna currents of the stations as well as times of measurements which were all chosen so that both transmitting and receiving stations are in daylight.

TABLE II

Observed Station	Wave-length (m)	Rad. Height of Antenna (m)	Ant. Current (a)	Time of Measurement		
				GMT	LTTS	JCST
Bolinas	13,100	51	650	2240	2.40 P.M.	7.40 A.M.
Kahuku	16,975	80	600	0300	4.30 P.M.	0.00 P.M.
Malabar	15,600	380	A 500 M 350	0100	8.00 A.M.	10.00 A.M.
Palao	10,000	65	120	0220	11.20 A.M.	11.20 A.M.
Saigon A	16,050	145	420	2330	6.30 A.M.	8.30 A.M.
Saigon B	20,800	145	600	0540	0.40 P.M.	2.40 P.M.

A. . . . . Arc
M. . . . . Machine
LTTS. Local times of transmitting stations
JCST. Japanese Central Standard Time

Monthly averages (5 to 9 points for each month) of the field intensities for the stations are plotted in Fig. 1 to Fig. 6, and their annual averages are given in column (I) of Table III. These data are roughly corrected to the day-time averages as shown in column (II) by using data of some 24-hour observations made throughout the whole year.

For comparison of the observed and calculated values, Eckersley's[7], Espenschied's[8], and Austin's[9] new transmission formulas are selected as the most suitable, on account of the similarity in wavelengths and

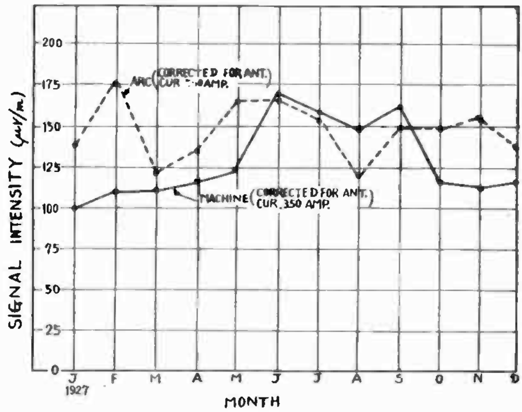

Fig. 3—Monthly Average Variations of Field Intensities, Malabar.

distances. Eckersley's is based on a series of tests which were carried out in day-time between a ship, and European and American high power stations during the voyage from England to New Zealand via Newport and Panama. On the voyage, the Pacific route was in the south-westerly direction and had little land intervening, which resembles the writers' experiments with Saigon and Malabar.

[7] $\epsilon = 377 \times 10^3 \frac{hI}{\lambda \sqrt{Rd^\circ \sin\theta}} e^{\frac{-0.000955d}{\sqrt{\lambda}}}$

λ	d°
10.000	1,150
13.100	700
15.600	520
16.050	500
16.975	450
20.800	400

R = radius of earth.

[8] $\epsilon = 377 \times 10^3 \frac{hI}{\lambda d} \sqrt{\frac{\theta}{\sin\theta}} e^{\frac{-0.005d}{\lambda^{1.25}}}$

[9] $\epsilon = 377 \times 10^3 \frac{hI}{\lambda d} \sqrt{\frac{\theta}{\sin\theta}} e^{\frac{-0.0014d}{\lambda^{0.6}}}$

In the above equations, h, λ, d, d°, R are in km; I in amperes, ϵ in μv per meter; θ in radians.

Espenschied's is based on over-sea tests, nearly in the direction of east and west, made between England and the United States, the condition of which corresponds to the writers' experiments with Bolinas and Kahuku. Austin's new formula is based on the results obtained by various experimenters, and the analysis of various conditions is, accordingly, very difficult. The values calculated by the above-mentiond three formulas are given in column (III) of Table III, and the ratios of the calculated and the corrected observed values in column (IV) of the same table. Furthermore, the values calculated by Hertz's formula[10] and their ratios are also included in the table.

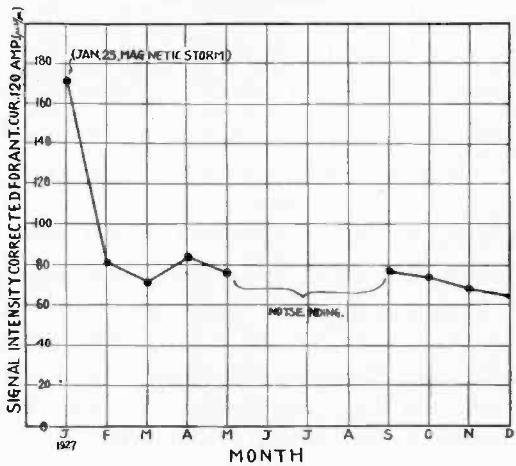

Fig. 4—Monthly Average Variations of Field Intensities, Palao.

As seen in Table III, the observed values for Bolinas and Kahuku are fairly close to those calculated by Espenschied's, whereas the values for Saigon and Palao are widely different. The calculated values for Malabar have been found by using the published figure, 380 meters, as its radiation height. The station uses the so-called "mountain antenna" and its radiation height is said to be that high. The antenna is, however, doubtful as to efficiency, at least towards Japan, because of the probable shadow effect of the mountain by which it is supported and of its poor radiation to that direction.[11] The station is, therefore, excluded from the present comparison. On the other hand, the observed values for Palao and Saigon are fairly close to those calculated by

[10] $\epsilon = 377 \times 10^3 \, hI/\lambda d$.

[11] C. W. Doetsch, "Die Grosstation Malabar-Radio auf Java," *Telefunken-Zeitung*, Nr. 40/41, S. 14, Okt., 1925.

Eckersley whereas the values for Bolinas and Kahuku are widely different.

The coincidence in the observed and calculated values of field intensities seems thus to depend upon the direction of the transmissions on which the formula is based. This indicates that the attenuation of radio waves in fairly high latitudes is governed by the direction of their propagation. Taking this into account, it appears advisable, for

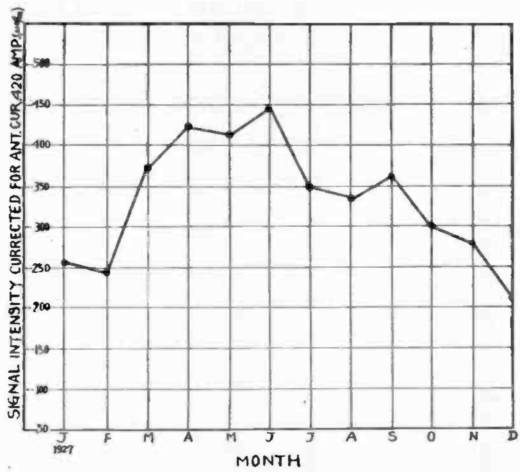

Fig. 5—Monthly Average Variations of Field Intensities, Saigon (A).

obtaining a more suitable formula, to take into consideration and introduce a factor depending on both direction and latitude.

TABLE III

Observed Station	(I) Observed Average μv/m	(II) Corrected Observed Average μv/m	(III) Calculated μv/m				(IV) Ratio of correc. obs. and calc.			
			Hertz	Eckersley	Espenschied	Austin's New	obs. Hertz	obs. Eckers.	obs. Espen.	obs. Austin N.
Bolinas	22	22	117	54	26	11	0.19	0.41	0.85	2.00
Kahuku	93	93	175	170	78	40	0.53	0.55	1.19	2.32
Malabar A	147	147	775	674	322	170	0.19	0.22	0.46	0.87
Malabar M	129	129	542	471	225	119	0.24	0.27	0.57	1.07
Palao	74	70	90	58	36	29	0.78	1.21	1.95	2.42
Saigon A	333	438	330	360	174	109	1.33	1.22	2.52	4.02
Saigon B	582	493	363	502	231	141	1.36	0.98	2.14	3.50

It is also noticeable from Table III that the observed values for Saigon and Palao are nearly twice as large as those calculated by Espenschied, and those for Bolinas and Kahuku are nearly half as small as the values calculated by Eckersley. This seems to indicate that north and south propagation of long waves goes on with less attenuation than east and west in rather high latitudes.

The values calculated by Austin's new formula approach all the observed values, but remain far less. As mentioned above, this is probably due to the complexity of conditions in the experiments on which the formula is based.

It is also interesting to note that the observed values in Saigon experiment exceed the values calculated by Hertz.

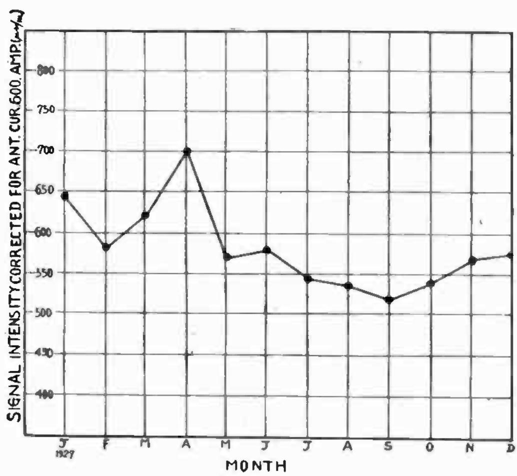

Fig. 6—Monthly Average Variations of Field Intensities, Saigon (B).

In the experiment[12] on which Eckersley's formula is based, attenuation of waves was greater at the positions of the ship between England and Newport than between Newport and New Zealand. Taking into consideration that the former course was in an east-west and the latter in a north-south or south-west direction this may be taken as an evidence of the difference in east-west and north-south wave propagations.

In addition to those, for the night transmission of radio signals at short and broadcasting wavelengths, many experimental results have also been obtained in Japan showing that signals in north and south directions are stronger than those from east or west, but it has not yet been confirmed quantitatively.

The conclusions arrived at are as follows:

[12] H. J. Round, T. L. Eckersley, K. Tremellen, and F. C. Lunnon: "Report on measurements made on signal strength at great distance during 1922 and 1923 by an expedition sent to Australia," *Jour.* I. E. E., 63, 933, No. 346, October, 1925.

1. East-west attenuation is decidedly greater than north-south attenuation in long-wave daylight propagation in fairly high latitudes, the former being about twice as large as the latter.

2. Observed values of long-wave day-time field intensities can be estimated only by a transmission formula which is based on experiments carried out under similar conditions.

3. In order to construct a transmission formula which is universally applicable, an additional factor, depending on both direction and latitude, must be introduced.

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BOOK REVIEW

Matter, Electricity, Energy; the Principles of Modern Atomistics and Experimental Results of Atomic Investigations, by WALTER GERLACH; translated from the second German edition by Francis J. Fuchs, New York, D. Van Nostrand Company, 1928, Pp. xii+427, 119 illustrations, $6\frac{1}{4} \times 9$, cloth, $6.00.

It is much to be regretted that so few scientists on this side of the Atlantic who are doing creative work in their several fields are willing to spend the necessary time and energy for popular or semi-popular writing. In this respect both the English and Germans are leading us by at least 45°. The book before us is a good example of semi-popular science in Germany, written by a prominent contributor to contemporary advance in physics. It covers the domain of modern physics down to 1923 very thoroughly, and for that reason cannot treat any one branch of the subject in sufficient detail to meet the needs of those who are especially engaged in "atomism." Nevertheless, engineers, chemists, and other workers in allied fields will find the book a rich storehouse of information on what is doing in modern physics. Unfortunately the development of the new mechanics took place after the book was written. As a rule each chapter may be read independently of the rest.

Among the thirty chapters the following are likely to be of most interest to readers of this journal: General Atomistics, The Specific Charge of the Electron, The Magnetron, Super-Conductivity, Spectral Emissions and the Periodic System of Elements, Resonance and Dispersion, the Compton Effect, The Extension of Our Knowledge of the Electromagnetic Spectra, The Photoelectric Effect, Practical Applications of the Photoelectric Effect, Infra Red Frequencies of Chemical Radicals in Crystals, Structure Analysis by Means of X-rays, Electron-Affinity, and Radiation Measurements.

There is also a good account of the quantum theory and of the work of Gerlach and Stern on the magnetic moments of atoms.

The reader who hopes to find in the chapter on "Practical Applications of the Photoelectric Effect" an account of the use of the photoelectric cell in picture transmission, television, etc., will be disappointed, as the only applications mentioned have to do with laboratory measurements.

The task of translating has in the main been well performed, although the translator's apparent unfamiliarity with technical terms sometimes makes the book savor more of the dictionary than of the laboratory. Thus we find, in reading of the vacuum-tube amplifier for photoelectric cells, the plate current referred to as the "anode stream," and the grid as a "grating electrode."

In the last chapter on "Atomism and Macrocosmos" a brief account is given of the atomic theory as applied to the stars. The recent speculations of Eddington and Jeans are not, however, included. A few misprints occur, especially on page 318.

