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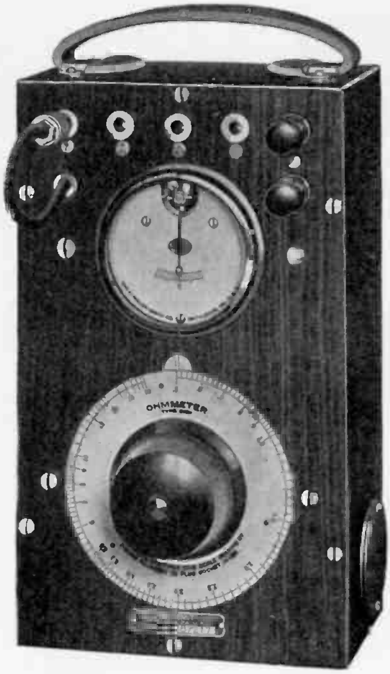

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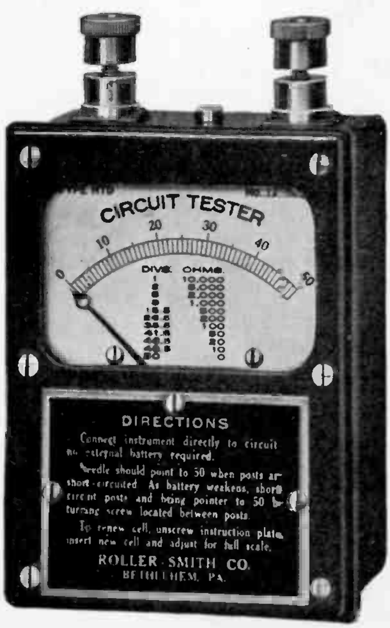

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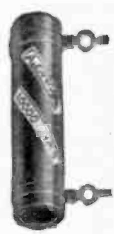

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 16 March, 1928 Number 3

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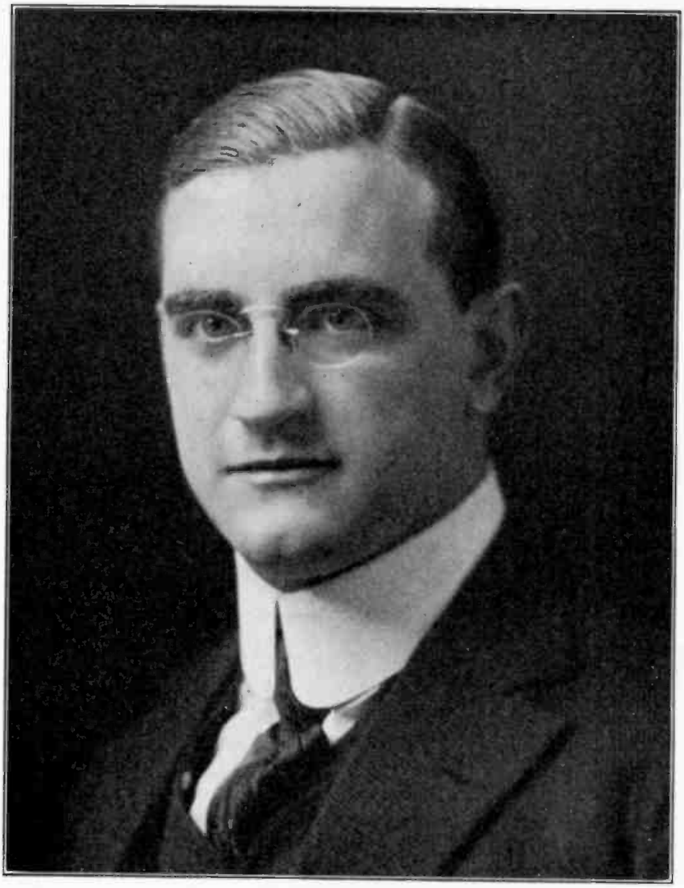


ALFRED N. GOLDSMITH

President of the Institute, 1928

Alfred N. Goldsmith

PRESIDENT OF THE INSTITUTE, 1928

Alfred N. Goldsmith was born in New York City on September 15, 1887. He attended grammar and high school in New York, received the B. S. degree from the College of the City of New York in 1907, and the Ph. D. degree from Columbia University in 1911.

For a number of years he was Associate Professor and Professor in charge of electrical engineering at the College of the City of New York. During 1912 he served as a consulting radio expert with the U. S. Department of Justice and in 1914 as a consulting radio engineer for the Atlantic Communication Company. From 1915 to 1917 Dr. Goldsmith did a considerable amount of consulting engineering work for the General Electric Company until he became director of research of the Marconi Wireless Telegraph Company of America. Upon the formation of the Radio Corporation of America he was appointed Director of Research. Since 1923 he has been Chief Broadcast Engineer of the Radio Corporation of America and in 1927 became Chairman of the Board of Consulting Engineers of the National Broadcasting Company.

During the World War he was Technical Director of the U. S. Signal Corps School of Communication and the U. S. Naval Radio School at the College of the City of New York.

To most members of the Institute Dr. Goldsmith is best known for his continuously active service for the Institute since its inception in 1912 He was one of the three or four engineers responsible for the organization of the Institute and has served continuously as Editor of the Institute's publications since 1913. From 1918 to 1928 Dr. Goldsmith was Secretary of the Institute. He has been a member of the Board of Direction of the Institute since 1913, and at one time or another has served in practically all capacities on the Institute's various committees.

Dr. Goldsmith has contributed a number of technical papers to the PROCEEDINGS of the Institute. He has been a Fellow in the Institute since 1915.

CONTRIBUTORS TO THIS ISSUE

Anderson, Clifford N.: Born at Scandinavia, Wisconsin, September 22, 1895. Graduated from Wisconsin State Normal School in 1913. From 1913 to 1917, supervising Principal of Schools, Amery, Wisconsin. During the World War served as Ensign, U.S.N.R.F. in the Aviation Section; received the Ph. B. degree from the University of Wisconsin in 1919 and the M. S. degree in 1920. During 1919 and 1920 served as Instructor in Engineering Physics at the University of Wisconsin; was with General Electric Company, Lynn, Mass. from 1920 to 1921; Fellow, American Scandinavian Foundation to Norway 1921–1922; from 1922 to date with the American Telephone and Telegraph Company, Department of Development and Research doing work in connection with transatlantic radio telephony. Associate member of the Institute.

Austin, L. W.: See PROCEEDINGS for February, 1928.

Bowditch, F. T.: Received the B. S. degree in electrical engineering from the University of Illinois in 1919. Was in the Research Laboratory of the Aluminum Castings Company (now a subsidiary of the Aluminum Company of America), 1919–1920. From 1920 to date has been a radio engineer in the Research Laboratory of the National Carbon Company. Associate member of the Institute.

Dahl, Odd: Born at Drammen, Norway, November 3, 1898. Introduced short-distance radio telephones in the Norwegian fishing industry in 1919; lieutenant in the Norwegian Army Air Force, 1920; aviator and radio engineer with Captain Roald Amundsen's *Maud* Expedition, 1922–1925; since January 1927, assistant physicist, Department of Terrestrial Magnetism, Carnegie Institution of Washington.

Gebhard, Louis A.: Born at Buffalo, New York, June 11, 1896. Received the LL. B. degree at Georgetown University; commercial radio operator, 1913–1917. In the naval radio service 1917–1923 at the Naval Radio Laboratory, Great Lakes, Ill.; Naval Radio Station, Belmar, N. J.; Naval Aircraft Radio Laboratory, Naval Air Station, Anacostia, D. C. Since 1923 at Naval Research Laboratory, Bellevue, Anacostia, D. C. At present in charge of the high-power transmitter department of the Naval Research Laboratory. Associate member of the Institute.

Hulburt, E. O.: See PROCEEDINGS for February, 1928.

Loftin, Edward H.: Born July 19, 1885 at Montgomery, Alabama. Graduated, U. S. Naval Academy, 1908; post graduate course at Naval Post Graduate School, Annapolis and Columbia University with M. A. degree; closely affiliated with naval radio activities from 1910 to 1924 during which time commanded naval radio research ship *Bailey*, pioneered development for radio aircraft, in charge of naval communications in France during the War, liaison officer on Inter-Allied Conferences, negotiations for and construction of the Lafayette station in France, in charge of naval research and development of radio for four years after war, member of Technical Committee of International Communication Conference (1921), and chairman of Inter-Departmental Radio Board. Since leaving the naval service in 1924 has been engaged in private research and development work. Member of the Institute.

Walmsley, Thomas: Born Burnley, Lancs., England in 1886. Graduate of Leeds Grammar School, Leeds Technical School, London Polytechnics School with the B. Sc. degree in 1917. From 1908 to date has held various positions in the British Post Office Engineering Department in both Central Power Section and Wireless Section; from 1920 to 1922 was engineer in charge of Abu Zabaal (Cairo) Wireless Station; since 1923 has been engineer in charge of the Rugby Radio Station GBR. Member of the Institute.

White, S. Young: Born April 11, 1901. For some time in testing course of the General Electric Company; spent a number of years as radio operator on ships throughout the world; engaged in special work on rectifiers in the United States and Europe for several years; during the past few years has been engaged in private research and development work, particularly in amplifying circuit and radio design work.

Wright, C. A.: Received the B. S. degree in M. E. and E. E., Tulane University, 1906; U. S. Engineer Office, Vicksburg, Miss., 1907; Testing Department, General Electric Company, Schenectady, N. Y., 1907–1908; Instructor in electrical engineering, graduate school of applied sciences, Harvard University, 1908–1909; received the E. E. degree (in absentia) from Tulane University in 1909; 1910–1915, telephone engineer with the American Telephone and Telegraph Company; Associate Professor of electrical engineering, Iowa State College, 1915–1918; 1918–1926, Professor of electrical engineering, Ohio State University; 1926 to date, Radio Engineer, Research Laboratory, National Carbon Company, Inc. Associate member of the Institute.

INSTITUTE ACTIVITIES

February Meeting of the Board of Direction

At the February meeting of the Board of Direction, held on February 1st in the offices of the Institute, the following were present: Alfred N. Goldsmith, President; L. E. Whittemore, Vice-President; Melville Eastham, Treasurer; Ralph Bown and Donald McNicol, Junior Past Presidents; Arthur Batcheller, W. G. Cady, R. A. Heising, R. H. Manson, R. H. Marriott, and J. M. Clayton, Acting Secretary.

Dr. Goldsmith was re-elected Editor of Publications, and Mr. Eastham, Treasurer. J. M. Clayton was elected Secretary. Dr. Leonard F. Fuller was elected a Manager of the Institute.

The following transfers and elections, upon recommendation of the Committee on Admissions, were authorized: Transfer to the grade of Member: H. A. G. Howse, E. M. Dupree, and C. M. Srebroff; Election to the grade of Member: E. A. Lederer, D. V. Adendorff, G. E. Bliziotis, D. H. Newman, M. L. Prescott, K. E. Rollefson, G. E. J. Suadicani, and W. A. Tolson.

One hundred and fifteen Associate members and eighteen Junior members were elected.

Patent Digests

The Board of Direction requests certain information from the Institute membership as to the continued publication of the Patent Digest pages of the Proceedings. The Board feels that these patents, as they have been published during the past several years, do not usefully serve the membership. Several questions are addressed to the membership on page 388 of this issue. The Board will be guided by the number and character of replies received to these questions. If the Patent Digests are discontinued, several additional pages of papers can be printed each month. If the Digests are to be resumed in any of the forms outlined on page 388, it may be necessary to decrease the number of editorial pages by an amount depending upon the space occupied by the Digests. Your comments are desired immediately.

Changes of Address

Members of the Institute are again cautioned to advise the office of the Institute in the event of any change in their mailing address in order to insure prompt and uninterrupted receipt of all

Institute publications. The Institute cannot be held responsible for failure to receive copies of the PROCEEDINGS if it has not been notified of changes in mailing addresses.

Committee Work

PROGRESS REPORT OF COMMITTEE ON STANDARDIZATION, 1927

The following report of the activities and progress of the Institute's Committee on Standardization has been submitted by the Chairman of the Committee, L. E. Whittemore:

The work of the Committee on Standardization has been carried on during 1927, as in 1926, largely through five subcommittees. The chairmen of these subcommittees during the year 1927 were as follows:

1. Vacuum Tubes, L. A. Hazeltine;
2. Circuit Elements, H. M. Turner;
3. Receiving Sets, J. H. Dellinger;
4. Electro-Acoustic Devices, R. H. Manson;
5. Power Supply, Walter E. Holland.

Preliminary drafts of reports of three of these subcommittees, namely, Vacuum Tubes, Receiving Sets, and Electro-Acoustic Devices, were printed under date of May 20, 1927, and were given fairly wide distribution in order that criticism and comments might be secured before their final consideration by the Committee on Standardization. In general, these subcommittee reports covered the formulation of methods expressing and measuring the characteristics of radio apparatus and devices falling within their respective fields. No general effort is being made by the subcommittees to revise the definitions contained in the Standardization Report published in 1926, but recommendations are being made as to new definitions or symbols, or changes in the 1926 definitions which the subcommittees find during the course of their work to be considerable.

During the course of the year there has been some discussion of the relation between the standardization work of the Institute of Radio Engineers and that of the associations of radio manufacturers. The chairman of the I. R. E. Standardization Committee has had some correspondence with a number of persons interested in this question and has found that the following statement appears to meet with general acceptance as an expression of the relationship between the standardization work of these two groups. It is recognized, of course, that in this new field it is impossible at the present time to determine upon any hard and fast dividing line.

Institute of Radio Engineers

(1) terms, definitions and symbols, and

(2) methods of testing materials and apparatus in order to determine their important characteristics. This work may consist of purely advisory discussion as to convenient forms of tests, precautions to be taken, etc., or it may include standardization of definite test procedures to serve as a common basis of comparison of the properties or performance of material or apparatus.

Manufacturers' Groups

(1) standardization of size and characteristics of apparatus, to promote interchangeability of parts, either mechanical or electrical, and

(2) setting of standard ratings for the properties or performance of material or apparatus.

At the request of the Federal Radio Commission a study was made of the suggestion that a system of assignments of frequencies to broadcasting stations be employed in which the frequencies would be those ending in the digit "5" rather than the digit "10", as at present. After correspondence with the members of the Standardization Committee, the Board of Direction and others, a report was prepared entitled "Discussion of Suggested Use of Broadcasting Frequencies Ending with the Digit 5." This report, dated May 23, 1927, was transmitted by President Bown of the Institute to the Federal Radio Commission.

Also at the request of the Federal Radio Commission, the Committee has been making a study of the power rating of radio stations. A draft of a report on this subject is in preparation. The completion of this report is awaiting the result of some additional correspondence with the Commission.

On several occasions during the work of the subcommittees the suggestion has been made that a special subcommittee be appointed to study the use of the transmission unit as an expression of the characteristics of radio circuits and devices. The subcommittee on Electro-Acoustic Devices, in particular, urged that this be done. A subcommittee on this subject was therefore appointed, and J. V. L. Hogan has consented to serve as its chairman.

The Subcommittee on Receiving Sets has recommended the appointment of a special subcommittee to prepare a bibliography covering the fields of five of the principal subcommittees. Bibliographical material has been prepared by the Subcommittee on Receiving Sets and the Subcommittee on Circuit Elements, and it is recommended that similar bibliographies covering the subjects of the other subcommittees be prepared for publication with the final report.

It is believed that the several subcommittees can complete their work during the first two or three months of 1928 and that a complete report of the Committee on Standardization can be published late in the spring of this year.

Professor Hazeltine served as acting Chairman of the Committee on Standardization during the last half of 1927 during the absence of the Chairman.

The progress made by the several subcommittees during the year 1927 may be summarized briefly as follows:

1. Vacuum Tubes—L. A. Hazeltine

A final draft of a report containing some modifications and additions to the preliminary draft of May 20, 1927, was circulated to members of the subcommittees under date of January 3, 1928. A few minor changes may be required but the report is believed to be substantially ready for final action by the main committee.

The symposium on the measurement of the inter-electrode capacity of vacuum tubes, forming a part of the 1928 I. R. E. convention program, was a direct outcome of the work of the members of this committee and those who are associated with them.

2. Circuit Elements—H. M. Turner

Material has been collected for a report of this subcommittee. A chart has been prepared giving references to several methods which are available for measuring the various properties of radio-circuit elements, and a bibliography has been compiled. It is expected that a report of this subcommittee will be prepared during the spring of 1928.

3. Receiving Sets—J. H. Dellinger

Meetings of this subcommittee were held on March 3, May 5, November 1, 1927. The preliminary draft report of May 20, 1927 has been revised and is being extended through the work of four subcommittees on the following subjects:

1. Field intensity measuring apparatus.
2. Test procedures.
3. Bibliography.
4. Additional quantities (additional to sensitivity, selectivity, and fidelity).

It is believed that the work of this subcommittee will lead to a revised report in the spring of 1928. This will not be a final report as the work of the subcommittee on this subject is likely to extend over several years.

4. Electro-Acoustic Devices—R. H. Manson

Several subcommittees have been working on special questions on which they expect to report at a meeting to be held early in February. At this time the preliminary draft of May 20 will be improved and probably somewhat extended. It is anticipated that a final report of this subcommittee will be ready some time in March.

5. Power Supply—W. E. Holland

This subcommittee has reviewed the present I. R. E. standard terms which pertain to power supply. It has suggested revisions in some of the definitions and has originated such new terms and definitions as seem to be needed. This work has been done in several meetings, one of which was a joint meeting with the Socket Power Committee of the Radio Division of the National Electrical Manufacturers' Association.

This subcommittee also has been making a study of the subjects listed below, and it anticipates that reports will be ready in the near future on one or more of these subjects.

(1) Methods of measuring inductances of iron core inductors (in coordination with the Subcommittee on Circuit Elements).

(2) Method of measuring capacitance and power factor of filter capacitors.

(3) Methods of measuring ripple in the output of power supply devices.

To all members of the Committee on Standardization for 1927 and its Subcommittees and especially to the chairmen of these subcommittees, the members of the Institute owe their thanks for the cooperation and splendid service given during the past year.

Institute Meetings

New York Meeting

At the New York meeting of the Institute held on the evening of February 1st in the Engineering Societies Building, two papers were delivered. The first, by Frederick E. Terman of Stanford University, entitled "The Inverted Vacuum Tube, A Voltage-Reducing Power Amplifier," was read by Dr. A. N. Goldsmith. In the discussion which followed the reading of the paper the following, among others, took part: Alfred N. Goldsmith, George Crom, and Harold A. Wheeler.

The second paper of the evening was presented by Professor Hidetsugu Yagi, of Tohoku Imperial University, Japan. The subject was "Beams of Ultra Short Waves." Messrs. Goldsmith, Kroger, Yagi, Crom, Martin, Whittemore, Hallborg, Bohn and others discussed the paper.

Both papers were profusely illustrated with lantern slides. They will be published in a forthcoming issue of the Proceedings.

The attendance at this meeting was about two hundred and seventy-five.

Atlanta Section

A meeting of the Atlanta Section was held on February 1, 1928 in the Chamber of Commerce Building, Atlanta, Georgia. Major Walter Van Nostrand, Chairman of the Section, presented a paper on "Advancements in the Measurement of Radio Frequencies."

The next meeting of the Atlanta Section will be held in the Chamber of Commerce Building on March 7th.

Canadian Section

On January 19, 1928 a meeting of the Canadian Section was held in Room 23 of the Electrical Building, University of Toronto. A. M. Patience presided.

C. V. Loughren, of the Research Laboratory of the General Electric Company, presented a paper on "A-C. Vacuum Tubes."

Messrs. Bailey, Baldwin, Price, Northover, Hepburn, and others discussed the paper.

The fifth lecture of the Junior Lectures on "Vacuum Tubes" was delivered by C. C. Meredith. Messrs. Price, Loughren, Lowry, Smith, Baldwin, and others discussed the lecture.

It was announced that the winners of the Membership Competition were (1) M. Hodsoll and (2) C. I. Soucy.

Eighty members attended the meeting.

On February 1st the Canadian Section held a meeting in the Electrical Building of the University of Toronto. Two papers were presented. The first, by G. E. Pipe of the Standard Radio Company, was entitled "Radio-Frequency Circuits." C. I. Soucy and others discussed this paper.

The second paper of the evening was on "Uni-Control Receivers," and was presented by Walter Jones of the Federal Radio Corporation of Buffalo. This paper was discussed by Messrs. Bagley, Soucy, Patience and others.

Sixty-one members attended this session.

The next meeting of the Section will be held on March 14th at which time R. C. Hitchcock, of the Westinghouse Company of Pittsburgh, will deliver a paper on "Crystal Control." The meeting will be held in the Electrical Building of the University of Toronto.

Cleveland Section

In the Case School of Applied Science, Cleveland, a meeting of the Cleveland Section was held on February 3rd. John R. Martin presided.

A paper by Drs. P. L. Hoover and C. Nusbaum, of the Case School of Applied Science, on "The Design of Filter Circuits" was the first paper of the evening.

The second, by Dr. C. Nusbaum, was entitled "Emission from Hot Bodies."

Seventy-five members and guests attended the meeting.

Detroit Section

The Detroit Section held a meeting on January 20th in the Conference Room of the Detroit News Building. Thomas E. Clark presided.

Captain Norman L. Baldwin, Signal Corps, U. S. Army, delivered a paper on "Short-Wave Transmission and Reception." A general discussion followed the presentation of the paper.

Officers of the Section for 1928 were elected as follows: Earle D. Glatzel, Chairman; A. B. Buchanan, Vice-Chairman; Walter R. Hoffman, Secretary-Treasurer. L. N. Holland was appointed Chairman of the Meetings and Papers Committee, and Charles H. Cox was made Chairman of the Membership Committee.

The next meeting of the Section will be held on February 17, 1928 in the Engineering Building, University of Michigan, Ann Arbor.

Philadelphia Section

On January 27th a meeting of the Philadelphia Section was held in the Franklin Institute. J. C. Van Horn presided.

The speaker of the evening was Carl Dreher of the National Broadcasting Company, who delivered a paper on "Broadcast Operation". Messrs. Frazier, Miller, and others discussed the paper.

Sixty members and guests attended the meeting.

The next meeting will be held on February 24th in Franklin Institute.

Rochester Section

A meeting of the Rochester Section was held in the Sagamore Hotel on January 13, 1928. Joseph Hichcock presided.

George B. Crouse, of the Conner-Crouse Corporation, presented a paper on "Development of Line 'A' Power."

Sixty members attended the meeting.

On February 3, 1928 another meeting of the Section was held in the Sagamore Hotel. H. J. Klumb presided.

A. Acheson, of the General Electric Company, presented a paper entitled "Broadcasting One Hundred Thousand Watts." The paper included lantern slides and the display of a 100,000-watt tube.

On March 2nd Hugh M. Stoller, of the Bell Telephone Laboratories, will present a paper on "Television" in the Hotel Sagamore at a regular meeting of the Section.

San Francisco Section

Upon the completion of the reorganization of the San Francisco Section the following officers for 1928 have been elected: Chairman, Dr. Leonard F. Fuller; Vice-Chairman, Donald Lippincott; Secretary, D. B. McGown.

On January 24, 1928 the first meeting of the year of the San Francisco Section was held. This was a joint meeting between the Institute of Radio Engineers San Francisco Section and the local American Institute of Electrical Engineers Section.

Dr. E. B. Craft, of the Bell Telephone Laboratories, delivered a paper on "Coordination of Research." Each person in attendance received a book showing the laboratory activities of the laboratories of the Bell Company.

Over four hundred and fifty persons attended the meeting. An informal dinner preceding the meeting was held in the Club Rooms of the San Francisco Engineers Club. One hundred and six members and guests attended the dinner.

Seattle Section

The Seattle Section of the Institute held a meeting on January 28, 1928 in the Club Rooms of the Telephone Building, Seattle. T. M. Libby presided.

E. L. White presented a paper, "Location and Mitigation of Radio Interference in Broadcast Receivers," and E. H. Schrieber presented a paper, "General Aspects of Radio Interference."

Messrs. Libby, Wilson, Burleigh, Kleist, and others discussed the papers.

The result of the election of 1928 officers of the Seattle Section is as follows:

Chairman, W. A. Kleist; Secretary-Treasurer, Oliver C. Smith. The following standing committees were appointed by the Chairman: Meetings and Papers: J. R. Tolmie (Chairman), A. V. Eastman, C. E. Williams and H. F. Mason. Membership Committee: J. A. Burleigh, H. E. Renfro, T. M. Libby, and W. A. Douglass.

Washington Section

On February 9, 1928 in Picardi's Cafe, 1417 New York Avenue, N. W., a meeting of the Washington Section was held. A. Hoyt Taylor presided.

Professor Hidetsugu Yagi, of Japan, presented a paper, "Beams of Ultra Short Waves," which was profusely illustrated with lantern slides. Following the presentation of the paper the following took part in the discussion: A. Hoyt Taylor, J. H. Dellinger, August Hund, Major Blair, Mr. Robinson, and others.

Dr. Dellinger spoke briefly on the New York Convention of the Institute and on the award of the Morris Liebmann Memorial Prize to Dr. Taylor.

The next meeting of the Washington Section will be held on March 8, 1928 at which time Dr. A. Hoyt Taylor and L. C. Young, of the Naval Research Laboratory, will deliver a paper on "Sending and Receiving Radio Signals Around the World."

Over seventy-five members attended the meeting.

Personal Mention

C. L. Davis, of Milwaukee, Wisconsin, has joined the staff of John B. Brady, Patent Attorney, of Washington, D. C.

Dr. M. A. F. Barnett, who has been at Clare College, Cambridge, England, is now Physicist at the Dominion Laboratory, Wellington, New Zealand.