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Volume 17, Number 7 *July, 1929*

MONTHLY LIST OF REFERENCES TO CURRENT RADIO LITERATURE

THIS is a monthly list of references prepared by the Bureau of Standards and is intended to cover the more important papers of interest to professional radio engineers which have recently appeared in periodicals, books, etc. The number at the left of each reference classifies the reference by subject, in accordance with the scheme presented in "A Decimal Classification of Radio Subjects—An Extension of the Dewey System," Bureau of Standards Circular No. 138, a copy of which may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D. C. The various articles listed below are not obtainable from the Government. The various periodicals can be secured from their publishers and can be consulted at large public libraries.

R100. Radio Principles

R113 Kruger, K. and Plendl, H. Ueber die Ausbreitung der kurzen Wellen bei kleiner Leistung im 1000 Kilometer-Bereich. (On the propagation of short waves with low power in the 1000 km range.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 85–92; March, 1929.

(Continuous communication on a frequency of 6000 kc between ground and plane over distances up to 600 km using a two-watt piezo-controlled transmitter with battery power was shown to be practical. Detailed description of experiments and explanation of results are given.)

R113.4 Kenrick, G. W. and Jen, C. K. Measurements of the height of the Kennelly-Heaviside layer. Proc. I. R. E., **17** pp. 711–733; April, 1929.

(Further contribution to the Kennelly-Heaviside layer problem is offered in the form of experimental data showing evidence of the diurnal cycles in layer height and a mathematical discussion of methods for the interpretation of group time and phase retardation experiments with the view of determining the relationship between "virtual" and "true" heights.)

R113.5 Dearlove, F. Radio frequency phenomena associated with the Aurora Borealis. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 193-195; April, 1929.

(Observations made in Labrador and Newfoundland on the effect of aurora borealis on reception at high frequencies. Two types of aurora appear; type A, a faint glow generally seen in Northern sky extending faint streaks of greenish light in all directions and appearing at a great altitude, generally moving slowly but sometimes stationary. Type B appears suddenly, consists of undulating patches of vivid greenish light. Type A and to a less extent type B, produces very abnormal types of reception for frequencies of 7500, 3750 and 1875 kc, even during daylight.)

R113.6 Lange, E. H. Note on earth reflection of ultra short radio waves. Proc. I. R. E., **17**, pp. 745–751; April, 1929.

(Computations and curves are given for the reflection coefficients and phase angles for various surface conditions in conjunction with a horizontal ultra short antenna. Theoretical polar diagrams were computed for various heights of horizontal antenna above the surface.)

R130 Kingdon, K. H. and Mott-Smith, H. M. The operation of radio receiving tube filaments on A. C.—Part II. General Elec. *Review*, **32**, pp. 228–232; April, 1929.

(Discussion of causes of distortion resulting from use of grid-leak with a detector tube which employs a.c. on the filament. When grid becomes sufficiently positive, grid current flows causing grid voltage fluctuations which in turn give rise to a double-frequency ripple in plate current. Serious disturbances are caused if filament drop is greater than 0.1 volt.

R131 Barclay, W. A. The algebraic representation of triode valve characteristics. *Experimental Wireless and Wireless Engr.* (London), **6**, pp. 178–183; April, 1929.

(Analytical treatment of the "lumped" triode characteristic holding over the entire characteristic curve.)

R131 Decaux, B. Un abaque de classification pour les triodes de reception, application a leur choix rationnel. (A chart classifying receiving tubes.) *L'Onde Electrique*, **8**, pp. 37–40; January, 1929.

(A chart is presented in which each tube is recorded as a point, its abscissa being the logarithm of the amplification factor, and its ordinate being the logarithm of the internal resistance. The position of the point with respect to indicated zones shows for what purpose the tube is suitable.)

R133 Latour, M. A propos de la communication de M. F. Bedeau sur "Les differentes methodes de determination de la condition d'entretien des oscillations dans les emetteurs a lampes." (Re a communication from M. F. Bedeau on "The different methods of determining the condition for continuous oscillations in electron transmitting tubes.") *L'Onde Electrique*, **8**, pp. 77–79; Feb., 1929.

(A brief summary of the author's earlier analysis of the conditions for continuous operation of a self exciting three-electrode tube generator.)

R133 Mercier, J. Le mecanisme de la stabilisation des oscillations dans un oscillateur a lampes. (The mechanism for stabilizing oscillations in electron tube oscillators.) *L'Onde Electrique*, **8**, pp. 29–36, Jan.; pp. 60–67, Feb., 1929.

(A mathematical graphical study of the building up and maintenance of radio frequency in an electron tube generator. The consideration extends to various orders of magnitude of the damping constant and to the effect of a grid current.)

R133 Okabe, K. On the short wave limit of magnetron oscillations. Proc. I. R. E., **17**, pp. 652–59; April, 1929.

(The short-wave limit for radio-frequency current generator by a magnetron is theoretically considered. Experimental results in support of the theory are given. Successful production of a wavelength of 5.6 cm is reported.)

R137 Hartshorn, L. The measurement of the anode circuit impedances and mutual conductances of thermionic valves. *Proc.* Royal Soc.(London), **41**, pp. 113–125; Feb. 15, 1929.

(Application of Wheatstone bridge to measurement of plate circuit admittance or impedance and mutual conductance of an electron tube under actual conditions. Current of audio frequency was used.)

R146 Guillemin, E. A. and Rumsey, P. T. Frequency multiplication by shock excitation. Proc. I. R. E., **17**, pp. 629–651; April, 1929.

(Fundamental principles involved in theory of frequency multiplication by means of iron-core coupled circuits are briefly reviewed from standpoint of Fourier's analysis as well as that of recurring transients.)

R146 Marique, J. Note sur le calcul des etages multiplicateurs de frequence a triodes. (Note on the design of frequency multiplying stages of triodes). *L'Onde Electrique*, **8**, pp. 1–19; January, 1929.

(Calculations are given based on the static characteristics of a tube for determining the power that can be drawn from a tube at twice or three times the frequency of the input. A simple theory is presented for choosing the best tube inductance, capacity, and grid and plate voltages for a frequency multiplying stage.)

R200. Radio Measurements and Standardization

R201.2 Lloyd, H. Note on an application of the Whiddington ultra-micrometer. *Jnl. Scientific Instruments* (London), **6**, pp. 81–84; March, 1929.

(Methods are given which have been employed for overcoming some difficulties met with in using a heterodyne micrometer and improved arrangements are described for the indication of the zero beat condition audibly or visibly.)

R210 Pession, G. and Gorio, T. Measurement of the frequencies of distant transmitting stations. Proc. I. R. E., **17**, pp. 734–744; April, 1929.

(Equipment installed in the Italian Royal Experimental Institute of Communications for radio-frequency measurements is described.)

R220 Cagniard, L. Deux examples de montages qui font intervenir la variation des caracterictiques d'un appareil recepteur ou de mesure. (Two examples of networks making use of the variation in characteristics of a receiving or a measuring apparatus.) *L'Onde Electrique* **8**, pp. 68–76; Feb., 1929.

(A circuit with its analysis is presented for the accurate measurement of capacities, self-inductances, etc. at higher frequencies. The circuit is a Wheatstone bridge employing in its resonant measuring diagonal a quadrant electrometer. The capacity of the latter being a function of its deflection increases the sensitivity of the circuit enormously.)

R230 Hartshorn, L. The measurement of the inductance and effective resistance of iron cored coils carrying both direct and alternating current. *Jnl. Scientific Instruments* (London), **6**, pp. 113–115; April, 1929.

(Method is described for measurement of effective inductance and resistance of coils of large self inductance which are required to carry a comparatively large direct current with a superposed a-c ripple. Hay's inductance bridge is used with special arrangement for independent control and measurement of the a-c and d-c components, the avoidance of earth capacity effects without grounding the a-c supply and elimination of the d-c from the vibration galvanometer used as detector without losing sensitivity. Typical results are given.)

R240 Sutton, G. W. A method for the determination of the equivalent resistance of air condensers at high frequencies. *Proc.* Royal Soc. (London), **41**, pp. 126–134; Feb. 15, 1929.

(Losses in air condensers are due to leakage through the solid dielectric and to terminal and plate resistance. A method is developed for measuring each under conditions such that the other is negligibly small. Limits of the errors to which the methods are liable are discussed and some results of practical measurements are quoted.)

R275 Jolliffe, C. B. The use of the electron tube peak voltmeter for the measurement of modulation. Proc. I. R. E., **17**, pp. 660–663; April, 1929.

(Method described whereby the peak value of the radio-frequency current is measured without modulation. The modulation is then applied and the peak value again measured.)

R300. Radio Apparatus and Equipment

R329 Eckersley, P. P. and T. L., and Kirke, H. L. The design of transmitting aerials for broadcasting stations. *Jnl.* I. E. E. (London), **67**, pp. 507–526; April, 1929.

(Presents theory of the antenna as a radiator with special reference to its ability to radiate rays parallel to the surface of the earth. Account of experiments with different types of antennas designed to achieve this result is given. Theory of attenuation of waves having frequencies between 500 and 1500 kc is given, and a complete set of curves taken from a transmitting antenna near London is shown. Data is given for aiding in the determination of extent of service area for a broadcasting station.)

R330 Sutherlin, L. and Upp, C. B. Characteristics of radio receiving tubes. *Electric Jnl.*, 26, pp. 146–152; April, 1929.

(Gives description of several power tubes and their characteristics.)

R333 Hull, A. W. Hot cathode Thyratrons—Part I. General Electric *Rev.*, 32, pp. 213–223; April, 1929.

(Three-electrode tube similar to pliotron into which a small amount of inert gas has been introduced. This gas changes the pure electron discharge into an arc so that the Thyratron is an electrostatically controlled arc rectifier. Characteristics of tube are given.)

R342.5 Lamb, J. J. A general purpose audio-frequency power amplifier. *QST*, 13, pp. 23–28; April, 1929.

(Design and construction data.)

R343 Jarvis, K. W. Radio receiver testing equipment. Proc. I. R. E., 17, pp. 664–710; April, 1929.

(Detailed description of testing equipment capable of measuring performance characteristics of modern radio receivers with design conforming to the restrictions of the Standardization Committee. A novel modulation meter is described.)

R343 Hendricks, P. S. Another 1929 receiver. *QST*, 13, pp. 15–18; May, 1929.

(Description of three-tube receiver suitable for frequencies of 2800 to 15,150 kc and also for the 28-megacycle band.)

R357 Greibach, E. H. A new type of precision frequency changer for instrument calibration. *Electric Jnl.*, 26, pp. 125–126; March, 1929.

(A photoelectric means of producing wide and accurately known variations in the frequency obtained through a standard tuning fork.)

R370 David, P. La qualite de la reproduction radiophonique. (The quality of radiophone reproduction.) *L'Onde Electrique*, 8, pp. 41–59; Feb., 1929.

(A summary is presented of the factors affecting the quality of radiophone reception discussing (1) distortion due to unfaithful reproduction of frequency and amplitude, (2) distortion due to parasitic frequencies and (3) necessary precautions in detection and in the amplification of audio frequencies. It is concluded that improvement in quality is to be secured at a sacrifice of sensitivity and selectivity in the receiving apparatus.)

R386 Tubbs, E. A. Practical design of audio frequency filters. *Radio* (San Francisco), 11, pp. 17–18; May, 1929.

(Design data.)

R388 Rangachari, T. S. The super-position of circular motions. *Experimental Wireless and Wireless Engr.* (London), 6, pp. 184–193; April, 1929.

(Derivation of expressions for the superpositions of circular motions such as produced in a cathode-ray tube.)

R500. Applications of Radio

R526.1 Aicardi. Reperage de directions fixes au moyen d'ondes Hertziennes —Radio alignements. (Fixed direction marking by radio waves.) *L'Onde Electrique*, 8, pp. 20–28; January, 1929.

(A beacon system is described employing the transmission on the same wavelength from two separate antennas. One transmission is slightly modulated. The number and the disposition of the nodal lines in the resultant field are indicated. A practical scheme for periodically displacing these lines to enable the observer to know his position with respect to them is also presented.)

R526.2 Gloeckner, M. H. Der Bordpeilungempfänger im Flugzeug. (The radio direction finder applied to aircraft.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 92–101; March, 1929.

(Complete description of a special radio direction finder developed by DVL and the Telefunken Co. with an explanation of its application to air navigation.)

R800. Non-Radio Subjects

534 On the sound waves radiated from loud-speakers diaphragms. *Experimental Wireless and W. Engr.* (London), **6**, pp. 175–177; April, 1929.

(A review of the radiation of sound waves from commercial types of loudspeakers with special reference to beam effects.)

621.314.6 Hermanspann, P. Untersuchungen an Drosseln mit geschlossenen Hypernik-Kern. (Experiments with Hypernik (iron-nickel-alloy) closed core chokes.) *Zeits. für Hochfrequenztechnik*, **33**, pp. 81–84; March, 1929.

(Report of experiments with Hypernik-cored chokes by the Physical Institute of the Technical University at Munich. Measurements of inductance and losses at varying field strengths were taken and compared with those of ordinary dynamo sheet iron. Hypernik is a special alloy of iron and nickel manufactured by the Westinghouse Co.)

Proceedings of the Institute of Radio Engineers
Volume 17, Number 7 *July, 1929*

CONTRIBUTORS TO THIS ISSUE

Austin, L. W.: Born October 30, 1867 at Orwell, Vermont. Received A.B. degree, Middlebury College, 1889; Ph.D. degree, University of Strassburg, 1893. Instructor and assistant professor, University of Wisconsin, 1893–1901. Research work, University of Berlin, 1901–1902. With Bureau of Standards, Washington, D. C., since 1904. Head of U. S. Naval Research Laboratory, 1908–1923; chief of Radio Physics Laboratory, 1923 to date. President of the Institute in 1914; served on Board of Direction, 1915–1917; awarded Institute Medal of Honor, 1927. Frequent contributor to the PROCEEDINGS. Associate member, Institute of Radio Engineers, 1913; Member, 1913; Fellow, 1915.

Ballantine, Stuart: Born September 22, 1897 at Germantown, Pa. Operator, Marconi Co., summers 1914–1915; H. K. Mulford Co., bacteriologists, 1916; Bell Telephone of Pa., 1917; expert radio aide, U. S. Navy, in charge of research and development of radio direction-finder apparatus, Philadelphia Navy Yard, 1917–1920; organized Philadelphia Section of the Institute, 1920, and served as chairman until 1926. Studied mathematics at Drexel Institute, 1919, and mathematical physics, graduate school, Harvard University, 1920–1921. With L. M. Hull organized research work at Radio Frequency Laboratories, Boonton, N. J., 1922–1923. John Tyndall Scholar in mathematical physics, Harvard University, 1923–1924. Privately engaged in miscellaneous research work in radio, spectroscopy, astrophysics, propagation of electric waves in the upper atmosphere, at White Haven, Pennsylvania, 1924–1927. In charge of Research Division, Radio Frequency Laboratories, 1927 to date. Frequent contributor to the PROCEEDINGS. Associate member, Institute of Radio Engineers, 1916; Fellow, 1928.

Bogardus, Henry L.: Born December 20, 1894 at Jersey City, N. J. Graduated from Pratt Institute, electrical engineering, 1917. Commercial radio operator, Marconi Co., 1913; radio research laboratory, Western Electric Co., 1917; signal corps, U. S. Army, A.E.F., 1917–1919. U. S. radio inspector, radio division, Department of Commerce, New York, 1920 to date. At present, Acting Supervisor of Radio, New York. Associate member, Institute of Radio Engineers, 1920; Member, 1923.

Crozier, William D.: Born May 24, 1900 at North Liberty, Iowa. Received B.E. degree, University of Iowa, 1923. Graduate student, department of physics, University of Iowa, with research assistantship, 1923–1927. Received Ph.D. degree, 1927. At present research engineer, United Reproducers Corporation, St. Charles, Illinois. Associate member, Institute of Radio Engineers, 1927.

Dean, S. W.: Received A.B. degree, Harvard University, 1919. Cutting and Washington, Inc., 1917; ensign, U. S. Naval Reserve Force, 1918; Radio Corporation of America, 1919–1925; Department of Development and Research, American Telephone and Telegraph Company, 1925 to date, working chiefly in connection with long-wave transatlantic radio receiving systems. Junior member, Institute of Radio Engineers, 1914; Associate, 1918; Member, 1926.

Greaves, V. Ford: Wireless operator, U. S. Navy, 1903; research assistant in physics, Harvard University, 1907–1912; appointed U. S. radio engineer, Department of Commerce, Washington, D. C., 1912–1917, organizing U. S. radio inspection service; lieutenant, U. S. Navy, 1917–1919; director and general manager, National Radio Co., San Francisco, Calif., 1919; director, service manager, and assistant general manager, Burnell-Faulkner Automobile Co., Boston, Mass., 1920; general sales agent, Federal Telegraph Co., San Francisco, Calif., 1921–1924; engineer, Magnavox Company, Oakland, Calif., 1924–1927; in charge field work, Argus Research Corporation, also with Jensen Radio Mfg. Co., sales and engineering, 1927–1929. At present chief engineer, United Reproducers Corporation, Newcombe-Hawley Division, St. Charles, Ill.

Harper, Augustus E.: Born December 30, 1896 at Brooklyn, N. Y. Marconi Wireless Telegraph Co. of America, 1917; signal corps, U. S. Army, 1918–1919; Independent Wireless Telegraph Co., 1920. Received M.E. degree, Stevens Institute of Technology, 1922; with Western Electric Co., 1922–1923; Department of Development and Research, American Telephone and Telegraph Company, engaged in work connected with long-wave transatlantic radiotelephony, 1923. Associate member, Institute of Radio Engineers, 1919; Member, 1926.

Kranz, Fred W.: Received A.B. degree, Lawrence College, 1911; M.A. degree, University of Wisconsin, 1919; Ph.D. degree, University of Chicago, 1922; research laboratory, Western Electric Co., 1913–1920; Riverbank Laboratories, Geneva, Ill., 1920 to date. Radio consultant, 1927 to date. Associate member, Institute of Radio Engineers, 1923.

Lack, Frederick R.: Born in England. Engineering department, Western Electric Co., 1913–1917; division of research and inspection, Signal Corps, A.E.F., 1917–1919; installing radio telephone link between Peking and Tientsin, China, 1920–1922; Harvard University, 1923–1925; research department, Bell Telephone Laboratories, 1925 to date. Associate member, Institute of Radio Engineers, 1920.

Manning, Charles T.: Born July 2, 1893 at Madison, N. J. Commercial radio operator, 1911–1913. Inspector and chief inspector, Marconi Wireless Telegraph Company of America for four and one-half years. Instructor at Radio Institute of America for two years; instructor at Marconi Institute for two years; instructor at Y.M.C.A. Radio School for one year. Radio inspector, Department of Commerce, office of supervisor of radio, 1922 to date. Associate member, Institute of Radio Engineers, 1917; Member, 1928.

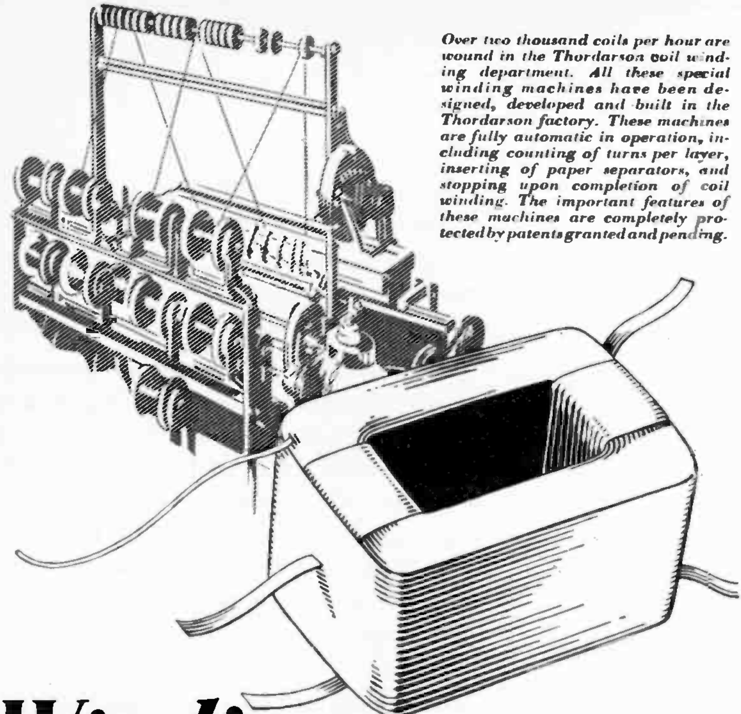
Marrison, W. A.: Born May 21, 1896 at Inverary, Ont., Canada. Received B.Sc. degree, Queens University, Canada, 1920; M.A. degree, Harvard University, 1921. During the war was wireless mechanic in Royal Flying Corps. Since 1921 has been in the Western Electric Company and Bell Telephone Laboratories working on development of constant frequency sources, studies of quartz crystals as resonators, temperature control, and picture transmission. Member, Institute of Radio Engineers, 1928.

Meissner, Alexander: Born September 14, 1883 at Vienna, Austria. Received degree of Doctor of Technical Science, Vienna Technical School, 1909. In 1922 received degree of Honorary Doctor of Engineering, Technical High School of Munich. Since 1907 with the Telefunken Gesellschaft, and at present head of the research laboratory. Honorary professor, Berlin Technical High School. Member, Institute of Radio Engineers, 1914; Fellow, 1915.

Nakai, Tomozo: Born March 10, 1901 at Fukuyama City, Japan. Graduated electrical department of Osaka Higher Technical School, 1922. Entered radio section of the Electrotechnical Laboratory, Ministry of Communications, Japan, engaged in radio researches. Since 1925 working on wave propagation. Associate member, Institute of Radio Engineers, 1929.

Wymore, Ivy Jane: Born in Mahaska County, Iowa. Received B.S. degree Drake University, 1918; M.S. degree, George Washington University, 1925. With Division of Metallurgy, Bureau of Standards, 1919–1924; Laboratory for Special Radio Transmission Research, 1924 to date.

Yokoyama, Eitaro: Born July 21, 1883 at Fukui City, Japan. Graduated Engineering College, Tokyo Imperial University, 1908. Entered Ministry of Communications, Japan, engaged in radio researches at the Electrotechnical Laboratory. One of the inventors of the T.Y.K. oscillation gaps for radiotelephony. Chief of Radio Section, Laboratory, 1920. Member, Institute of Radio Engineers, 1917.



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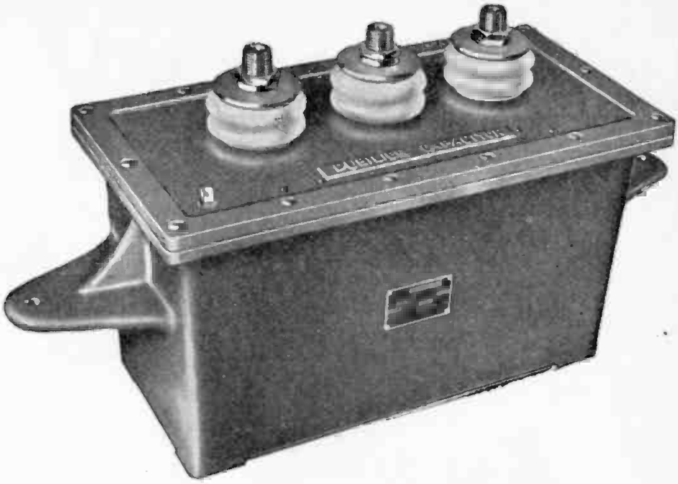

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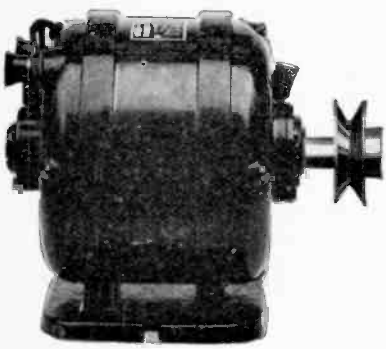

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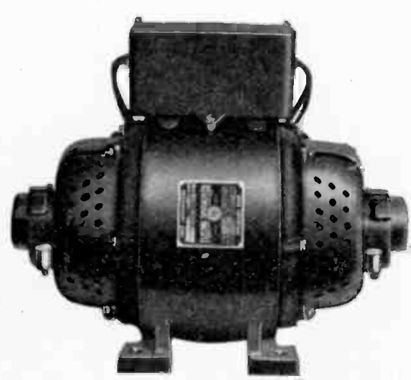

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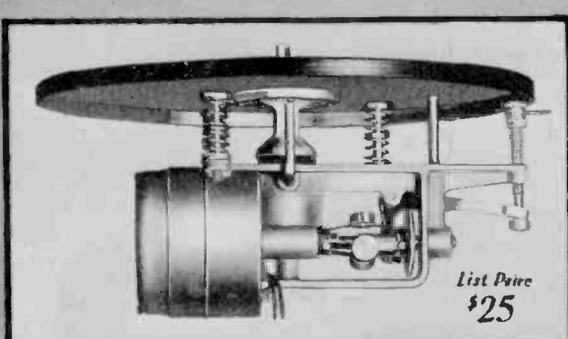