Bernard H. Linden, formerly Radio Inspector in the Sixth Inspection District, has been promoted to the position of Supervisor of Radio with Headquarters at San Francisco.

H. T. Melhuish, late manager of sales administration of the Radio Corporation of America, has joined the staff of the National Electrical Manufacturers' Association as Director of the Radio Division.

Charles V. Litton has joined the engineering staff of the Federal Telegraph Company of Palo Alto, California. Mr. Litton was with the Bell Telephone Laboratories, stationed at Deal, New Jersey.

Alan N. Ramsay recently resigned as Sales Manager of Sherman, Clay and Company of Los Angeles to become General Sales Manager for the Precision Electric Manufacturing Corporation of the same city.

Engineering Societies Building

New Headquarters of the Institute of Radio Engineers

New Quarters of the Institute

The offices of the Institute have been removed from 37 West 39th Street, New York, to the 8th floor of the Engineering Societies Building, 33 West 39th Street.

To provide for the increased office staff at Headquarters of the Institute, approximately fifteen hundred square feet of floor space have been secured.

The Headquarters now contain adequate space to carry on the many duties involved in the operation of the Institute and the publication of the PROCEEDINGS.

In addition a Members' Room for the use of members of the Institute has been provided. This room contains facilities for correspondence, copies of current radio periodicals, and provides a place in which members of the Institute may meet.

Members of the Institute are invited to partake of the facilities offered in the Engineering Societies Library located on the thirteenth floor of the Engineering Societies Building. This library contains a collection of over one hundred thousand technical books, and several hundred monthly engineering journals. Photostat copies of pages from any book in the Library can be obtained very reasonably. The Library is also prepared to furnish information monthly as to the publication of papers and articles appearing in current journals and engineering magazines, both domestic and foreign, at very reasonable prices. The library is open every day except Sunday and can be used by all members of the Institute. Members residing out of town are invited to communicate either with the Institute or directly with the Library for information regarding a number of services which can be rendered to them.

The regular monthly New York meetings of the Institute have been held in the meeting rooms in the Engineering Societies Building for a number of years. It is a source of much gratification to the Board of Direction of the Institute that our Headquarters are now located in this splendid building, a photograph of which appears on the opposite page.

Members visiting New York are invited to make The Institute Offices their Headquarters for their correspondence and meeting place.

OBITUARY

With deepest regret the Institute announces the death of

Robert Loughry

Colonel Loughry served continuously in the Army of the United States from the beginning of the Spanish-American to the close of the World War. During the World War he served as Lieutenant Colonel in charge of all Army radio communication on the American front. For his skillful organization of the wartime radio activities he was cited by General Pershing both as a radio officer of the First American Army and later as radio officer of the Zone of Armies.

Since 1922 Colonel Loughry had been Radio Engineer of the 9th Corps Area in San Francisco. At the time of his death he was Commander of the California and Nevada Department of the Veterans of Foreign Wars.

His great genius for organization, and his infectious enthusiasm and unlimited capacity for hard work were surpassed by his kindly, genial nature and quality of friendliness, rarely found in men of his ability. For these he was best loved by his comrades.

Colonel Loughry was a Fellow in the Institute.

OPENING ADDRESS OF RALPH BOWN RETIRING PRESIDENT

Annual Meeting and Convention, Institute of Radio Engineers, January 9, 1928

At this the annual meeting of the Institute it is customary that the retiring president give a summary of the activities of the organization. I find upon looking over again the report given by Mr. McNicol at the last annual meeting that much of historical importance was included in his remarks which became of record* and therefore does not need repetition.

The time required for the registration of so large a number of members as is present today has already cut heavily into the time available for this session and there is need for brevity in its proceedings. I shall therefore merely touch upon a few of the more important matters of the past year.

On January 1, 1927 the Institute entered upon a new phase of its development. Employee management of its office and many of its business affairs was initiated. A year's trial of this new departure has proved it to have been a wise one. The Institute has prospered. Many things hopefully planned in previous years it has been possible to bring to fruition. It seems appropriate to mention in this connection that our Assistant Secretary, Mr. John M. Clayton, deserves major credit for the success of the new policy.

At the beginning of the year the actual paid membership was approximately 2800. There were also being carried on the lists nearly a thousand names of members who had become inactive and which have since been deleted. The growth in new membership has been large and steady; the paid membership has now reached over 4200, an increase of about 55 per cent during the year.

The increase in income from dues represents a considerable increase in the margin between the basic running expenses and the total income. This margin, except for a small surplus to be carried into the protective fund, has been spent in ways which should carry it back directly to the membership. The number of issues of the PROCEEDINGS has been increased from six to twelve a year and 34 per cent more technical material published. Preprints of papers were provided on a much better scale than had

* See PROCEEDINGS for February, 1927.

been possible before. A complete year book was sent to each member and preliminary reports of standardization work were published and circulated. A fourteen-year index of the PROCEEDINGS has been furnished each member.

Without going through the list to mention the particular achievements of each, it may be said that all of the standing committees have shared in the progress of the year. The increased membership, secured in part through good publicity; the standardization reports; the expansion in publications; the new Sections; all reflect credit on the work of the standing committees and their chairmen.

The future growth of the Institute is largely bound up in the fortunes of its Sections. Four new Sections were organized in 1927, at Atlanta, Buffalo, Cleveland, and Detroit respectively. The PROCEEDINGS furnishes the primary bond between the Institute and its members. But membership in the Institute, to be an attractive and useful thing of real value to engineers, must mean more than subscription to a technical periodical even though it be a periodical of great merit. It must mean frequent opportunity to attend meetings for the reading and discussion of technical papers, personal contact with other engineers of the community, and opportunity to hear and meet engineers from other communities. These aspects of the Institute, so familiar to members in the metropolitan district, can be furnished to members in other parts of the country only by active, well-organized Sections. I was fortunate enough last Fall to have been invited to talk at meetings of five different Sections in the eastern part of the United States. To visit these Sections and participate in their meetings was a pleasant and profitable experience and it left with me a firm conviction that the section idea is a sound basis upon which to build a better and larger Institute which has a personal value to each member.

The Institute Gold Medal for 1927 was presented at the June meeting to Dr. L. W. Austin for his pioneer work in the quantitative measurement of radio transmission. It was noted at that time that the study of radio transmission, in the initiation of which Dr. Austin had so important a part, has now become one of the most engaging present-day activities of radio engineers. The apparatus side of our art has to a degree outrun the transmission side and we are now endeavoring that it catch up.

It is now my pleasant duty to represent the Institute in the bestowal of the Morris Liebmann Prize for 1927. The meritorious work which this prize recognizes was done in the very newest field of radio transmission study, the field of short waves. It seems entirely appropriate that its recipient should be a member of the United States Navy, which has been so forward-looking in the application and use of this novel mode of sending human intelligence through space. Whether Dr. Taylor coined the term "skip distance" I do not know, but there is no doubt that he has made very important contributions to our knowledge of this phenomenon. It is a pleasure to present this prize to Dr. A. Hoyt Taylor.

Before relinquishing the duties of office I wish to tell you that I have thoroughly enjoyed being president of our Institute and to thank you for the privilege of serving in that capacity. It has been a beneficial experience to me. I only hope that some small benefit may have accrued to the Institute.

Our new president is so well-known to you that anything in the way of an introduction would be superfluous. He might almost be called the godfather of the Institute, since in his capacity as Secretary and Editor of Publications he held it together through many lean years and contributed much to building the firm foundation on which it now stands. It seems particularly fitting that he should become our president at a time when the Institute is so flourishing. Our president, Dr. Alfred N. Goldsmith.

ADDRESS OF DR. ALFRED N. GOLDSMITH

President of the Institute of Radio Engineers

It is rather overwhelming to contemplate the marvelous strides which have been made by the Institute of Radio Engineers in its fifteen-year growth. Originating among "a little group of serious thinkers" in the radio field who felt the urgent need for some means for self-expression and mutual cooperation among radio engineers, it has grown to be an internationally known and leading engineering association, with many thousands of members, and with a publication, its PROCEEDINGS, which is to be found on the desk of practically every active worker in the radio field.

It is the finest sort of an honor to have been chosen as the President of such an organization, however undeserved may be this friendly commendation from the Institute membership.

High standards have been set by past Presidents of this Institute. Let me recall to you the list of these gentlemen who have worked so effectively and loyally in order that the Institute might be what it is today. In order of their tenure of office, they are:

Mr. R. H. Marriott, veteran radio engineer and indefatigable organizer of the Institute.

Mr. G. W. Pickard, a radio scientist noted for the exquisite elegance of his researches and no less for the continued service he has given the Institute.

Dr. L. W. Austin, who has literally been a right-hand of the Government in radio matters and has shown the way in orderly measurement of complicated radio transmission phenomena.

Mr. John Stone, a pioneer in the wire telephone field, and in radio circuit investigations.

Prof. A. E. Kennelly, a master electro-mathematician who brought all the wisdom of his past presidency of the American Institute of Electrical Engineers to the aid of the Institute of Radio Engineers.

Prof. M. I. Pupin, that brilliant scientist of vivid and charming personality. If I did not fear that it would detract from his otherwise flawless reputation, I would stress the pleasure I experienced while I studied under his able direction.

Prof. G. W. Pierce, one of America's leading electrical teachers and investigators.

Mr. J. V. L. Hogan, a gentleman whose combined engineering skill and knowledge and executive ability have ever been freely at the disposal of the Institute.

Mr. E. F. W. Alexanderson, a most original and fruitful worker in the field of radio.

Dr. Fulton Cutting, who may be described as a "gentleman scientist," in the finest sense, in the field of radio research.

Dr. Irving Langmuir, a research worker combining rare originality and the capability of applying effectively abstruse basic principles.

Prof. J. H. Morecroft, one of the country's best-known radio teachers and a prominent author of radio texts from which we all learn.

Dr. J. H. Dellinger, who may be termed a national and international "liaison" officer in every important aspect of radio.
Dr. Donald McNicol, veteran wire telegraph engineer, and radio worker and organizer; and
Dr. Ralph Bown, one of the leaders in the public service engineering applications of radio and a most capable and effective executive of the Institute.

With these gentlemen as my predecessors, you will readily appreciate that the truly hard work has been largely done and that the credit for reaping what they have sown should be justly given to them.

These gentlemen have carried forward radio development through this Institute during the most romantic period in the radio field. Every communication field has been romantic at one time or another although most of us have had no opportunity to realize the romance of other communication fields than radio.

And yet wire telegraphs and cables were once most romantic. As late as 1885 Owen Meredith in his novel "Lucile" described the plight of a gentleman whose financial fortunes had fallen into sad confusion because there was no way of getting word to him quickly of the impending failure of his banker. Meredith in a quizzical footnote comments poetically on the situation:

These events, it is needless to say, Mr. Morse,
Took place when Bad News as yet travel'd by horse;
Ere the world, like a cockchafer, buzz'd on a wire,
Or Time was calcined by electrical fire;
Ere a cable went under the hoary Atlantic,
Or the word "Telegram" drove grammarians frantic.

That same year, a musical gentleman by the name of H. H. Thiele composed a rather indifferent piece of music which he termed "The Telephone Gallop" which starts picturesquely with a trill which is supposed to represent a telephone ringing, and two emphatic notes which are labeled "Hello!" More than thirty years later, as a result of experimental radio telephony from Arlington to Honolulu, one of a later generation of musicians was moved to write a parallel selection entitled "Hello, Hawaii, How Are You?" Thus does history repeat itself.

The other day I found among my papers a yellowed newspaper clipping dated April 25, 1915. I think it will interest you to hear its contents because it gives you some idea of what the Institute was doing only thirteen years ago. And yet these thirteen years have been so crowded with events that those of us here present who are described in this clipping are already finding their memories of those days dimming. This is the clipping:

Wireless Men at Dinner

Radio Engineers Entertain for Professors Ferdinand Braun and Johann Zenneck

Seventy members and guests of the Institute of Radio Engineers, including representatives of the wireless systems of England and Germany, last night gave a dinner at Luchow's to Professors Ferdinand Braun and Johann Zenneck, of the German Telefunken Wireless Co. John S. Stone, president of the Institute, was toastmaster. Besides Professors Braun and Zenneck those at the speakers' table were: Dr. Lee DeForest; Judge Julius M. Mayer; Nikola Tesla; Dr. Fritz Lowenstein; Robert H. Marriott, U. S. Radio Inspector; William Dubilier; Professor Alfred Goldsmith; Roy E. Weagant; Edward J. Nally; and Professor G. W. Pierce. A miniature wireless plant on the speakers' table sent out messages during the dinner.

Today new radio triumphs loom before us, shortly to be achieved. Such startling developments as international broadcasting combining the world into a unit, and television which shall carry the aspect of nature and man to all parts of the habitable globe, seem to be "just around the corner". It is no wonder that this Institute of Radio Engineers has progressed with most unusual rapidity. It is composed of televisionaries—men who see far into the future and are yet realists. May this next year of the Institute's activities be in some measure a worthy continuation of its splendid past history.