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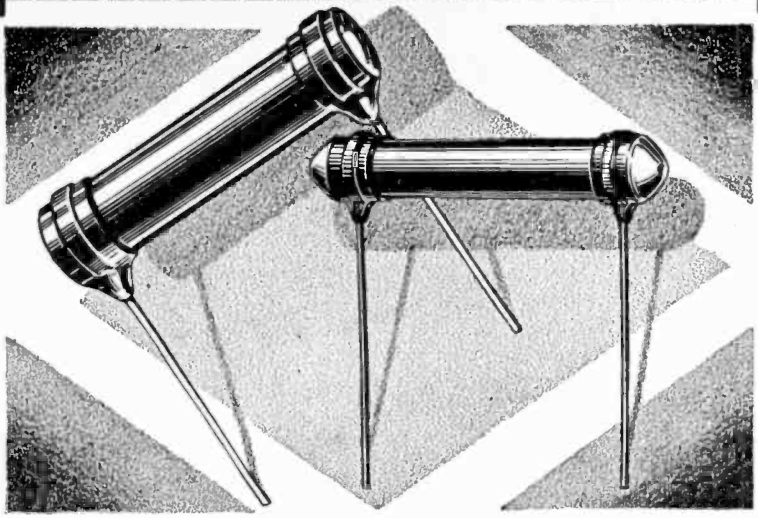

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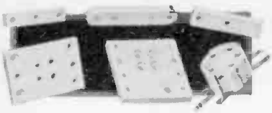
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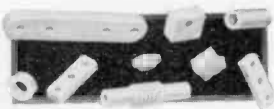
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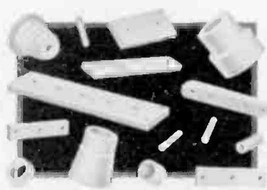
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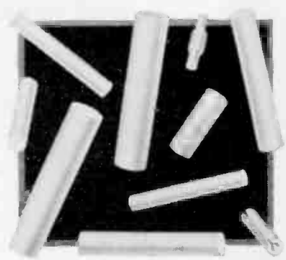
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2 Insulating bridges for variable condensers.

3 Terminal strips, panels, bushings, washers and insulating sleeving.

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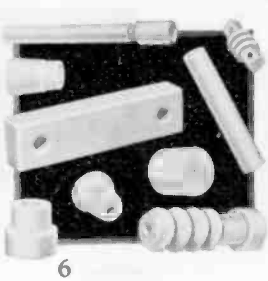
5



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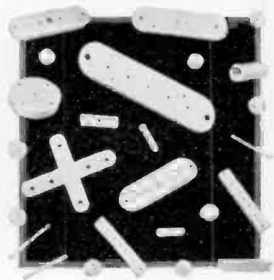

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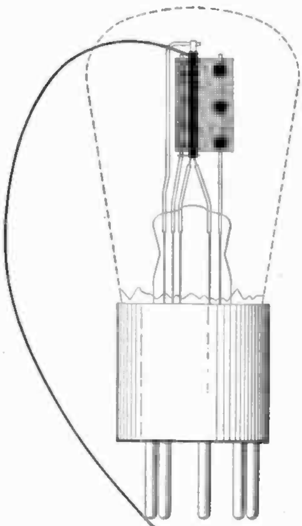

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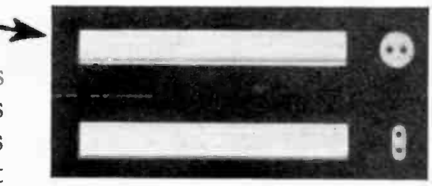

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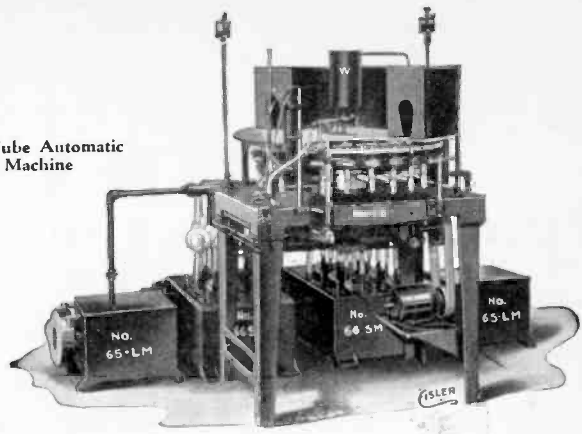

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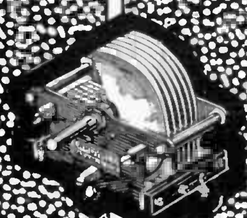

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To the Board of Direction
Gentlemen:

I hereby make application for Associate membership in the Institute.

I certify that the statements made in the record of my training and professional experience are correct, and agree if elected, that I will be governed by the constitution of the Institute as long as I continue a member. I furthermore agree to promote the objects of the Institute so far as shall be in my power, and if my membership shall be discontinued will return my membership badge.

Yours respectfully,

....

(Sign with pen)

....

(Address for mail)

....

(Date) (City and State)

References:

(Signature of references not required here)

Mr.............................. Mr..............................

Address.......................... Address..........................

Mr.............................. Mr..............................

Address.......................... Address..........................

Mr..............................

Address..........................

The following extracts from the Constitution govern applications for admission in the Institute in the Associate grade:

ARTICLE II—MEMBERSHIP

Sec. 1: The membership of the Institute shall consist of: * * * (d) Associates, who shall be entitled to all the rights and privileges of the Institute except the right to hold the office of President, Vice-president and Editor. * * *

Sec. 5: An Associate shall be not less than twenty-one years of age and shall be: (a) A radio engineer by profession; (b) A teacher of radio subjects; (c) A person who is interested in and connected with the study or application of radio science or the radio arts.

ARTICLE III—ADMISSION

Sec. 2: * * * Applicants shall give references to members of the Institute as follows: * * * for the grade of Associate, to five Fellows, Members, or Associates; * * * Each application for admission * * * shall embody a concise statement, with dates, of the candidate's training and experience.

The requirements of the foregoing paragraph may be waived in whole or in part where the application is for Associate grade. An applicant who is so situated as not to be personally known to the required number of members may supply the names of non-members who are personally familiar with his radio interest.

(Typewriting preferred in filling in this form) No.————

RECORD OF TRAINING AND PROFESSIONAL EXPERIENCE

1 Name..

(Give full name, last name first)

2 Present Occupation..

(Title and Name of concern)

3 Permanent Home Address..

4 Business Address..

5 Place of Birth.................. Date of Birth.............. Age.......

6 Education..

7 Degree..

(college) (date received)

8 Training and Professional experience to date..............................

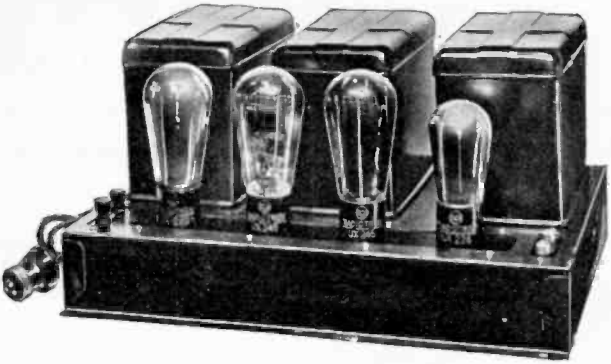
NOTE: 1. Give location and dates. 2. In applying for admission to the grade of Associate, give briefly record of radio experience and present employment.

DATES HERE	

9 Specialty, if any..

Receipt Acknowledged............ Elected............ Deferred...........

Grade.......... Advised of Election......... This Record Filed...........



Our rich experience is at your disposal

POWERIZER
REG.

Power and Super Power AMPLIFIERS

Take up your special problems in tone reproduction with us and benefit by our lifetime of experience in this field. Often our standard POWERIZER models can meet your individual requirements. Where special conditions make this impossible, you will gain by conferring with us freely.

We illustrate here our *PXP-245* 2-stage Powerizer, an exceptionally efficient unit, using two UX-245 tubes in push pull. Other moderately priced units using the new UX-245 tubes are available for your needs. We are now manufacturing rack and panel units in all combinations.

Send for Bulletin R. E. 1028

RADIO RECEPTOR COMPANY, INC.

106 Seventh Avenue
NEW YORK CITY

307 No. Michigan Blvd.
CHICAGO, ILL.

Licensed by Radio Corporation of America and Associated Companies

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

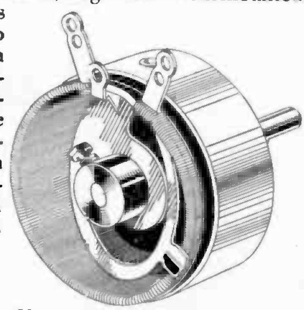
FROST-RADIO VOLUME CONTROLS

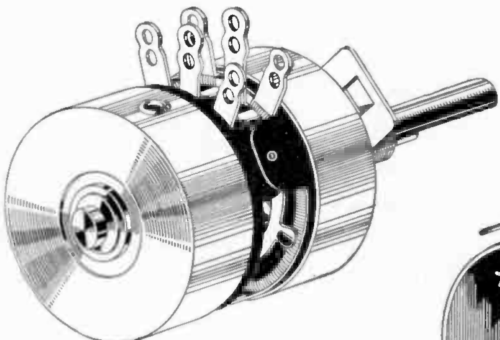
A complete line that gives you a wide range of types to choose from, in either wire wound or carbon element design

FROST-RADIO

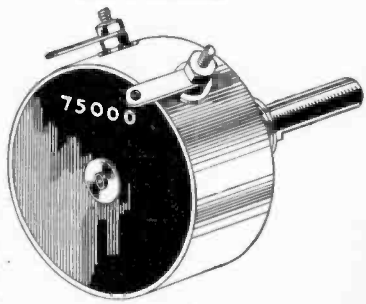
YOU can secure Frost-Radio Volume Controls in any of the curves shown herewith, as well as in many other curves to suit your most exacting needs.

These reliable, finely-built volume controls are made with any desired resistance gradient, in metal shell or Bakelite shell type, and with either wire wound or carbon element construction, single or tandem mounted. Resistance is designed to increase with either clockwise or counter clockwise knob rotation. Smooth running, non-inductive and not affected by temperature or humidity changes.





No matter what your volume control requirements may be, Frost-Radio can meet them. Our long experience and tremendous volume of production have placed us in a unique position to be of service to you in supplying exactly what you want when you want it.



Frost-Radio Wire Wound Resistors are made in four different sizes, all metal shell, with resistances ranging from fractional to 10,000 ohms, with or without D. C. battery switches . . . Frost-Radio Carbon Element Resistors are made in several types, Bakelite or metal shell cases; distinguished by low hop-off, in fractional ohms if desired; also may be combined with A. C. switch.

HERBERT H. FROST, Inc.

***Main Offices and Factory:* ELKHART, INDIANA**

160 North La Salle Street, CHICAGO

The Largest Manufacturers in the World
• • of High Grade Variable Resistors • •

Efficient Short Wave Receivers

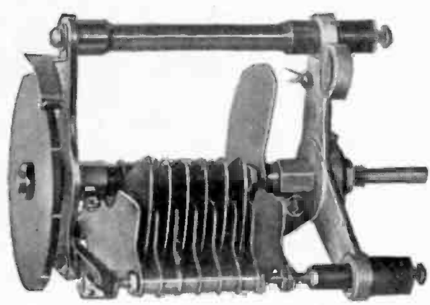
Must Use Correctly Proportioned

Coils and Condensers

REL Units Solve the Problem

For universal short wave reception use REL-Cat. 229 Coil Kit (3 coils and base) and REL-Cat. 181B Condenser—adaptable to all circuits—covers every wavelength from 15-100 meters.

For exclusive amateur band receivers use REL-Cat. 182 Coil Kit (3 coils and base) and REL-Cat. 187E Condenser—adaptable to all circuits—will give full spread tuning on each of the popular bands.



Illustrates the REL Cat.—187E combined tank and vernier condenser—can be used to obtain full spread coverage of any desired narrow frequency band.

Illustrates the REL one-piece bakelite plug-in coil and base—space wound—heavy enamel covered wire—positive base contact.

Full Information Gladly Forwarded upon Request

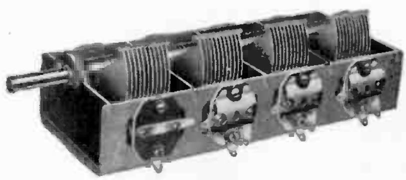
REL MANUFACTURES A COMPLETE LINE OF APPARATUS FOR SHORT WAVE TRANSMISSION AND RECEPTION.

RADIO ENGINEERING LABORATORIES

100 Wilbur Ave. Long Island City, N.Y., U.S.A.

Prophecies - in old Madrid

IN OLD Madrid the Grandees of Spain went to the Gitanos, Spanish gypsies, to have their fortunes told. There, in the flickering light of a crude torch, the old woman of the tribe pored over the lines in aristocratic hands and muttered imprecations or promised future blessings while proud Castilian features reflected scornful disbelief.



The hands of the modern radio manufacturer bear no lines which need the interpretations of a crone to tell him that this is a day of new developments. There is no disbelief, scornful or otherwise, in his features when he is told that his equipment must meet the demands of a highly competitive market. And usually he turns to Scovill for condensers and radio parts manufactured in accordance with the latest and most efficient scientific developments. For he knows that Scovill service insures satisfaction.

Every step in the manufacture of Scovill Condensers is under strict laboratory supervision.

SCOVILL
MANUFACTURING COMPANY
· WATERBURY · · CONNECTICUT ·

New York Los Angeles	Providence Atlanta Cleveland	San Francisco Philadelphia Cincinnati	Boston Detroit Chicago

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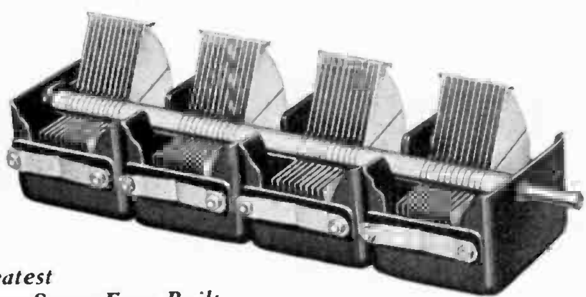
TRADE MARK
UNITED SCIEN. LAB
INC.

IT'S PRECISE! IT'S RIGID! AND IT'S COMPACT



Greatest Space Saver Ever Built

NEW TYPE B. T. ARMORED CONDENSER

This new condenser from the United Scientific Laboratories meets all the scientific requirements of present day radio design and construction. It is the most convenient multiple tuning unit made for individual shielding work. For ultra precision electrical and mechanical perfection, compactness and harmony in design, this new type B. T. Armored Condenser outclasses and out-tests any other condenser on the market. Test this new tuning unit before making your condenser decision. Made in single, two gang, three gang, and four gang units of .00035 mfd. capacity and lower.

Write for Samples, Prices and Complete Construction Details

UNITED SCIENTIFIC LABORATORIES, Inc.
115-C Fourth Avenue, New York City

Branch Offices for Your Convenience in

St. Louis
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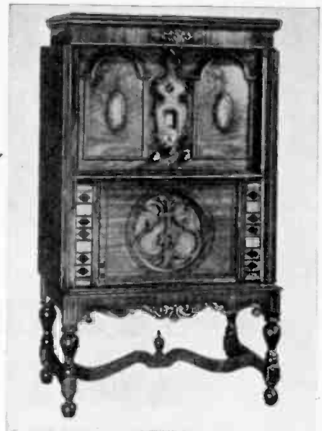
RADIO MANUFACTURERS ASSOCIATION RMA MEMBER

Steinite
ELECTRIC RADIO



Model No. 102

Only DURHAMS are good enough *for this Great Receiver*

ANY manufacturer can cut his parts costs, but it takes leadership to aim at quality reception as a means of winning a quality market, such as Steinite has done in a few short years. Steinite operates on the principle that you can get out of radio only what you put into it. And so Steinite means a quality circuit embracing every practical modern idea, not the least of which is DURHAM Resistors and Powerohms—the metallized resistances which are endorsed and used by leaders in every division of the industry. Durhams may cost a trifle more than average resistances, but experience has proved that their slight additional cost is cheap insurance against imperfect performance and against dissatisfied purchasers. Ask Steinite! We shall be glad to send engineering data sheets and samples for testing upon request. Please state ratings in which you are interested.

THE LEADERS STANDARDIZE ON DURHAM RESISTANCES

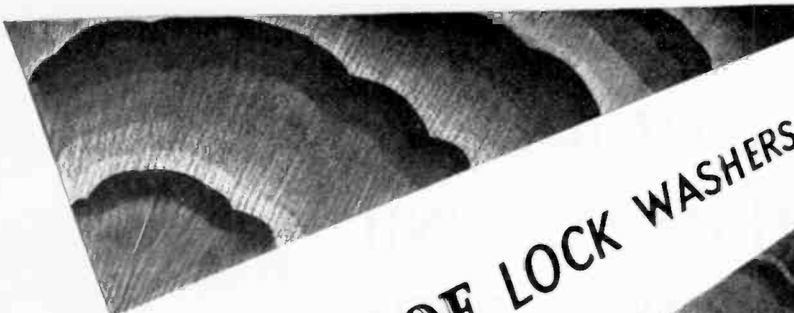
Metallized

DURHAM Metallized RESISTORS and POWEROHMS are available for every practical resistance purpose in radio and television circuits, 500 to 200,000 ohms in power types; 1 to 100 Megohms in resistor types; ratings for all limited power requirements; standard, pigtail or special tips.

DURHAM METALLIZED
RESISTORS & POWEROHMS

International Resistance Co., 2006 Chestnut Street, Philadelphia, Pa.

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*



SHAKEPROOF LOCK WASHERS

UNDER the whip of modern production—no time to waste—the finest possible job in the shortest possible time—here is where Shakeproof is solving the problems of modern industry. A modern washer with teeth that bite into the nut with a grip of steel that only applied force with a wrench can loosen.

Shakeproof Lock Washers are made in a wide variety of types and sizes to fit every need of modern industry. Mail the coupon below for samples and make your own tests. Shakeproof can save you time and money and assure a better job on your production line.

U.S. Patents 1,419,564; 1,604,122; 1,697,954.
Other patents pending.
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☐ Shakeproof Lock Washers to fit bolt size ______
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Town ______ State ______
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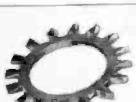
SHAKEPROOF
Lock Washer Company
(Division of Illinois Tool Works)
2501 North Keeler Avenue **Chicago, Illinois**



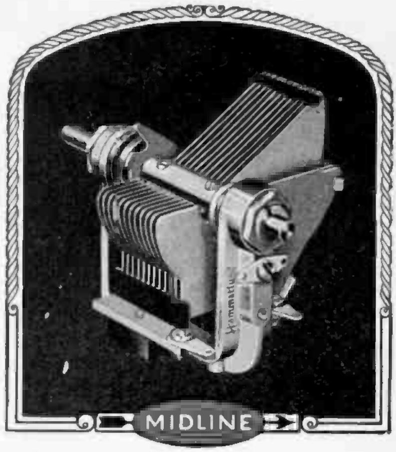
Type 11 External

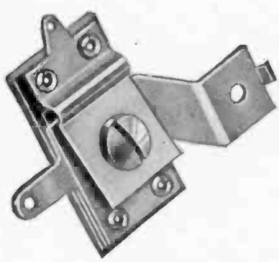
Type 12 Internal

Type 20 Terminal

Standard or Special

HAMMARLUND WORKMANSHIP Assures Condenser Perfection





When the standard Hammarlund Equalizing and Neutralizing Condensers do not fit into your receiver design, we are prepared to make special models, either single or in gang, to your specifications.

THE most advanced radio engineering produced the Hammarlund "Midline" Condenser. It has enjoyed more than three years of leadership because it was *born* a leader—the first embodiment of laboratory precision in a stock condenser model.

Sturdy aluminum alloy frame; soldered brass plates, carefully aligned and fixed by tie-bars; cone and ball bearings; phosphor-bronze pig-tail; removable rotor shaft. Individual and gang models. Also the new "Battleship Midline"—the master of multiple tuning units, with sections matched to within ¼ of one per cent.

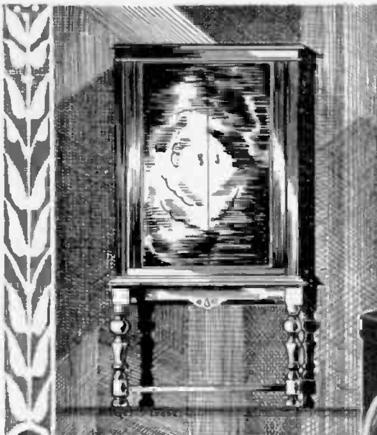
All desirable gang sizes and capacity ratings.

Write us your needs. Hammarlund cooperation and facilities are yours for the asking. Address Dept. PE7.

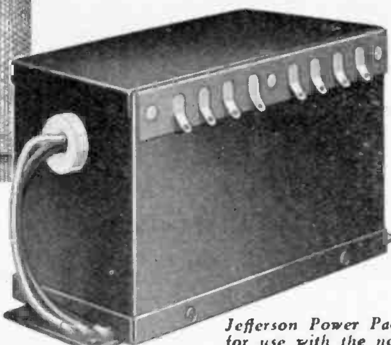
HAMMARLUND MANUFACTURING COMPANY

424-438 WEST 33rd STREET, NEW YORK, N. Y.

For Better Radio
Hammarlund
PRECISION
PRODUCTS



PERFECTED for your new power tube set . . . . .



Jefferson Power Pack for use with the new 245 and 224 tubes

Engineering Co-operation

Jefferson engineers, pioneers in the field of transformer development, are ready to assist in solving your transformer and choke problems. In our own modern research laboratories—or working with your engineers—Jefferson engineers can offer valuable aid in the design of your audio and power equipment.

Protection in Peak Periods

The Jefferson world-wide reputation for quality transformers and integrity in trade relations, combined with tremendous production capacity, is your assurance of a reliable source of supply. During last year's peak season, although besieged with outside business, not one of our customers was forced to seek another source of supply. Deliveries were made promptly under all conditions—production schedules protected.

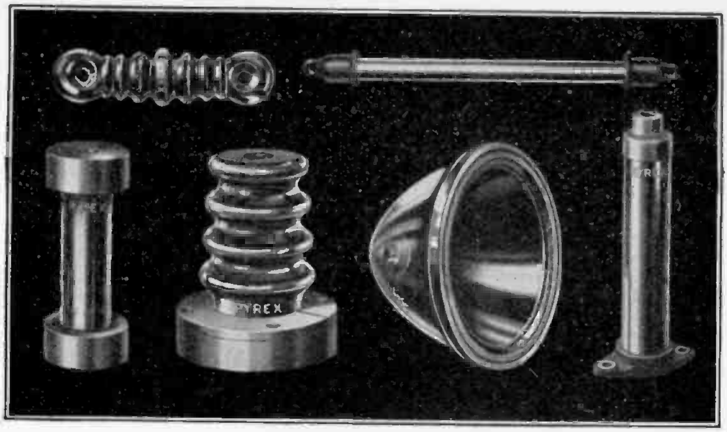
Jefferson . . . .
Transformers and Chokes

Forseeing the present trend toward the use of new power tubes in receiving sets, Jefferson engineers have perfected a special transformer—and a wide choice of choke units—for co-ordinate use with the new 245 power tube and the 224 shield grid tube. Likewise, Jefferson audio transformers have been improved in design to make use of all the potentialities of these new tubes. Complete electrical specifications and quotations will be furnished reliable set manufacturers on request.

JEFFERSON ELECTRIC CO.
1591 South Laflin Street Chicago, Ill.

JEFFERSON

AUDIO and POWER TRANSFORMERS and CHOKES



For full utilization of radio energy,
use PYREX Insulators throughout

Perfect transmission or reception demands this.

First: PYREX Antenna, Strain, Entering, Stand-off, Pillar and Bus-bar Types afford correct selections in the system.

Second: PYREX Insulators are thoroughly impervious and compel the radio current to stay where it belongs.

Third: Their super-smooth diamond-hard surface repels the soot, dirt and moisture deposits that invite leakage and impair quality, especially in wet weather.

To know important differences between what your radio system should do and what it actually does, send for and read the PYREX Insulator booklet. Then if your dealer offers an inferior substitute, insist upon PYREX Insulators and if necessary, buy from us direct.