ON THE DISTORTIONLESS RECEPTION OF A MODULATED WAVE AND ITS RELATION TO SELECTIVITY*

By

Frederick K. Vreeland

Summary—*The importance of overtones in the faithful reproduction of speech and music. Overtones are transmitted by the extreme side bands of a modulated wave. Distortionless reception of the full side bands necessary for faithful reproduction. Crowding of the air channels brings adjacent waves into such close juxta-position that selectivity demands a sharp cut-off at the limits of the band. Selectivity by the usual resonance methods trims the side bands. Attempts at compromise by employing damped resonant circuits do not achieve distortionless reception and sacrifice selectivity. Description of an amplifier giving uniform amplification over the entire band width with a sharp cut-off. Description of a band selector having an approximately rectangular frequency characteristic. Frequency control and volume control. Various applications of the band amplifier and the band selector to broadcast reception.*

The Problem of Fidelity in Radio Telephony

It is well known to communication engineers that faithful reproduction of music and clear articulation in speech require distortionless transmission and reception of a wide range of audio frequencies. The vibrations of music, and especially the vibrations of articulate speech, are exceedingly complex. When analyzed, however, it is found that the most intricate sound may be reproduced by the combination of a sufficient number of simple harmonic vibrations of different frequencies, combined in the proper relative intensities. Distortionless transmission means that each of these component vibrations must be represented by an alternating current wave of corresponding frequency and that the relative intensities of these current waves must truly correspond to the relative intensities of the component sound waves. These currents must be transmitted without change in their mutual relations and translated again into sound waves, while preserving their true relative intensities.

The problem of distortionless transmission and reception thus means that each of the component frequencies of the sound must go through the many transformations of the signal energy with equal efficiency and all must come out in the finished product in their true mutual relations.

This is an intricate matter. In the field of wire telephony many years of research, involving investigations and technique of the

*Original Manuscript Received by the Institute, December 23, 1927.

highest order, have produced the perfected results of the present day. Much of this knowledge is applicable in the field of radio telephony, and has been used to good advantage, but radio has its own peculiar problems. At the transmitting end of the radio telephone system the terminal problems are similar to those involved in wire telephony and have been met by similar though specialized means. Between the transmitter and the receiver there is no line to introduce distortion, and the causes of fading distortion appear to be beyond our reach at the present time. To this extent the problem is simplified for the radio engineer. But the receiving end of the system involves peculiar difficulties due to the fact that the transmitted waves are not directed to individual receivers and so must be separated from each other by frequency selection.

Selectivity requires that a certain group of radio frequencies, comprising a modulated signal wave, must be separated from all other radio waves.

Fidelity requires that all the frequencies included in the transmitted wave must be received in their true relative proportions.

These two conditions give rise to a peculiar and highly specialized problem of receiver design, namely to construct a selective system that is equally responsive to all frequencies within a given range or band and unresponsive to frequencies outside this band. And the condition of crowded air channels requires a very sharp cut-off at the edges of the band.

The Importance of Overtones in Sound Reproduction

It becomes important therefore to determine what range of frequencies must be included in sound reproduction to give a faithful and satisfactory result. There has been much discussion on this subject and much difference of opinion. The human ear is a marvelously tolerant organ, and the mind by training is able to supply gross deficiencies in the sound. The tolerance of the human ear to distortion made wire telephony possible during the many years that preceded its present high state of perfection. This tolerance is taxed severely, even at the present day, in radio broadcast reception, but it is now generally recognized that faithful reproduction is highly desirable, and once it is made available it will be demanded by broadcast listeners.

A mental picture of the range of audible frequencies may be obtained by reference to the scale of a piano. This ordinarily includes a little over seven octaves, the lowest note having a frequency of approximately 26 cycles per second and the highest note 4,096 cycles. But this is only half the story. Each note on the piano includes not only the fundamental frequency but also many harmonic overtones. Harmonics at least as high as the eighth, that is, eight times the fundamental frequency, play an important part in determining the tone of the piano, and the seventh harmonic, which produces a rough and discordant tone, is carefully eliminated by piano makers. It is these harmonics that produce the characteristic tone of the piano and differentiate it from a harp, for example. When broadcast listeners hear a piano that sounds like a harp they may know of a certainty that some of the component frequencies of the tone are excluded or distorted.

Each instrument in an orchestra has a characteristic timbre or tone quality depending on the number and relative strength of the harmonic overtones. The tone of a flute impresses the listener as being pure and limpid because of its extreme simplicity. It has only the fundamental and the octave or second harmonic. The French horn is next in purity, including the third harmonic. On the other hand the tones of the violin, oboe, clarinet, saxophone, etc., are very rich in overtones. To bring out the characteristic timbre of these various instruments the harmonic overtones are absolutely essential.

In the case of percussion instruments such as drum, cymbals, xylophone, castanets etc., the tones are even more complex, for here we have to deal, not with steady harmonic overtones, but with transients of an abrupt and impulsive character. These transients, like others with which the electrical engineer is familiar, involve a whole series of component overtones, and the sharper and more abrupt the pulses the higher the frequencies required to represent them faithfully. If the high frequency overtones are suppressed the transients are rounded and blurred and they lose their sharp brilliancy. The clean cut reproduction of a jazz band, whether wholly desirable or not, is a severe test of the fidelity of a radio receiver.

It is thus clear that the range of frequencies that faithful radio phone reception must include is far greater than that indicated by the fundamental frequencies of the notes in the musical scale.

In the case of articulate speech, overtones, both harmonic and inharmonic, are even more important. The vowel tones are relatively simple, including, like the tones of musical instruments, various harmonic overtones which determine the vowel. Consonants are very much more complex and involve high overtones. The sibillant consonants such as *s*, *z*, *ch* and *zh* involve extremely high sustained frequencies. Other consonants such as *p*, *b*, *t*, *d* involve abrupt pulses which have essentially the nature of transients and like other transients, when analyzed into their components, involve very high frequencies. When the high frequencies are excluded these transients lose their characteristic abruptness and become rounded or blurred and so are unintelligible. Everyone is familiar with the frequent necessity of spelling "C— for Charles, A— for Arthur, T— for Tommy" when talking over the telephone. If the high-frequency overtones were all transmitted this would be unnecessary.

Just how much of the total range of overtones is required for acceptable reproduction is a question of compromise and individual judgment. All the overtones are desirable, but perhaps not all are necessary. The average human ear hears frequencies as high as 15,000 cycles, though extremely high frequencies are usually unimportant. Frequencies as high as 10,000 cycles are of material value, and it is generally considered that frequencies as high as 6,000 or 8,000 cycles are necessary in the faithful reproduction of tone and speech. To avoid needless debate it would seem proper to place the desirable upper frequency somewhere between the limits of 6,000 and 10,000 cycles per second.

The lower limit of frequency is unimportant here, since it concerns chiefly the design of the audio-frequency amplifier and sound projector, which are outside the scope of the present paper. This fact is pertinent, however. With the advent of improved audio-frequency amplifiers and loudspeakers the lower end of the scale has been greatly extended, but when a good audio system is attached to an ordinary radio receiver the results are often disappointing. There is a preponderance of bass and the tone has an unreal, hollow sound—the "rain-barrel" effect. It is not safe to blame this on the audio system. Usually it is due simply to the lack of sufficient overtones to balance the bass. When the overtones are supplied by the radio receiver the tone becomes normal, with its full richness and with a brilliancy that must be heard to be appreciated.

The Width of the Modulation Bands and their Relation to Selectivity

Now when a given band of audio frequencies is used to modulate a high-frequency carrier wave, a corresponding series of frequencies appears in the modulated wave. The various frequencies occur in the same arithmetical progression but stepped up to a higher level, *i.e.*, for each frequency f of the modulation there is a corresponding radio frequency $F+f$, F being the carrier frequency. These summation frequencies make up the upper side band. There is also an inverted arithmetical series of frequencies equal to $F-f$, which constitutes the lower side band. The width of each side band, measured in kilocycles, is equal to the highest frequency included in the modulation. Thus if we assume that the modulation includes frequencies up to 10,000 cycles per second, the total width of the transmitted spectrum, including both side bands, will be 20 kilocycles. If the highest frequency of the modulation is 5,000 cycles the total width of the transmitted spectrum is 10 kilocycles.

The two side bands are not both necessary for distortionless transmission. Either may be suppressed without affecting the fidelity of reproduction, and in some transmitting systems one side band is suppressed; but when both are transmitted, each must be received in its entirety. If either side band is trimmed, the symmetry of the reception is destroyed and distortion results.

The condition of distortionless reception and faithful reproduction of tone is that all the frequencies in the transmitted band of the modulated wave shall be received in their true relative intensities.

On the other hand *the condition of selectivity requires the effective separation of all the frequencies of an interfering wave from those of the desired signal.*

Obviously, if the side bands of two interfering waves overlap the two conditions of fidelity and selectivity are incompatible. If they are closely adjacent but not overlapping the problem resolves itself into securing uniform reception of all frequencies within the modulation band, with a sharp cut-off at the extremities of the band.

The legalized broadcast channels at the present day include carrier frequencies differing by as little as 10 kilocycles, but the geographic locations are so assigned that such closely adjacent frequencies are widely separated so that the problem of overlapping bands usually is not serious, but interference between waves differing by 20 kilocycles is not unusual.

If we are to receive a full frequency band or spectrum of 20 kilocycles width, including modulation frequencies up to 10,000 cycles, obviously the bands of two modulated waves 20 kilocycles apart will meet with no space between. To receive without distortion one wave band of 20 kilocycles width and exclude the

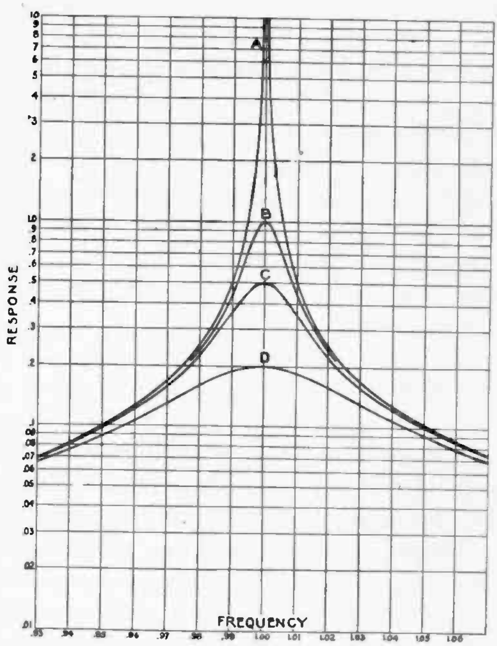


Fig. 1—Generalized Frequency Characteristic (computed) for a Single Resonant Circuit.
Graph A—for an ideal circuit with zero damping.
Graph B—for a circuit having an effective resistance equal to 1 per cent of the reactance at resonant frequency.
Graph C—for 2 per cent effective resistance.
Graph D—for 5 per cent effective resistance.

adjacent wave requires a receiver of extraordinary qualities, receiving with equal efficiency all the frequencies within the 20-kilocycle band and abruptly cutting off all frequencies outside this band. In other words it requires a receiver whose frequency characteristic of reception is substantially rectangular.

The receivers in general use today do not work that way. In the allied art of wire telephony filters of the Campbell type are used to separate adjacent frequency bands. Similar means may be used at radio frequencies where the bands are fixed and where such complicated circuit networks are permissible, but *in the field of broadcast reception there is one added condition that must be met, namely the feasibility of adjustment of the band of reception in the frequency scale.* This requires simplicity of the circuits and apparatus and the operation of all frequency adjustments by a single control.

To meet these three conditions of fidelity, selectivity, and simplicity was the object of the research set forth in this paper.

Limitations of Selectivity by Resonance

Actual broadcast reception, as practised today by the ordinary methods, falls far short of meeting these conditions. A receiver whose selectivity depends on the use of tuned resonant circuits operated in synchronism, such as the tuned radio-frequency amplifier, has an overall frequency characteristic determined by the well-known resonance curve.

The ideal resonance curve of a single circuit without damping is shown at A in Fig. 1. The curve of such an ideal circuit rises to infinity at the resonance point, and at frequencies above and below resonance follows a hyperbolic law. When resistance or other damping is introduced into the circuit the current is always finite. At the resonance point, where the total reactance is zero, the current is determined by Ohm's law, assuming all the energy losses in the circuit to be included in its effective resistance. The peak of the resonance curve thus comes down to a point B, Fig. 1. At frequencies above and below resonance the curve drops off less abruptly than in the case of zero resistance and the actual curve approaches the ideal as the departure from resonance frequency increases in either direction. The graphs B, C, D, of Fig. 1 are a family of resonance curves plotted for effective resistances equal to 1 per cent, 2 per cent and 5 per cent respectively of the capacity reactance or the inductance reactance at resonant frequency. These figures represent that may properly be called the power factor of the resonant circuit. In Fig. 2 the same thing is shown by oscillograph records of the current in an actual resonant circuit.