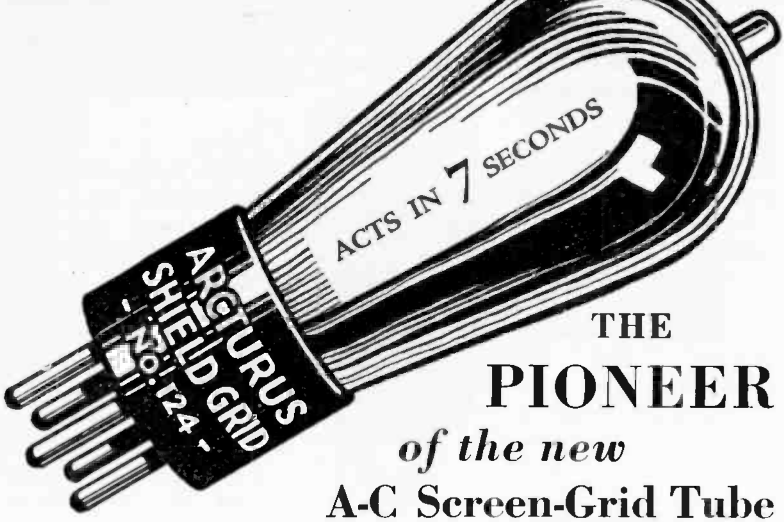
CORNING GLASS WORKS, Dept. 63
Industrial and Laboratory Division
CORNING, N.Y.

T. M. REG. U. S. PAT. OFF.

CGW **PYREX**

A MARK OF CORNING GLASS WORKS

RADIO INSULATORS



THE
PIONEER
of the new
A-C Screen-Grid Tube

A YEAR AGO—the Arcturus A-C Screen-Grid Tube was placed with set manufacturers. TODAY—leading set manufacturers use this new Arcturus A-C Screen-Grid Tube as standard equipment.

Arcturus *pioneered* this latest A-C Radio Tube development and is now building into the No. 124 A-C Screen-Grid Tube *a full year's experience.* Arcturus Tubes act in 7 seconds, give clearer reception as hum is banished, and they hold the world's record for long life.

Insist on Arcturus *Blue* A-C Tubes in your A-C set. Your dealer has an Arcturus A-C Tube for every socket. Try them today—you'll be amazed at the vast improvement.

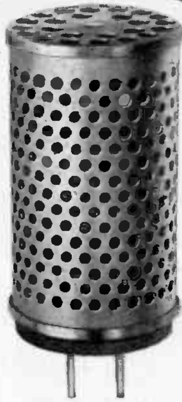
ARCTURUS
BLUE A-C LONG-LIFE TUBES

ARCTURUS RADIO TUBE COMPANY ~ NEWARK, N.J.

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

Solving the "X" in Line Voltage Problems WITH LINE BALLAST CLAROSTAT

DESPITE the frequent reassurances of electric power companies that line voltages are positively maintained at all times; despite the fact that many set manufacturers give no thought to line voltages; despite the prime requisite of low production costs—you *must* face the problem of fluctuating line voltage!



½ Actual size

Present A.C. heater tubes, particularly the screen-grid type, cannot stand excessive voltage. Secondary voltages of power transformer must be maintained within plus or minus 5 per cent which tube makers specify. Yet our survey shows line voltage fluctuations of 30 per cent in some areas.

Remember, low voltage means poor performance and loss of sales. High voltage means frequent tube renewals, excessive service troubles, loss of customer good will, and adverse criticism of your engineering.

Why not make your design complete? The cost is negligible. The increased sales will more than compensate for the addition.

The LINE BALLAST CLAROSTAT is the ideal solution of this problem. A sturdy metal cartridge with plug-in terminals. Holds secondary voltages within plus or minus 5 per cent, even with line voltage fluctuating between 100 and 135 volts, or any comparable range. *Designed for your specific transformer.* Weighs only 3 ounces. Rugged. Will outlast any set. Standard equipment in many leading sets and power amplifiers. And the public is now looking for an automatic line voltage control in the better grade radio sets.

Write for data on the LINE BALLAST CLAROSTAT. To save time, if you are a manufacturer, send sample power transformer and we shall make up samples for your inspection and test.

Clarostat Manufacturing Company, *Inc.*

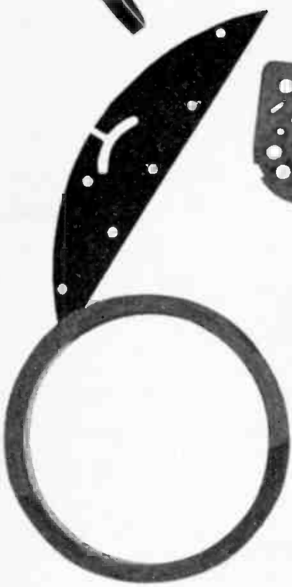
Specialists in Radio Aids

MEMBER R.M.A.

289 North Sixth Street :: Brooklyn, N.Y.

Remember—there's a CLAROSTAT for Every Purpose

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*



WE HAVE SERVED *for* SIXTEEN YEARS

PRACTICALLY since the beginning of the industry Formica has been making Laminated Pnenolic materials for American electrical organizations.

The names of many of the leaders have been on our books almost from the beginning.

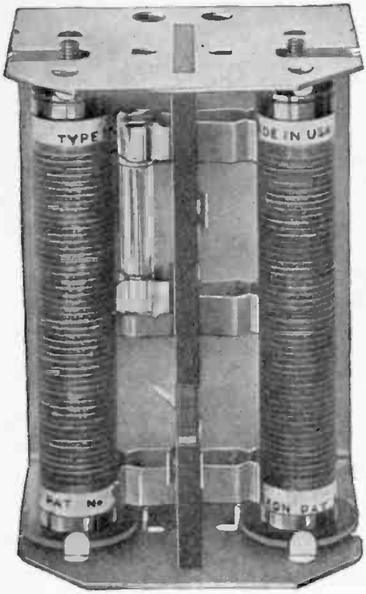
This continued confidence can only be due to good and uniform materials promptly made and delivered.

We have steadily added to plant and equipment - - - even now a new factory building which will house new producing tools is under construction.

THE FORMICA INSULATION CO.
4646 Spring Grove Ave. Cincinnati, Ohio

FORMICA
Made from Anhydrous Bakelite Resins
SHEETS TUBES RODS

This New Elkon Rectifier Eliminates the Power Transformer in Dynamic Speakers



AGAIN Elkon leads the field. The new Elkon D-30 Power Supply is the outstanding development of the year in rectifiers for dynamic speakers. This remarkable rectifier operates directly from the AC power line eliminating the Power Transformer and reducing the cost of assembly.

Supplied complete, ready to install, or the rectifier units (two required on each speaker) can be sold separately.

Wonderfully efficient, quiet in operation. The units can be replaced when necessary as easily as a tube is changed in a socket.

If you have not already sent us a sample of your new speaker, do so at once. We will equip it with the new Elkon rectifier and return it to you promptly.

ELKON, Inc.

Division of P. R. Mallory & Co., Inc.

3029 E. Washington St.

Indianapolis, Ind.

COUPON

ELKON, Inc., Radio Dept. E-73,
3029 E. Washington St., Indianapolis, Ind.
Please send us complete information on your new ELKON D-30 Power Supply for Dynamic Speakers.

Name ....

Address ....

"Here's where we need Your help"

NOT very long ago a prominent radio manufacturer unrolled a blue-print, and turning to the Dudlo sales engineer who stood by his desk, said: "Here's a job for you fellows at the Dudlo plant. We've had a lot of trouble with this power coil. Can't seem to get it to deliver the proper "B" voltages for these new tubes without overheating. Here's where we need your help . . . what can you do for us?"

The Dudlo man's assurance that this manufacturer's coil troubles would be overcome proved to be fact. Now every radio that leaves the factory is equipped with a specially designed Dudlo power transformer coil, and all former complaints against voltage loss or overheating have automatically ceased.

DUDLO

In this manufacturer's newest model, Dudlo coils occupy the strategic positions in all audio, power and speaker units. He is taking no chances on slipshod coils again playing havoc with his reputation.

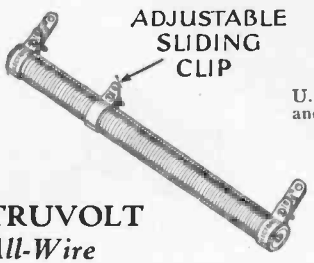
DUDLO MANUFACTURING COMPANY, FORT WAYNE, INDIANA

Division of General Cable Corporation

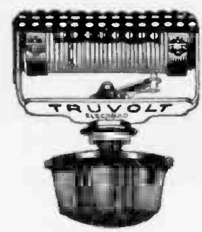
DUDLO

THE COIL'S THE THING IN RADIO

Built for the QUALITY-MINDED



U. S. Pat. 1676869 and Pats. Pending



TRUVOLT *All-Wire* Resistances

While sharpening your pencil to figure prices, give a thought to QUALITY.

Price isn't everything, especially when you can have quality too, *at the right price*.

Cotton in an "all-wool" suit doesn't pay. In radio, likewise, only the *best* is good enough.

When figuring on resistances for eliminators and power-packs, you can't go wrong on TRUVOLTS.

TRUVOLT Variables

Distinctive air-cooled open winding provides unusual ventilation and compactness. Voltages are accurate and stable.

An exclusive Electrad feature is the sliding clip contact, giving convenient adjustability of fixed voltages.

Truvolt variables have a handy knob with a contact arm that travels endwise over the resistance wire. This gives unusually fine regulation and materially lessens wear.

Both the fixed and variable Truvolts are made in 22 stock sizes for all average needs—and you'll like the prices.

List $2.50

We welcome the opportunity to cooperate in designing special units. Our engineers and laboratory are yours to command.

ELECTRAD INC.

ELECTRAD, INC.
Dept. PE7, 175 Varick St.,
New York, N.Y.

Please send technical data on Truvolt Resistances.

Name . . . .

Street . . . .

City . . . .

State . . . .

AEROVOX
BUILT BETTER
CONDENSERS AND RESISTORS

PREPAREDNESS PAYS

IT is safe to say that during the past year, more tempers were ruined, more headaches were caused and more money was lost because of delayed deliveries than from any other one factor which causes the hair of purchasing executives and production managers to grow thin and gray prematurely.

To meet the peak requirements of radio receiver manufacturers for quality condensers and resistors, the Aerovox plant has been increased to a total of 45,000 square feet, with every facility to produce, at short notice, any reasonable quantity of condensers and resistors.

To be assured of an unfailing supply of these units during the peak of the manufacturing season, it is important that tentative production schedules be arranged for, well in advance of actual requirements.

Quality Condensers and Resistors

IN the Aerovox Wireless Corporation, radio manufacturers will find a dependable source for quality condensers and resistors. Aerovox paper condensers are accurate, ruggedly made, have a high safety factor and are non-inductively wound, using 100% pure linen paper as dielectric material. They are thoroughly impregnated and protected against moisture.

Aerovox mica condensers are the acknowledged standard mica condensers in the industry.

A complete line of resistors for every requirement includes Pyrohm vitreous enamelled resistors in fixed and tapped combinations, Lavite non-inductive resistors, Metalohm grid leaks, wire-wound grid suppressors and center-tapped resistors in all standard and special values.

A COMPLETE CATALOG containing detailed specifications of all Aerovox units, including insulating specifications of condensers, current-carrying capacities of resistors and all physical dimensions, electrical characteristics and list prices of condensers and resistors will be sent gladly on request.

AEROVOX WIRELESS CORP.
80 Washington Street, Brooklyn, N. Y.
PRODUCTS THAT ENDURE

"It's great, Bill, since you removed the 'ADENOIDS'"

—And indeed it is. Bill knows the difference now between ordinary "radioed" music and that which the AmerTran Power Amplifier and Hi-Power Box gives him. And his friends do, as well. Bill performed the "adenoid" operation on his set—and when you do—you will know what radio can be like.

Take out the inferior audio system—replace it with the best that money can buy—and your set, no matter how old or out of date will be better in tone than the most expensive receivers on the market.

The new AmerTran Power Amplifier push-pull for 210 tubes and the improved ABC Hi-Power Box will do the trick or if you do not want to spend that much money use the push-pull amplifier for 171 tubes or a pair of AmerTran De Luxe transformers. Any AmerTran outfit will eliminate the adenoids. See your dealer or write to us today.

AmerTran ABC Hi-Power Box—500 volts DC plate voltage, current up to 110 ma; AC filament current for all tubes for any set. Adjustable bias voltages for all tubes. Price, east of Rockies—less tubes—$95.00.