This family of curves illustrates the effect of damping on selectivity. Damping causes a large diminution in the peak value of the resonance curve and a smaller diminution at points off resonance. *It will be noted that damping does not broaden the resonance curve. It merely flattens it.* This fact is sometimes overlooked.

When a resonant circuit is used as a selective element in a radio receiver, the amount of distortion is measured by the dropping off of the frequency characteristic curve, Fig. 1, within the range of frequencies included in the modulation band. The ideal circuit with no damping would not receive any modulation at all, since the ratio of the current strength at carrier frequency to that at any of the side band frequencies is infinite. This explains the poor tone quality of a regenerative receiver, since the effective

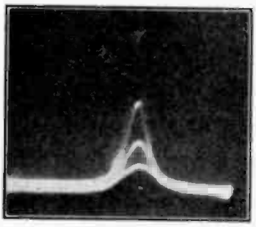


Fig. 2—An Oscillograph Record Showing a Family of Response Curves Corresponding to Fig. 1, for an Actual Resonant Circuit.
Graph A—with no external resistance, effective resistance of the circuit being 0.5 per cent of the reactance at resonant frequency.
Graph B—the same circuit with an added ohmic resistance of ½ per cent.
Graph C—the same circuit with an added ohmic resistance of 1 per cent.
Graph D—the same circuit with an added ohmic resistance of 2 per cent.

resistance is reduced to a very small value by regeneration and the response curve approaches the ideal.

Fig. 3 is a similar family of graphs showing the characteristics of two resonant circuits in cascade and tuned to synchronism. Because of the geometric property of such circuits the ordinates of each graph for a two-circuit system are equal to the squares of the corresponding ordinates for a one-circuit system. The graphs are plotted on a logarithmic scale of ordinates so that the graphs of Fig. 3 are derived from Fig. 1 by simply doubling all ordinates, the ordinates being measured from the resonance point, so that the peak values of all curves coincide, the response of the system at resonance being taken as unity. The value of the ordinate at any frequency will then measure the response of the system at that frequency, relative to its response at resonance.

Fig. 3 shows a similar family of graphs for three synchronously tuned circuits in cascade. These are obtained from Fig. 1 by trip-

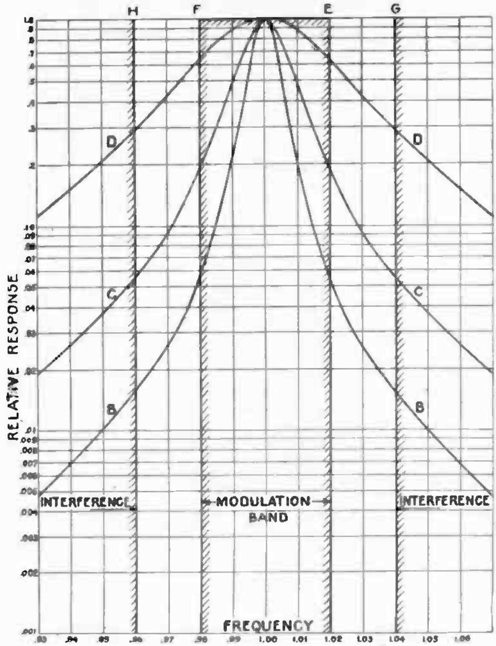


Fig. 3—Response Curves of a System of Two Resonant Circuits in Cascade, Synchronously Tuned. Derived from Fig. 1 by Squaring the Ordinates and Reducing to a Common Origin.

Graph B—for effective resistance = 1 per cent.
Graph C—for effective resistance = 2 per cent.
Graph D—for effective resistance = 5 per cent.

The lines *E*, *F* represent the boundaries of the side bands of a modulated wave with a limiting modulation frequency of 10,000 cycles and a carrier frequency of 500 kilocycles.

The lines *G*, *H* represent the frequency of an interfering wave differing by 20 kilocycles or 4 per cent from the carrier frequency of the signal wave.

The intersections of these lines with the several graphs give the relative reception of the various frequencies.

ling all ordinates, and reducing the curves to a common origin, as in Fig. 3.

These graphs are perfectly general and independent of any particular values of inductance, capacitance, or frequency, and they do not involve any assumptions as to whether the circuits are coupled by amplifying tubes or otherwise, or as to the degree of amplification. The frequency coordinates are plotted on a linear horizontal scale, the frequency at resonance being taken as unity. The vertical coordinates, which represent the relative response of the system to a given impressed electromotive force at the different frequencies, are plotted on a logarithmic scale, the unit of the

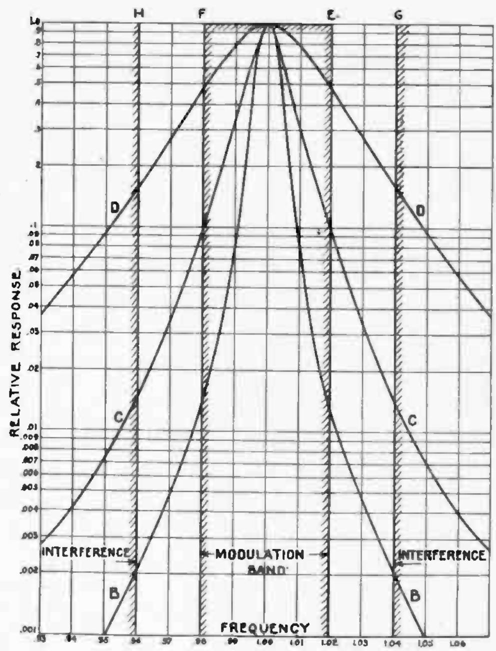


Fig. 4—Response Curves of a System of Three Resonant Circuits in Cascade Synchronously Tuned. These Circuits Are Derived from Fig. 1 by Cubing the Ordinates and Reducing to a Common Origin.
Graph B—for effective resistance = 1 per cent.
Graph C—for effective resistance = 2 per cent.
Graph D—for effective resistance = 5 per cent.
The dotted lines *E, F, G, H* correspond to the similar lines of Fig. 3.

scale being the current set up in the last circuit of the system at resonant frequency. They can be applied to any particular case by substituting the proper numerical values.

Assume for example that it is desired to find the amount of distortion in a two-circuit receiver with 1 per cent power factor when receiving a signal band whose carrier frequency is 500 kilocycles and whose side bands extend 10 kilocycles on each side of the carrier. The frequency at the upper limit of the band is then $\frac{510}{500} = 1.02$, and at the lower limit is $\frac{490}{500} = 0.98$. The vertical dotted lines E, F drawn at these points on the frequency scale of Fig. 3 thus represent the band width of the modulated signal wave. The intersection of these lines with the graph B for 1 per cent gives the relative current strength at the extreme side-band frequencies. This is found to be 0.055, the current at carrier frequency being 1.0. The received signal strength at the extreme side-band frequency is thus only $\frac{0.055}{1.0}$ or 5.5 per cent of that which would be required for distortionless reception. This amounts practically to the elimination of the extreme side bands. The received signal strength for a

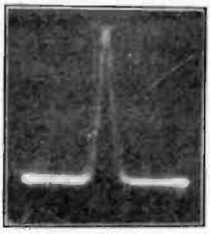


Fig. 5—Oscillogram of the Frequency Characteristic of a Typical Broadcast Receiver, Showing its Sharply Peaked Form, Corresponding to a Typical Resonance Curve, Fig. 4.

The horizontal coordinate is the frequency scale, the vertical coordinate is the scale of response to unit impressed electromotive force at the various frequencies.

This graph, like Fig. 2, differs from the computed curves in having a linear scale of ordinates while the computed curves have a logarithmic scale.

modulation frequency of 5,000 kilocycles is 0.21 or 21 per cent, hence the distortion even at moderate frequenciesis serious.

Again, suppose the condition of selectivity requires excluding a frequency differing from the signal carrier by 20 kilocycles or 4 per cent. Drawing another pair of lines G, H at frequencies 1.04 and 0.96 respectively, the intersection of these lines with the 1 per cent graph B shows that the interfering signal strength will be 0.015 or 1.5 per cent of the signal carrier frequency. It thus appears that while the selectivity may be considered passable, the side-band frequencies are reduced to the point of serious distortion.

If we attempt to remedy this defect by the introduction of damping we find that with 5 per cent damping the side-band reception is 0.62 or 62 per cent of the carrier, which might be acceptable, but the receptional interfering frequency has risen to 0.29 or 29 per cent of the reception at carrier frequency, which is no selectivity at all. At the same time, the sensitivity at carrier frequency has fallen from 1.0 to 0.04, or only 4 per cent of the sensitivity with 1 per cent damping.

Taking any intermediate value of damping these two factors will differ in relatively lesser or greater degrees, but in no case can a reasonable approximation to full band reception be secured without an undue sacrifice of selectivity.

Making similar assumptions for a three-circuit system, the similar lines *E*, *F*, *G*, *H* of Fig. 4 show that, for 1 per cent power factor, the 10-kilocycle side band has a relative intensity of 1.3 per cent while the 20-kilocycle interfering frequency is 0.2 per cent.

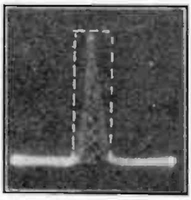


Fig. 6—The Same Graph Shown in Fig. 5 Superimposed on a Rectangle Representing the Modulation Band of a Wave Having a Limiting Modulation Frequency of 10,000 Cycles.
The shaded area illustrates the effective reception of the set, the unshaded area represents the portion of the side bands that is eliminated.

Even for a 5-kilocycle side band the relative intensity is only 9 per cent, showing a degree of distortion that is prohibitive.

The graph for 5 per cent damping shows that the 10-kilocycle side band has a relative intensity of 46 per cent, as compared with 62 per cent, for the two-circuit system, while the interfering signal strength is decreased from 29 per cent to 15 per cent, which is still far too large for satisfactory seletivity.

A study of these graphs shows clearly that any attempt to improve fidelity of reception by the introduction of damping does not change the essential form of the frequency characteristic, but merely flattens it. The characteristic is always essentially curved and the result at best is merely to mitigate the evil. It is impossible to obtain distortionless reception in this way. Furthermore any improvement in the fidelity of reception is accompanied by a corresponding loss of selectivity, and reasonable selectivity cannot be secured without a considerable distortion. The essential limitation of a system including synchronously tuned circuits is thus evident.

As a practical illustration of the way this works out, Fig. 5 shows by an oscillogram the frequency characteristic of a receiver of well-known and very popular make. The width of this curve at its base is of the order of 15 kilocycles, the carrier frequency being 600 kilocycles, indicating good selectivity, but the peak of the curve is so sharp that the side bands are severely trimmed. The resulting distortion of tone is clearly evident in the output of the receiver.

In Fig. 6 this curve is shown superimposed on a dotted rectangle representing the modulation band of a signal wave having a 10-kilocycle limit. It is readily seen how small a fraction of the side bands is effective.

It is thus clear that any attempt to improve the quality of reception by flattening the resonance curve by means of damping, results at best in mitigating the distortion but can never entirely remove it, and it is accompanied by a serious loss in selectivity.

If full-band reception is to be secured with reasonable selectivity, clearly something more than the usual multiple resonance methods is required.

The Possibilities of Band Reception

The ideal solution of the problem is a system which has a substantially rectangular frequency characteristic, that is, one which gives substantially uniform reception over a definite band of frequencies, including all the side-band frequencies of the modulated wave, with a sharp cut-off for frequencies outside this band. Such a system in its ideal form would give distortionless reception, with a selectivity that is limited only by the overlapping of an interfering wave with the signal band. The closeness with which this ideal has been approximated will appear later.

The problem admits of two distinct solutions.

1—The use of one or more band selectors, each of which possesses a substantially rectangular frequency characteristic.

2—The use of two or more receiving elements whose individual frequency characteristics are not rectangular but which in combination have an overall characteristic that is substantially rectangular.

Again various combinations of these elements are possible. For example we may have—

a—A band selector with a flat amplifier.

b—A band amplifier.

c—Various combinations of band selector and band amplifier.

All of these solutions have been developed into practical working receivers.

The Band Selector

A band selector has been developed which meets the three stated conditions *i.e.*, fidelity, selectivity, and simplicity. It comprises in general a system of reactances so related to each other that they are mutually balanced, not merely at a single

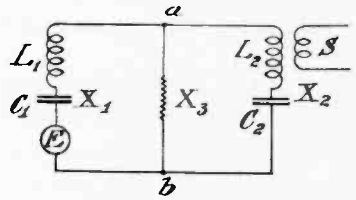


Fig. 7—Generalized Schematic Diagram of a Band Selector.
X_1 and X_2 are two reactive couples. X_3 is the bridging or band-forming reactance. E represents the impressed signal electromotive force. S represents the output.

frequency as in the case of the ordinary tuned circuit, but also at any frequency within a given band. At any frequency outside of this band the reactances are not balanced and the unbalanced reactance is high. As a result of this property, the band selector unit responds with substantial equality to all frequencies within its characteristic band and is non-responsive to frequencies outside this band. When the system is suitably designed the cut-off at the limits of the band is very sharp. The electrical and mechanical construction is exceedingly simple, and frequency adjustment is obtained by means of only two variable elements operated by a single control.

The band selector is shown in generalized form in Fig. 7. It employs two reactive couples X_1 and X_2, preferably alike, each having a capacitance and an inductance that are balanced within themselves at the same frequency, together with a third reactance X_3 which is common to both. This third reactance is small in relation to the reactances of the two reactive couples and may be either inductive or capacitive.

An input electromotive force is impressed on the system in any suitable way as at E and the output is taken off in any suitable way as at S. At a particular frequency F_1, this being the frequency at which the reactances of the couples X_1 and X_2 are balanced within themselves, the overall reactance of the circuit including X_1 and X_2 will be zero, current at the frequency F_1 will circulate through the branches X_1 and X_2 without traversing X_3, and the system has zero reactance at this frequency.

At any other frequency the reactive couples X_1 and X_2 will not be balanced within themselves. The result will be a potential difference across points a, b, the terminals of the bridging reactance X_3. If the frequency is lower than F_1 the réactancs of X_1 and X_2 will be capacitive. If now the reactance X_3 is inductive, it will tend to neutralize the unbalanced capacitance of branches X_1 and

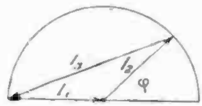


Fig. 8—Vector Diagram Showing the Phase Relations of the Currents in the Band Selector.

I_1, I_2, and I_3 represent the currents in the Branches X_1, X_2, and X_3 respectively. φ is the phase difference between I_1 and I_2, which varies from zero to 180 deg. The semicircle is the locus of the apex of the triangle formed by I_2 and I_3, I_1 being fixed.

X_2, provided their combined reactance is no greater than X_3. In that case current will flow through X_3 of such amount that the reactive electromotive force across points a, b, due to the current in X_3, is equal to that due to the currents in X_1 and X_2. The phases of the currents in X_1 and X_2 will adjust themselves so that I_3 is equal to the vector sum of I_1 and I_2.

The operation of the band selector unit may be more readily understood by reference to the vector diagram Fig. 8. Let the currents set up by the impressed electromotive force E in the three branches X_1, X_2, and X_3 be I_1, I_2 and I_3 respectively. These three currents are considered positive when they flow in the direction from the common point a of the branches to the common point b. Since the total current flowing into or out of points a and b must be zero, the current I_3 in the common reactance X_3 must be equal and opposite to the vector sum of currents I_1 and I_2 in the other two branches. This relation is shown by the vector diagram Fig. 8, I_1 being regarded as fixed and I_2 rotating with relation to I_1, with the phase difference ϕ. For any value of ϕ the current indicated by the vector I_3 is the third side of the triangle formed by I_1 and I_2.

In the case of a symmetrical system where the branches X_1 and X_2 are alike, the currents I_1 and I_2 will be equal and the current I_3 will have the value:

$$I_3 = -I_1 - I_2 = -2I_1 \cos \frac{\phi}{2}$$

It thus appears that the current in the common reactance I_3 varies between the limiting values $-2I_1$ and zero, as the phase difference ϕ between currents I_1 and I_2 varies from zero to 180 deg.

This phase relation depends upon the frequency of the impressed electromotive force in the following manner. Since the points a, b, are points of like potential difference in the three branches of the system, the current distribution in the system must be such that the reactive electromotive forces in the three branches are equal, that is

$$x_1 I_1 = x_2 I_2 = x_3 I_3$$

In the case of symmetry this becomes

$$x_1 I_1 = x_2 I_2 = -2x_3 I_1 \cos \frac{\phi}{2}$$

or

$$x_1 = x_2 = -2x_3 \cos \frac{\phi}{2}$$

For the limiting case where ϕ equals zero this becomes

$$x_1 = x_2 = -2x_3$$

For the other limit where ϕ equals π or 180 deg.,

$$x_1 = x_2 = o.$$

In other words there is a limiting frequency F_2 at which the reactances are balanced when the phase difference between I_1 and I_2 is zero and the current in the common reactances X_3 becomes equal to twice I_1, and there is another limiting frequency F_1 at which the reactances are balanced when the currents I_1 and I_2 differ in phase by 180 deg. and the current in X_3 becomes zero. This latter frequency is the one at which the reactances of the reactive couples X_1 and X_2 are balanced in themselves, and the current circulates wholly through the branches X_1 and X_2, no part of it traversing X_3. At the former frequency the reactances of the reactive couples X_1 and X_2 are not balanced in themselves, but they are completely balanced by the reactance X_3 when the entire current of both branches flows through X_3.

At any frequency between these limits, the phase difference between the currents I_1 and I_2 will have a value lying between zero and 180 deg., the resulting current I_3 will have a value intermediate between $-2\ I_1$ and zero, and the reactive electromotive force across X_3 will have a corresponding intermediate value equal to the reactive electromotive force in the branches X_1 and X_2.

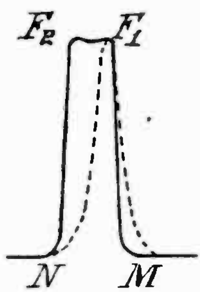


Fig. 9—Frequency Characteristic (computed) of the Band Selector Shown in Fig. 7.

F_1 is the first limiting frequency, where $\varphi=180$ deg., and $I_3=0$. F_2 is the second limiting frequency where $\varphi=0$, and $I_3=2I_1$. The dotted curve is the characteristic of the same system with X_3, open circuited. It is a typical damped resonance curve whose peak frequency is equal to F_1.

Note the steep gradient of the cut-off, F_1M and F_2N, and the sharpness of the bend at the base compared with the resonance curve.

The reactances of the system as a whole are thus completely balanced at any frequency between the limiting values F_1 and F_2, and the system will transmit freely any frequency in a band comprised between these limits. When X_3 is an inductance the frequency F_2 is lower than F_1. When X_3 is a capacitance F_2 is higher than F_1.

Since the phase difference between I_1 and I_2 cannot be less than zero or greater than 180 deg., if the impressed electromotive force has a frequency lower than the limiting frequency F_2 or higher than the limiting frequency F_1; (or vice versa when X_3 is capacitive) there is no possible phase adjustment which will cause the reactances to balance, hence there will be an unbalanced reactance in the system that will prevent the flow of current.

The above analysis neglects the resistance of the system. If the resistance and other losses are low, as they should be, the cut-off at the limiting frequencies is very sharp, and the frequency characteristic of the band-selector unit has the form shown in Fig. 9.

The width of the band depends upon the relation of the reactance x_3 to the other reactances of the system. Thus if X_3 is an inductance, the band width depends upon the relation of this inductance to the inductances L_1 and L_2. If the reactance X_3

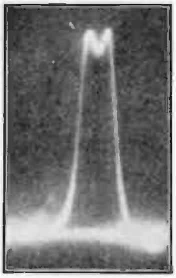


Fig. 10

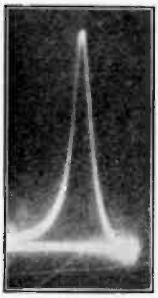


Fig. 11

Fig. 12

Fig.10—Oscillogram Showing the Frequency Characteristic of an Actual Band Selector Corresponding to Fig. 9. Carrier Frequency, 635 kc. Effective Band Width, 18 kc.

Fig. 11—Oscillogram Showing the Frequency Characteristic of the Same Band Selector Converted into a Simple Resonant Circuit by Opening the Reactance X_3.

Fig. 12—Composite Oscillogram, the Graphs of Figs. 10 and 11 Being Super-imposed on the Same Film.

Note that the width of the band characteristic is equal to the width of the resonance characteristic at a point above the base. As the zero axis is approached the band characteristic becomes much narrower than the resonance curve, showing improved selectivity.

is a capitance the band width is determined by the relation of the capacity reactance of X_3 to the capacity reactance of C_1 or C_2.

It is of interest to note the relation of the frequency characteristic of the band-selector unit to the characteristic of a tuned resonant circuit. Thus if the common or bridging reactance X_3 is omitted the two branches X_1 and X_2 together constitute a resonant circuit tuned to a certain frequency F_1; this being one of the limiting frequencies of the band of the selector unit. The resonance curve of such a tuned circuit is shown by the dotted lines in Fig. 9 in its characteristic sharply peaked form.

When the common reactance X_3 is added to the system the curve takes the band form shown in full lines, the limiting frequency F_1 corresponding to the natural frequency of the tuned circuit and the limiting frequency F_2 being below or above this frequency, depending upon whether the reactance X_3 is inductive or capacitive.

When the reactance X_3 has a suitable small value in reference to the other reactances the widths of the two curves at the base are substantially the same, showing that the uniform band reception is achieved without any loss in selectivity, but rather with a noteworthy gain, as will now appear.

The frequency characteristic of an actual selector of this type is shown in the oscillograph record Fig. 10. It will be noted that the band is substantially rectangular, the sides being almost vertical. The gradient of the cut-off is very much sharper than that of a resonant circuit made up of similar reactances. For comparison Fig. 11 shows a true resonance curve obtained with the bridging reactance X_3 removed, in which case the system X_1, X_2 becomes a simple resonant circuit. In Fig. 12 the two graphs are superimposed on the same film.

When the band selector is completed by inserting the reactance X_3, the point F_1 remains fixed and the cut-off from F_1 to M becomes very much steeper, corresponding to the cut-off from point F_2 to N. The width of the curve at its base is substantially equal to that of the resonance curve notwithstanding the great width of the band at its top.

The full gain in selectivity is not clearly seen from the films, but it will be noted that the cut-off lines drop straight to a point close to the zero axis, into which they merge by a sharp bend. In the resonance curve Fig. 11 the approach to the zero axis is gradually rounded. This bend of the characteristic is the factor that chiefly determines selectivity. A sharp bend of the curve at these points means a small value of an interfering current.

The superior selectivity of the band selector is thus evident. In fact, a single band selector has a selectivity about equal to two resonant circuits made up of the same coils and condensers.

It will be noted that the amplitude of the transmission in the band selector is substantially the same as that of a resonant circuit having the same elements, notwithstanding the greatly widened band. In other words, the band selector broadens the scope of the reception without any loss in signal strength. This is in marked contrast with the results obtained by damping a tuned circuit in an effort to improve the fidelity of reception. In that case any gain is accompanied by a flattening of the response curve, i.e., reducing its amplitude, and at the same time reducing its selectivity, as shown in Fig. 2, and the result is, at best a makeshift.

With the band selector the characteristic is broadened, giving perfect (not approximate) side-band reception, with no loss in sensitivity and with a great gain in selectivity.

Applications of the Band Selector

The generalized band selector Fig. 7 may be readily adapted to radio reception by antenna or loop. Such an arrangement

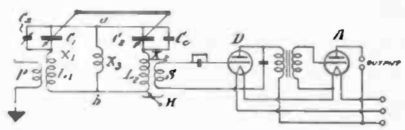


Fig. 13—Schematic Diagram of a Broadcast Receiver Including a Single Band Selector X_1, X_2, X_3 Coupled to an Antenna A and Feeding an Aperiodic Amplifying System, D, A.

Cc is the fixed antenna compensator, *Cx* is a variable condenser for adjusting the compensation.

using an antenna is shown in Fig. 13. The antenna coil P, is coupled to the band selector by the coupling P, L, a, preferably with a step-up ratio. The capacity introduced into the branch X_1, by the antenna is compensated by a fixed capacity C_c in the branch X_2. In order to permit compensation for an antenna of any desired capacity without disturbing the frequency calibration of the system an additional variable condenser C_x is inserted, which makes up the difference between the capacity introduced by the antenna and the capacity C_c, so that the symmetry of the system is secured.

The adjustment of C_x is made arbitrarily until the signal strength becomes maximum, after which no further adjustment of C_x is required for a given antenna. The sole frequency adjustment is that of the two coupled condensers C_1 and C_2.

It is of interest to note that any lack of symmetry in the system that might result from careless or imperfect adjustment or the capacity C_x, within reasonable limits, does not materially alter the band form of the characteristic but merely reduces its amplitude.

The band selector may be used in a variety of ways. It may be employed as the sole selective element of a receiving system, feeding a flat amplifier, as shown in Fig. 13. This makes a system of great simplicity and high efficiency, and with sufficient sensitivity and selectivity for ordinary broadcast reception. It is particularly adapted to use in the metropolitan areas.

The band selector lends itself readily to use as an interstage coupling element of a radio-frequency amplifier. Such an arrangement is shown in Fig. 14.

In this arrangement each of the selective elements has in itself a substantially rectangular band characteristic. With two or more such units combined in an amplifier the over-all frequency characteristic has a similar rectangular form with a sharper cut-off.