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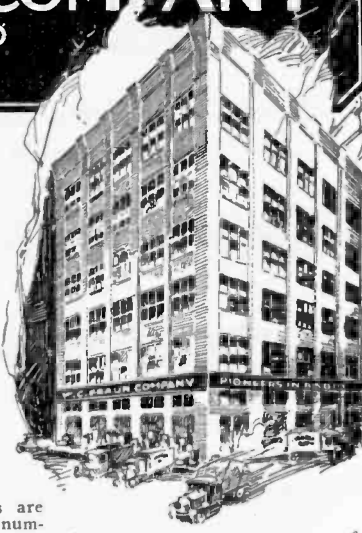

Keep Abreast of the New Developments in Radio

No industry in the world's history has attracted so many inventors and experimenters as the radio industry. Something new is always on tap. Contrast the old wireless days with the modern electrically operated talking radio. Think of what is still to come when perfected television, telephony, short wave control, etc., are fully realized.

In keeping with the policies of *Wholesale Radio Headquarters* (W. C. Braun Company), our service lies in testing out and determining which of these newest marvels are practical, salable and usable for the greatest number. Our task is to study the multitude of new merchandise, select those items that are thoroughly proved and reliable, and make it easy for the public to secure these while they are estill new.

A huge and varied line of standard radio merchandise is carried in stock for quick shipment to all parts of the country. This service assures the dealer and set builder of *everything he needs,* all obtainable from one house, without shopping around at dozens of different sources. It saves considerable time, trouble and money. For example, when you want a complete radio set or parts for a circuit, you also will want a cabinet, loud speaker, tubes and other supplies and accessories. You know that at Braun's you can get everything complete in one order, and thus save days and weeks of valuable time, besides a considerable saving in money.

New Lines for the Summer Months

Here, all under one roof, is carried the world's largest stocks of radio sets, kits, parts, furniture, speakers and accessories for the radio season, portable radios and phonographs for summer trade and a complete line of auto tires, tubes and supplies, electrical and wiring material, camping and outing equipment, tents, golf goods, sporting goods; in fact, a complete merchandise line to keep business humming every day, every week and every month in the year.

NEW LINES FOR THE SUMMER

RADIO SETS, KITS, PARTS SHORT WAVE, TELEVISION, SPEAKERS, SUPPLIES, PORTABLE RADIOS and PHONOGRAPHS AUTO TIRES and ACCESSORIES

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If you don't receive our catalog, by all means send us a request on your letterhead to insure getting each new edition as promptly as it comes out. Braun's Big Buyers' Guide is crammed full of bargains and money-making opportunities that you cannot afford to pass up.

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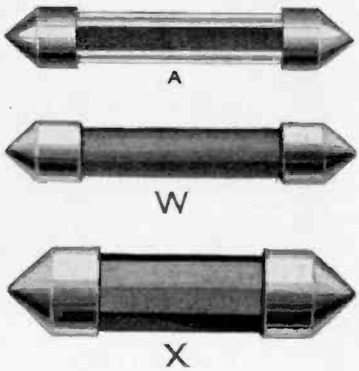


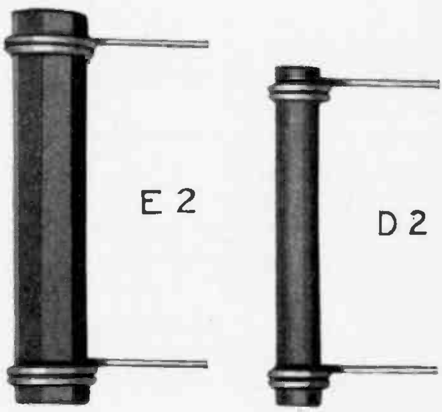
Type A for grid leaks and light power purposes. Will dissipate ½ watt safely.

Types W and X for greater power dissipation.

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.



Samples for test sent on receipt of specifications.

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Three men who are making radio-tube history

Ernest Kauer. The man whose scientific experiments produced the first practical screen-grid tube for use in A. C. sets. Also, under his direction CeCo engineers have produced many other tubes of special design that can be obtained only from the CeCo Manufacturing Company.

N. O. Williams. One of the world's leading authorities on radio tube construction. Formerly Factory Chief Engineer of the Westinghouse Lamp Works in charge of the tube divisions.

John E. Ferguson. The man who invented and perfected the high speed machines for the testing and seasoning of radio tubes. He is responsible for many of the most important improvements in tube manufacture in the past 10 years.

THESE three men are the operating executives of the CeCo Manufacturing Company. They have recently completed a new factory that provides 120,000 square feet of floor space and is equipped to turn out 45,000 tubes a day. This is the largest factory in the world devoted exclusively to research and manufacture of radio tubes.

Recent tests of CeCo Tubes by four impartial laboratories show that CeCo Tubes have 30% to 50% longer life.

Licensed under patents and applications of the Radio Corporation of America, General Electric Company, and the Westinghouse Electric and Manufacturing Company.

This AC224 Screen Grid Tube was developed and perfected by CeCo over a year and a half ago. Recent market surveys indicate that this tube will be an outstanding leader during the coming season.

CeCo Manufacturing Co., Inc.

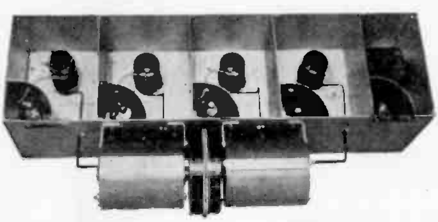
PROVIDENCE, R. I.

THE NEW

"SEVEN SEAS" CONSOLE

A new design by C. R. Leutz using 3 A/C screen grid radio frequency stages, all tuned; power detector; initial audio stage and push pull power audio amplifier for either two 210's or two 250's. Split, single dial control; 100% scientific shielding; dynamic loud speaker and an adjustable selectivity device.

The result, a night range loud speaker volume of from 500 to 1,000 miles using an indoor aerial only a few feet long, great selectivity and the very finest quality of reproduction.



View of the radio frequency and detector chassis showing the efficient shielding arrangement resulting in a minimum of losses. Condensers also totally shielded. Power audio amplifier and power pack are in separate chassis.

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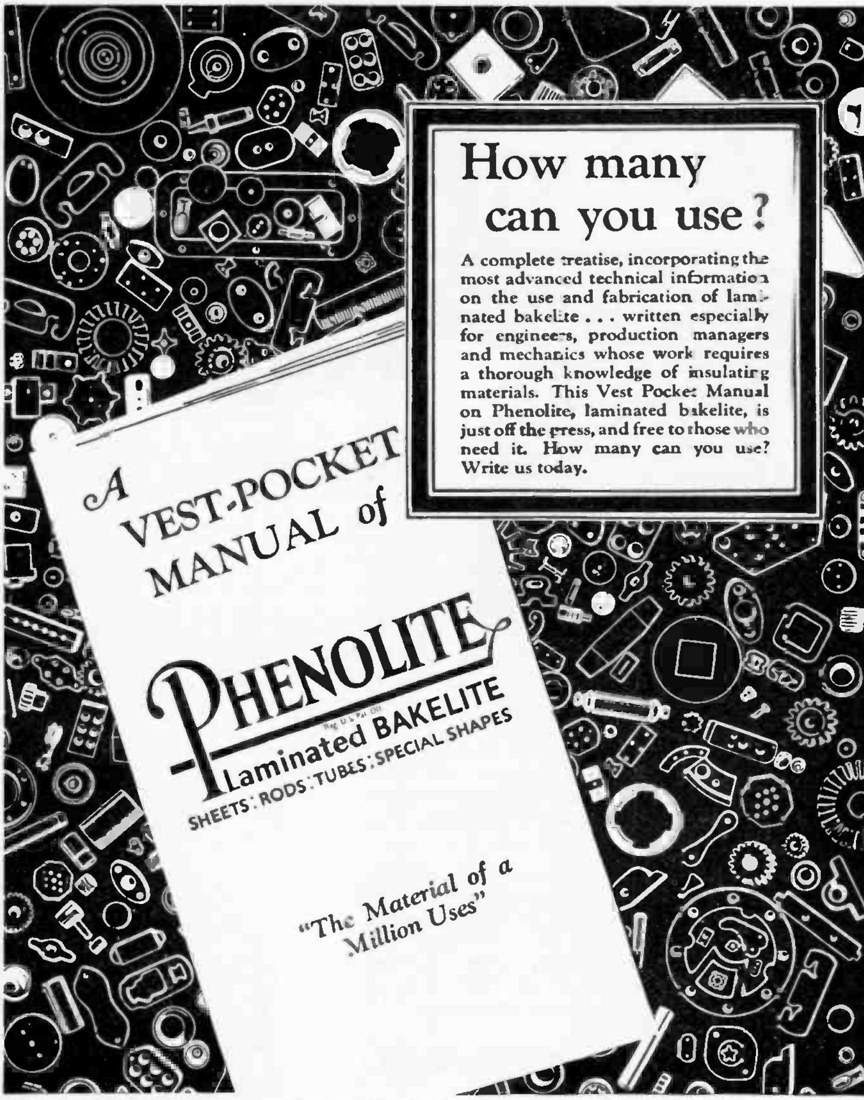

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A NEW JEWELL 199 Set Analyzer

TESTS SCREEN GRID Sets

The rapid development of screen grid tubes and the marketing of screen grid receivers by large radio manufacturers demands a set analyzer for testing screen grid sets.

With the keen foresight which has characterized Jewell efforts in the radio service field, Jewell Engineers have already solved this problem. The New Jewell 199 Set Analyzer is equipped to test screen receivers.

Through a remarkable engineering achievement, this valuable feature has been added to the 199 without increasing the selling price. Today radio dealers and servicemen can get a Jewell 199, equipped for testing screen grid receivers, *at no extra cost.*

THE New Jewell Pattern 199 Set Analyzer answers every requirement of accurate and rapid radio service. It is the same unit which has proved so popular with radio servicemen everywhere, plus the provision for testing screen grid sets.

Encourage your dealers and servicemen to equip themselves with Jewell 199's and pave the way to satisfied customers and profitable sales by making service calls on radio users. It is the most profitable way to utilize their spare time during the summer months, and is a sure road to accessory sales and leads to new set sales. Sold by radio jobbers everywhere.

The Jewell system of radio service eliminates guesswork. Write today for copy of the Jewell "Instructions for Servicing Radio Receivers," which contains accurate service data on sets of leading manufacturers.

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High and Low Voltages
Ideal for Filter Blocks

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North Chicago, Illinois
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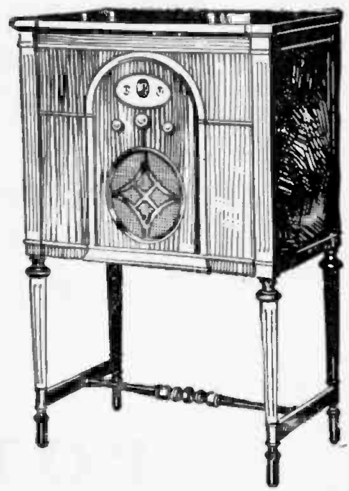
Engineering Frankness in Advertising

As the oldest manufacturer of screen-grid apparatus among all RCA licensees, Silver-Marshall has carried boldly into the complete-set field its policy of revealing at once to the radio engineering fraternity all technical information and performance data applying to SILVER RADIO. This data was printed in the 67,000 copies of the S-M house-organ, the RADIOBUILDER, on May 15th, as well as in Radio Broadcast for June and Radio News for July.

Silver-Marshall screen-grid engineering is so far in advance of less experienced competition that it can afford to be frank in its disclosures.



SILVER RADIO Lowboy (illustrated): eight tubes including four 224's; price $160.00. SILVER RADIO Highboy is electrically identical, but the cabinet (larger) has sliding doors; price $195.00. Slightly higher west of the Rockies.
Average sensitivity, 1.2 to 2.2 microvolts per meter, over all; fidelity curve practically flat from 100 to 4000 cycles; selectivity ratio 12 kc. off resonance at 550 kc., 200:1.

Silver Radio

While SILVER RADIO is strictly a completely-manufactured product, Silver-Marshall will not discontinue the manufacture of S-M parts, but instead will continue to present to experimenters the very finest parts the market affords, as well as S-M RCA-licensed receivers of advanced type, assembled from them in accordance with fully-published constructional details. The very latest developments of the S-M laboratories will continue to be described in the monthly RADIOBUILDER; if you are not getting it regularly, ask for a sample copy.

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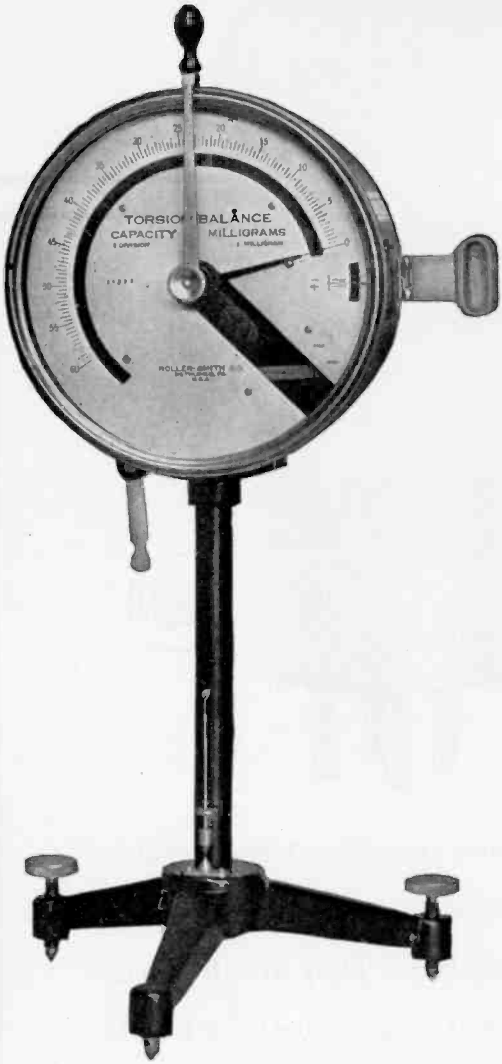

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These balances are made in ranges from 0-6 milligrams to 0-50 grams. They are recommended for the weighing of lamp filaments and other masses within their range.

They are direct reading, have scales 10″ long and are accurate within one fifth of one per cent of full scale value at any point on the scale.

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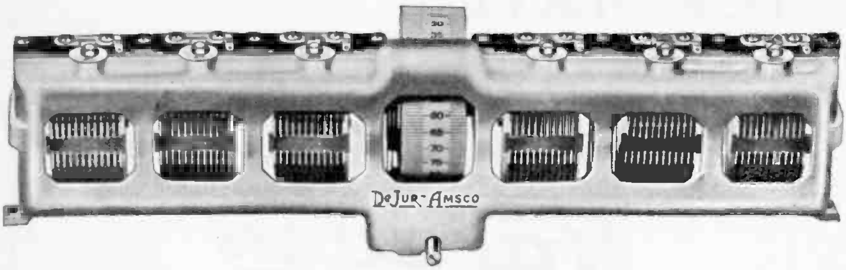
WITH DIAL ASSEMBLY



THESE DeJur-Amsco Multiple Condensers with dial assembly completely matched and balanced are great cost cutters and space savers. They cut your costs because they come to you completely assembled ready to incorporate in your receiver, thus saving time in construction. They save space because they are compact, combining this feature of compactness with precision and rigidity. If you want to speed up your production and cut your costs, have your engineers try out this new DeJur-Amsco tuning assembly.

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2 to 8 Gang Units With Dial.

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With its uniform glow over the entire plate . . . tested performance . . . long life . . . perfect reproductive qualities . . . the Eveready Raytheon Kino-Lamp is a great step forward in Television.

The Eveready Raytheon Foto-Cell is a long-life transmitting tube for Television. Used also for talking pictures. Made in two sizes, either hard vacuum or extra-sensitive gas filled.

Correspondence is invited from everyone interested in Television. Foto-Cells to special specifications will be made at reasonable prices.

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Unit of Union Carbide UCC *and Carbon Corporation*

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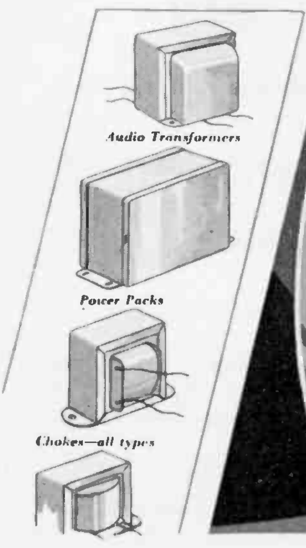
What counts like tone quality?

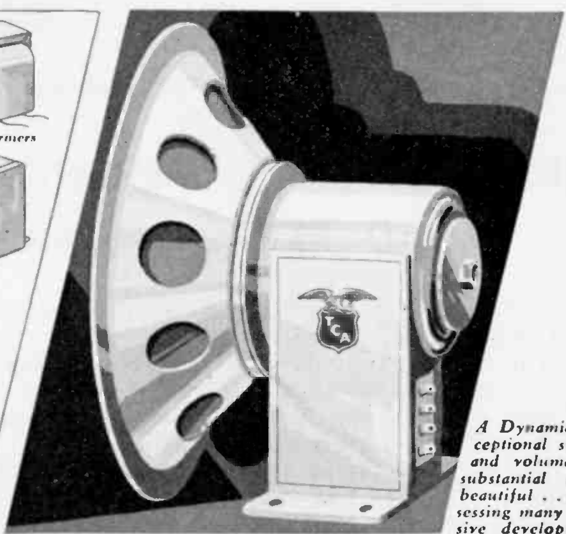
In the last analysis the customer's yard-stick is the one by which radio values will be measured. In his judgment tone quality comes first.

The audio end of the set controls the final performance—so transformers and speakers can make or mar a receiver.

T.C.A. products meet their responsibility squarely. They deliver the goods. In perfection of design and construction, they fulfill the most exacting demands of your designing department.

Completely manufactured . . . rigidly inspected . . . carefully tested . . . and through controlled volume production, offered at a price no higher than you pay elsewhere.





A Dynamic of exceptional sweetness and volume . . . substantial . . . beautiful . . . possessing many exclusive developments. Write for details.

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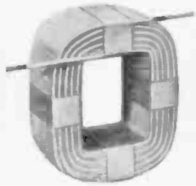


Reconsider your Coils in the Light of these New Standards

Whether you buy coils or wind your own, it will be worth your while to find out what the Rome Precision Process of Winding means to you.

Rome is now producing a wide variety of fine and heavy wire coils to meet all requirements.

Of special interest is the Rome Process of Winding heavy wire coils,—which represents a distinct departure from prevailing practice. It has sharp influence on both costs and performance. It effects economies that reach beyond the coils themselves and extend to parts of the device into which the coils fit.

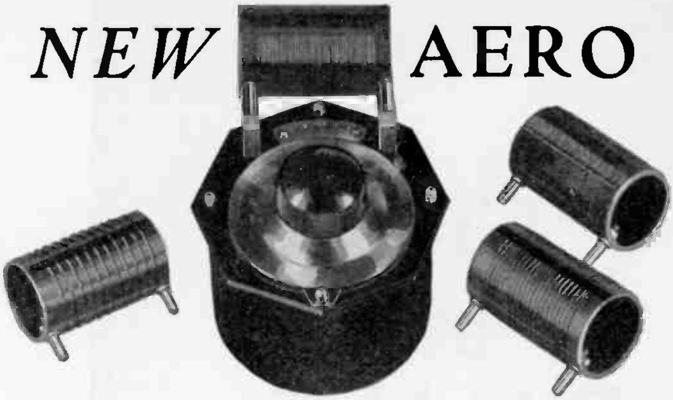
Rome Coil Engineers, in command of the principles of this new process, are anxious to demonstrate specifically what it will do for you.

Bearing in mind the cumulative value of economies projected into the years ahead, you owe it to your cost figures and performance records to investigate Coils by Rome.

ROME WIRE COMPANY
Division of General Cable Corporation
ROME, NEW YORK

ROME PRECISION COILS

NEW AERO



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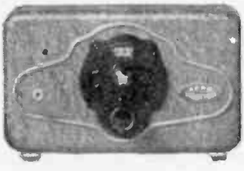
THE AERO WAVEMETER was designed for the radio amateur and the experimenter. It is of rugged mechanical and good electrical construction and meets the exacting requirements of the properly conducted amateur station.

Using the principle of the "series gap" condensers, and having a definite fixed minimum capacity, the amateur wavelength bands are spread over a great many dial divisions. The velvet vernier dial has 100 divisions, each of which may be read to one-tenth of a division. The 5-meter band covers 40 dial divisions; the 10-meter, 40 divisions; 20-meter, 17 divisions and the 40-meter band, 25 divisions. For the 80-meter band, two coils are used. One (72 to 82 meters) covers 45 divisions, and the other (80 to 90 meters) covers 65 divisions.

Each coil, excepting the 5-meter, uses No. 18 enameled wire tightly wound into grooves of the bakelite tubing. The tubing has a ⅛ in. wall and is 2 in. in diameter. The Aero heavy duty plugs and jacks make positive contact. The heavy brass case has a black crackle finish. The 3/16 in. black bakelite top is hexagonal shape to prevent rolling. Each wavemeter is individually hand calibrated. Standard coils are 20, 50 and 80 meters. 5- and 10-meter coils extra. Price................ **$24.00**

Aero Listening Monitor



The Aero Listening Monitor enables any amateur transmitter to check his own note, to know whether it is pure D.C. or not. It is a safe, sure and accurate way of knowing your station without depending upon the reports of others. Watching the ammeter won't help you—you need the Aero Monitor to be absolutely positive. The Aero Monitor is a completely shielded unit encased in a black metal cabinet, size 9 x 5½ x 2½ in. Filament and B supply is included. It operates with a UX-199 type of tube and employs a stable circuit, delivering a signal intensity of about R-4 or 5. Equipped with automatic filament control. The battery supply is thoroughly shielded from the R.F. A reliable, scientific instrument. Ship. wt., about 2½ lbs.

Model M-29 Aero Monitor. Including Dry Batteries, but no tube. List Price **$15.00**

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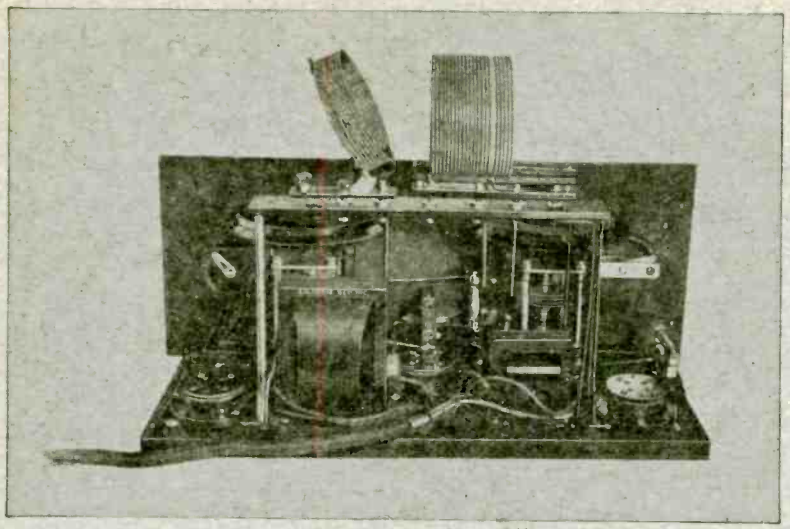

View of Grebe CR-18 Special Short Wave Receiver

Short Wave
Exploration

For radio explorers who like to drop in on the far places via short waves, we suggest a CR-18 Special. Built by radio pioneers for fellow enthusiasts.

The set provides two stages of audio, making it adaptable to the use of a power tube for loud speaker operation. And a single adjustment gives volume control from headset level to full audio output.

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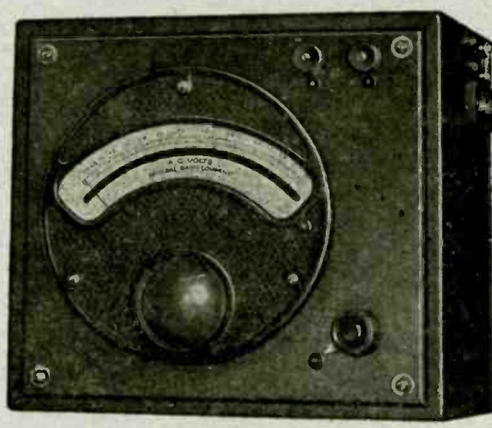
SYNCHROPHASE
RADIO

MAKERS OF QUALITY RADIO SINCE 1909

Thermionic (Vacuum-Tube) Voltmeter



A calibrated, readily-portable vacuum-tube voltmeter has many uses in the laboratory where measurements are being made at audio and the lower radio frequencies. The Type 426-A Thermionic Voltmeter with a range of 0-3 volts weighs but 11 pounds (without batteries).

Details

Meter uses the bridge circuit.

Calibrated to within 0.5% in r.m.s. volts.

Calibration good over entire audio-frequency range. Error at 20 kilocycles less than 2% of full scale, at 300 kilocycles less than 3% of full scale.

Small waveform error. A 20% third harmonic produces an error of only 0.4% in the meter reading.

Batteries may be either external or placed within the cabinet, only 22.5 volts being required.

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