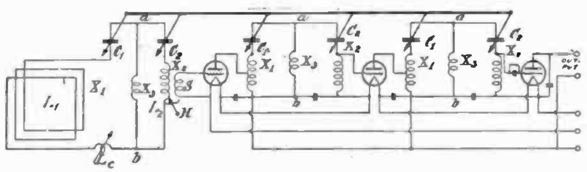


Fig. 14—Schematic Diagram of a Receiver Including Three Band Selectors. The first selector includes a collecting loop L_1 and the second and third selectors are used as interstage couplings in a radio-frequency amplifier. The inductances X_1 and X_2, and the capacitances C_1 and C_2 are all alike, hence frequency selection is accomplished by a single control, coupling the equal condensers C_1 and C_2.

Lc is a small compensating inductance to adjust any inequality between the inductance of the loop L_1 and that of the selector coil X_2.

Increased sensitivity and selectivity are thus secured with no diminution in the band width. This is in marked contrast with the tuned radio-frequency amplifier, where an increase in the number of stages inevitably narrows the characteristic. When the various band selector units are made alike, as they may readily be, the whole system, including the compensated antenna selector, is symmetrical and all the variable elements may be operated by a single control, as shown.

The Spaced Band Amplifier

In the band amplifier of the second type the several stages have different frequency characteristics which are not rectangular in themselves, but in combination they produce an over-all band characteristic. This is done in the manner illustrated in Fig. 15 where 1, 2, 3 are of the individual characteristics of a three-stage amplifier. These will have in general the characteristic form of a damped resonance curve, and they are made similar but differently spaced in the frequency scale. When the three stages are combined in an amplifier the over-all characteristic does not follow the geometric law, as in the case of synchronously tuned stages, but has a form totally different from that of the resonance curve. In general there is a certain spacing at which the over-all amplification becomes substantially constant over a considerable frequency band, and drops off abruptly with a sharp cut-off at the extremities of the band, as shown in curve 4 Fig. 15. The cut-off is very much

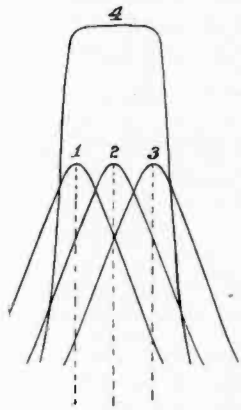


Fig. 15—Graphs Illustrating the Principle of the Spaced Band Amplifier. Graphs 1, 2, 3 represent the frequency characteristics of three successive amplifier stages. These characteristics are similar except that they are spaced in the frequency scale.

Graph 4 shows the overall characteristic of an amplifier whose individual characteristics are 1, 2, 3.

It will be seen that the overall characteristic is substantially flat over a definite band, with a sharp cut-off at the extremities of the band.

sharper than that of the component characteristics; in fact it is much sharper than the gradient for a three-stage synchronously tuned system of the same damping. When the circuits are made with small damping and the correct spacing the characteristic is substantially rectangular. If the spacing is closer than the optimum value the over-all characteristic will have a bump in the middle. If the spacing is greater than the optimum there will be a double peak. The value of the optimum spacing depends upon the form of the individual characteristics.

The spacing may be secured in a variety of waves. Thus the coupling coils or transformers may be made with different inductances and the frequency adjusting capacities made alike, in which case the band width, measured as a fraction of the carrier frequency, will be uniform over the range of the frequency adjustment. Or the transformers or inductive elements may be made alike and the capacities different, or both inductances and capacities may be made alike and a small spacing inductance added to each of the lower frequency stages. From a practical standpoint it is usually desirable to make the coils and capacities alike and to add spacing inductances or spacing capacities to the lower frequency stages, as shown in Fig. 18.

The graph in Fig. 15 is a typical over-all frequency characteristic of a three-stage amplifier, this curve being derived by

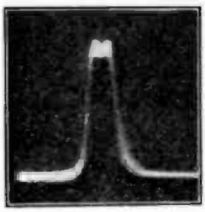


Fig. 16—Oscillogram Showing the Frequency Characteristic of an Actual Spaced Band Amplifier of the Type Shown in Fig. 15.
Note the steepness of the cut-off and the sharpness of the bend at the zero axis.

computation. A photographic oscillogram made from an actual amplifier of this type shown in Fig. 16.

The band characteristic Fig. 16 may be compared with the peaked characteristic of a standard commercial receiver of the tuned radio-frequency type shown in Fig. 5.

It will be noted that, although the band amplifier curve of Fig. 16 is substantially flat for a band width of 20 kilocycles (the carrier frequency in this case being 600 kilocycles,) the cut-off is so much sharper than that of the tuned radio characteristic Fig. 5 that the widths of the curves at the base are substantially the same, but the bend is sharper in the case of the band amplifier. It is this width and bend that determine the selectivity of the system. It thus appears that a band amplifier giving a band width of 20 kilocycles is fully equal or superior in selectivity to receivers of the geometrically tuned type.

The spaced band principle may be applied to a great variety of constructions, including the usual type of tuned radio-frequency amplifier. Fig. 17 shows an oscillogram obtained from the same receiver that gave the sharply peaked characteristic Fig. 5, by the simple expedient of suitably spacing the several stages. It will be noted that the width of the curve at the base is substantially

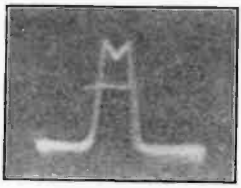


Fig. 17—Oscillogram Showing a Frequency Characteristic of the Same Amplifier Whose Normal Characteristic is Shown in Fig. 5, Now Converted Into a Band Amplifier by Spacing the Several Stages.

the same as in the case of the peaked characteristic Fig. 5 while the band width is sufficient to include a range of 15 kilocycles.

An important feature of the spaced band amplifier is its inherent stability. Since the several circuits are not synchronized, the tendency to regeneration and oscillation is small. In addition to its inherent stability other features are employed which make

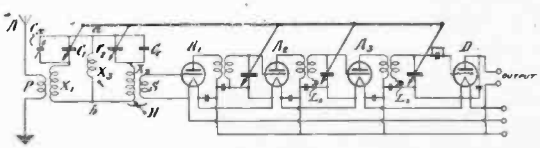


Fig. 18—Schematic Diagram of a Receiver Including a Single Band Selector Coupled to a Receiving Antenna and a Spaced Band Amplifier.
Ls, Ls are the spacing inductances.
The frequency adjusting capacities of the band selector and the amplifier are all coupled with a single frequency control.

the amplifier exceedingly stable. These features include an astatic winding of the coupling coils or transformers, which renders magnetic coupling between the stages negligible, and mutually reversed primary and secondary windings, which cause a phase reversal of any external electrostatic couplings, putting the potentials of the several stages in such phase relation that they do not cause regeneration. The resultant of these three features is an amplifier of such stability that no capacity neutralization or balancing of any kind is required, and the coupling transformers may be placed closed together without shielding.

Various combinations of the band selector and band amplifier are possible. One of the most useful is shown in Fig. 18. The band selector is coupled to the antenna and feeds, through its output coil S, a spaced band amplifier of the type just described. In the arrangement here shown the three stages are all structurally similar and the spacing is accomplished by fixed spacing inductances L_s in two of the stages, as shown. Or two of the stages may have small spacing capacities.

In the design of the apparatus due attention is given to securing a suitable relation between the effective inductance and effective capacitance of the amplifier stages and the effective inductance and effective capacitance of the band selector elements. When this is done the frequency control curves of the various elements are readily synchronized so that the whole system may be operated by a single control means.

Practical Results

There has been much discussion as to the utility of the high overtones transmitted by the extreme limits of the side bands. The human ear is a long suffering organ, and will submit without protest to a degree of distortion of tone that is extraordinary. For this reason there is a great difference of opinion as to what degree of side-band reception is necessary to produce a passable result.

It is not the purpose of the present paper to enter into this discussion except to say that the development of the human ear to broadcast reception has been a progressive thing. At the beginning almost anything would be tolerated. As improvements have been introduced public taste has become more critical, and as each new improvement in tone quality has appeared the results that were formerly tolerated became unsatisfactory. Practical tests with listeners of all types and mental attitudes have shown without exception that when they are allowed to hear broadcast reception of a high quality, with all the overtones present, they are struck immediately by its superiority. The timbre of the various musical instruments takes on a brilliancy and a character that is startlingly realistic. The human voice is reproduced with all its subtilities, all the consonants being clearly articulated. The "rain-barrel" effect that occurs when a good audio amplifier is combined with a selector that trims the side bands is entirely absent, and in its place is a balance of tone that is very satisfying to the much distressed feelings of a sensitive musical ear. With the correct tone balance, power amplifiers of any desired capacity may be used and the full round tone of an organ or an orchestra comes in with tremendous realism but with nothing to jar sensitive nerves.

It is believed that these results fully demonstrate the correctness of the theoretical considerations that have been set forth.

DIRECT COUPLED DETECTOR AND AMPLIFIERS WITH AUTOMATIC GRID BIAS*

By

Edward H. Loftin and S. Young White

Summary—*A system for direct coupling of vacuum tubes to give composite detection and amplification is described. The system is designed to avoid frequency discrimination in amplifying audio frequency, and to be free from electrical and acoustical feed-back effects. High-μ tubes are used to control the output of the power amplifier through the aid of the very high filament-to-plate impedance of such tubes with extremely small expenditure of energy therein, and in such a way as to avoid effect of so-called "detector overloading." Microphonic effects are avoided. A unique method of automatically regulating the system to be responsive to carrier currents of different intensities is described, and includes an extension of the automatic effect to volume control. The entire system is designed to be inexpensive and extremely simple in the matter of construction.*

It is the purpose of this paper to describe a composite detecting and amplifying system for modulated carrier currents having negligible frequency characteristics and minimum electrical and acoustical feed-back effects.

The fundamental system is shown in Fig. 1, where the effect of battery B_1 upon the grid of vacuum tube VT_2 is controlled by impedance of the plate-filament path of vacuum tube VT_1. Battery B_1 may be of the order of four volts. The resistance R_1 returns to positive filament. The potential which can develop

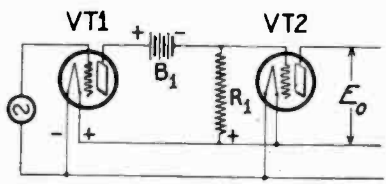


Fig. 1

across R_1 varies between zero and approximately $10\frac{1}{4}$ volts depending upon the potential of the grid of VT_1.

It will be noted that there is substantial freedom from coupling between the input and output circuits of each tube.

VT_1 operates at a very high plate-filament impedance value which results in small space current (order of 10 to 15 microamperes) with resultant long life of the tube and battery. When

* Original Manuscript Received by the Institute December 20, 1927.

the tube is operated at this small space current mechanical movements of the elements of the tube have no appreciable effect upon the magnitude of the current with the result that negligible microphonic effects and acoustical feed-back occur. It will be noted there are no resonant points or phase shifting means employed in the coupling. It is particularly desirable to use so-called high-μ tubes to obtain substantial amplification.

The circuit of Fig. 2 is merely that of Fig. 1 feeding into a power tube VT_3. Battery B_2 is selected to have the C-battery value required for the usual normal operation of the power tube plus about 50 per cent. Means to obtain a variable bias on the grid of the first tube are shown.

This system can be used as a combined rectifier and amplifier. A modulated carrier current impressed upon the input of the first

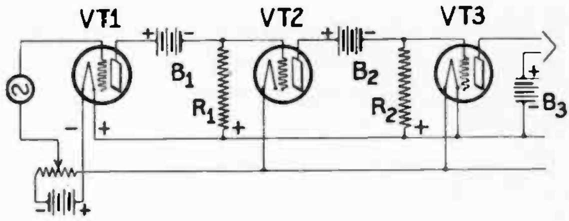


Fig. 2

tube lessens its plate-filament impedance, thus allowing B_1 to act more strongly on the grid of VT_2 as a negative bias to increase VT_2's plate-filament impedance and causing B_2 to be less effective on the grid of VT_3, all of which in turn causes the space current of VT_3 to rise in value. The current flow between VT_1 and VT_2 is mainly radio frequency, somewhat rectified, and this radio-frequency component persists even to the plate circuit of VT_3, this being demonstrated by the fact that tuned traps placed between any two tubes are quite effective in diminishing signal strength. Likewise any capacity to ground of the batteries lessens the sensitivity because of by-passing this persisting radio-frequency component.

The variable bias on VT_1 is necessary for several reasons. A strong carrier current, by reason of the rectifying properties of the system, will cause the plate current of the last tube to rise to saturation value, but this effect can be corrected by adding enough negative bias to VT_1. The bias is also needed to compensate for the lack of uniformity of impedance of different high-μ tubes, these impedances having been found to vary widely in commercial tubes. This variable bias can also be used to compensate to some degree for variations in the A and B battery potentials on the tubes, and thus help to keep constant the steady component of the plate current of the last tube.

It is difficult to overload this system in the function of detection as the grid potential swing of the first tube is several times longer than the allowable grid potential swing of the second tube, which in turn is longer than the maximum allowable grid potential swing of the third tube.

The preceding system is principally of laboratory interest without some form of automatic control for the bias of VT_1. In a form

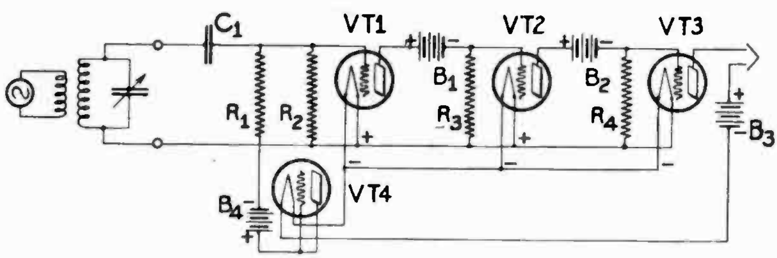


Fig. 3

of auto-compensator for the effect on the magnitude of the plate current of the last tube of varying intensities of carrier currents, it is possible to employ a rise of plate current above the normal to affect the grid bias of the first tube. However, the correction must apply only to the steady or direct current component of the plate current as affected by variations in tube impedances, carrier wave intensities, and the like, and not for plate current changes at an audio-frequency rate representing desired signal tones, as this would introduce audio-frequency feed-back, either positive or negative. One method suggesting itself is to take the voltage drop across a resistance in the plate circuit of the last tube and impress this drop on the grid circuit of the first tube. This requires filtering that introduces frequency discriminative elements in the system, and does not hold the plate current in the last tube to the close limits desired. A more satisfactory auto-compensator is shown in Fig. 3.

VT_4 is the commercial tube type 199 so connected that its filament current is the total plate current drain of the radio-frequency and power tubes of a receiver, which current usually totals from 30 to 35 milliamperes. Anything tending to make the plate current of the last tube rise will allow this filament to warm up to the electron-emitting temperature to make the filament-plate path conductive, resulting in placing the potential of B_3 on the grid of VT_1. This filament-plate resistance of VT_4 is continuously variable from infinity to a comparatively small value with a change in filament current of a very few milliamperes, and consequently will place just enough negative bias on the grid of VT_1 to compensate for the strong carrier currents that may be encountered in receiving nearby or local stations.

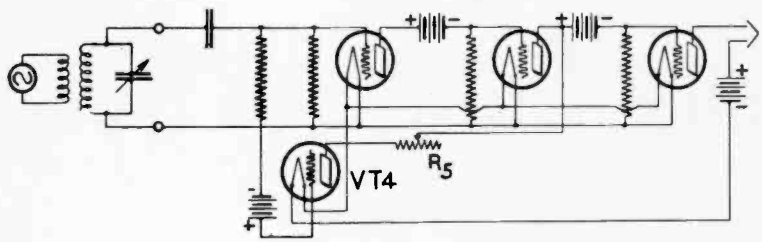


Fig. 4

With the tube so used the filament operates at very low temperature and consequent high thermal lag, which lag does not allow it to heat and cool rapidly enough to follow alternating currents even in the very low side of the audio range, and thus compensates only for effects lasting at least a substantial portion of a second.

R_1 must be smaller than R_2 for the reason that the voltage of B_3 is divided between VT_4, R_1 and R_2, and only the voltage across R_2 is effective in placing the bias on the grid. R_1 is useful only to lessen the effect of the capacity of B_3 to ground on the tuned circuit.

Fig. 5 shows a means for overcoming differences between current furnished by the high voltage plate supply and the current required to operate the 199-tube filament at its operating point in the neighborhood of 34 milliamperes. The resistance R_1 is a potentiometer of the order of one or two thousand ohms. When adjusted toward the minus side a local circuit is formed which furnishes any additional steady heating current desired, to compensate for too little current from the plate supply. When adjusted toward the plus side its resistance is so low that its shunting action predominates, and equalization of too high a plate current is obtained.

The curve of Fig. 6 shows how bias due to B_4 becomes effective on the grid of VT_1 through variations in filament current of VT_4.

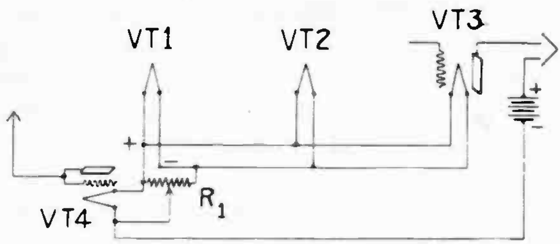


Fig. 5

This tube is usually operated at 34 milliamperes and will compensate for carrier wave intensities of 10 or 15 volts with a rise in plate current of VT_3, which will not exceed 3 milliamperes.

C_1 is used merely to isolate the input from any direct current potentials which might exist in the system to which the detector is

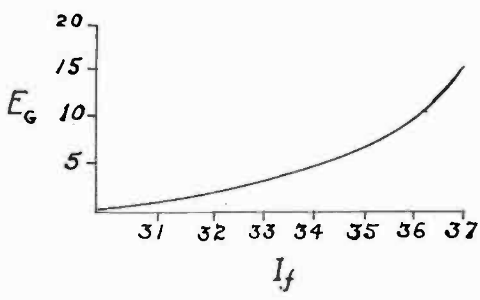


Fig. 6

connected. There is no grid rectification due to C_1 as the carrier wave causes an increase in conductivity of VT_1. If C_1 is small enough attempts at grid rectification will occur, which rectification will buck the plate rectification and weaken it. To prevent this C_1 must exceed 2000 $\mu\mu$f.

The 199-tube may also be used to prevent signal intensity from exceeding a predetermined limit in the manner shown in the circuit of Fig. 4, where the grid of VT_4 is used for the correction of carrier current effect and the plate is used to introduce a comparatively low resistance in parallel with the plate circuit of VT_2. The impedance of VT_2, when handling a high intensity signal, is of the order of several megohms, so that placing a few hundred thousand ohms in parallel, as is done by the connection shown, results in a short circuiting effect that makes the variations less effective on the succeeding grid, thereby limiting volume.

The system may be used on alternating current throughout by isolating the filament sources to permit the use of a common high potential source for the B battery. Due to the unavailability of high-μ a-c. tubes this practice is not commercially expedient at the present time.

The sensitivity of the system is equivalent to the usual detector and two-stage transformer-coupled audio system.

The system described has proved very useful both in the laboratory and on the usual types of radio receiving sets. It is extremely simple and cheap to construct, and seems to avoid most of the troubles and disadvantages generally encountered in amplifying systems.

Discussion

Henry Shore: I think the answer to Mr. Dreher's question as to why the particular amplifier described is free from microphonic noises lies in the fact that the plate voltage is only four volts.

With such low voltage, the ionizing potential of the metallic plate is not reached and consequently, no secondary emission can take place. It happens that microphonics are, in the main, due to secondary emission and since this is absent with low-plate voltage, the amplifier is free from acoustical feedback.

ON ROUND-THE-WORLD SIGNALS*

By

E. O. Hulburt

(Naval Research Laboratory, Washington, D. C.)

In his discussion of the measurement of E. Quäck of the time taken for the radio signal to go around the world[1] G. W. O. Howe has tacitly assumed, as Quäck did, that the ray goes roughly as shown in Fig. 1, that is, that the ray has the curvature necessary to keep it parallel to the surface of the earth. Using Quäck's time 0.137 sec. and Howe's group velocity calculation,

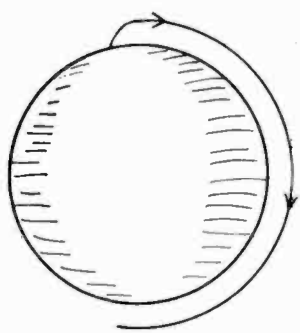


Fig. 1

we find that a 20-meter wave travels at a height of 48 miles above the earth, and the electron density at this height is 6.7×10^4; in the case of a 15-meter wave the height is 48 miles and the electron density 1.20×10^5. It seems possible that the round-the-world ray drawn in Fig. 1 (which is the ray of Howe's group velocity calculation), is a special case, and may not be the real path actually followed by the radio signal. Another hypothesis is to assume that the ray goes around in a sort of a polygon, as shown in Fig. 2. The sides of the polygon may or may not actually touch the earth at points *a*. Assuming that the sides of the polygon are close to tangency to the earth at points *a*, the length of the perimeter of the polygon is, from geometry

* Original Manuscript Received by the Institute, December 23, 1927.
* Published with the permission of the Navy Department.

[1] *Jahrbuch der drahtlosen Tel. und Tel.*, 30, 42, August, 1927.

$$\frac{2\pi r}{\theta} \tan \theta,$$

where r is the radius of the earth, 3970 miles $= 6.38 \times 10^8$ cms. The perimeter is also equal to ct, where c is the velocity of light in vacuum, 3×10^{10} cm. per sec. and $t = 0.137$ sec. Then

$$\frac{2\pi r}{\theta} \tan \theta = ct.$$

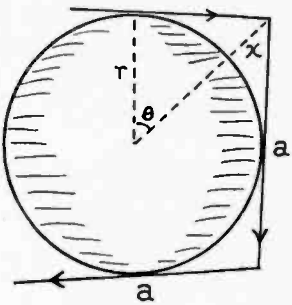


Fig. 2

Solving this for θ, gives $\theta = 15$ deg. 1 min. Hence the polygon has 12 sides, and the height x of the corners above the surface of the earth is 142 miles.

This calculation is independent of group velocity considerations in the case of the wave polarized with electric vector parallel

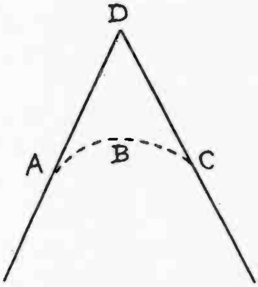


Fig. 3

to the magnetic field, for Breit and Tuve have shown[2] that for this wave the measured retardation along a curved path ABC (Fig. 3) is the same as that which would take place in vacuum along ADC where AD and DC are tangents at the points A and C.

[2] *Physical Review*, **28**, 554, 1926.

Thus the ray of Fig. 2 may be as in Fig. 4 with no change in the calculation. For other possible states of polarization the group velocity consideration may enter and may produce a small lengthening or shortening or displacement of the round-the-world pulse. Just to what extent this effect may exist will depend upon the distribution of the electrons in the upper atmosphere.

I do not know the accuracy of the time $t=0.137$ sec., but if it changes by $\pm$ 1 per cent, θ changes by $\pm$ 3 deg. (and x by ± 50 miles). It is seen that if θ does not have the value suited to the distances

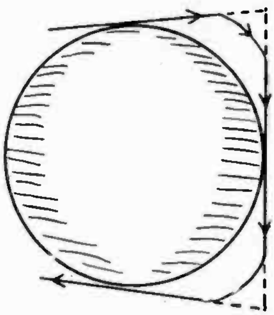


Fig. 4

between the transmitting station, the signal may be very weak. On this view small movements of the Kennelly-Heaviside layer would be expected to cause violent fading of the round-the-world signals (as is observed), whereas if the ray were as in Fig. 1 violent fading would perhaps not be expected. It also follows that a weak signal might have a time t different from 0.137 sec. Perhaps data may be obtained from which this might be decided.

Whether the round-the-world ray-path is that of Fig. 1 or Fig. 4 (or some other kind) depends upon the distribution of the electrons in the upper atmosphere. It is because of this that the question of the ray path is an interesting one.

MEASUREMENTS OF THE EFFECTIVE HEIGHTS OF THE CONDUCTING LAYER AND THE DISTURBANCES OF AUGUST 19, 1927*

By

Odd Dahl[1] and L. A. Gebhardt[2]

([1] Department of Terrestrial Magnetism, Carnegie Institution of Washington; [2] Naval Research Laboratory, Bellevue, Anacostia, D. C.)

Summary—*An account is given of further improvements in the echo method of observing effective heights of the reflecting layer. A table of values is given showing effective heights at various times of day from August 15 to 25, 1927, covering a period of general disturbance in transmission phenomena. The table shows an increase of height after the disturbance as compared with the days preceding it. The data obtained are compared with those furnished by Mount Wilson on disturbances in sun spots as well as the general condition of radio reception. An unusually active spot was observed at Mount Wilson several days before August 19. If it was responsible for the disturbance its effect must have been cumulative. More systematic data are necessary to ascertain whether the rise in heights observed is characteristic for radio disturbances covering large areas.*

General Method

THE experiments described below were carried out during the summer of 1927. The method is that described by Breit and Tuve.[1] As before, the signals were transmitted at the Naval Research Laboratory and received at the Department of Terrestrial Magnetism.

The experimental arrangements were almost identical with those employed by Breit and Tuve. The general scheme was as follows: A crystal-controlled, 4,015 kilocycle, 10-kilowatt set located at Bellevue was modulated so as to send out short interrupted trains of waves. The duration of each train was roughly 1/1,500 second, the space between the end of one train and the beginning of another being about 1/750 second. The signals were received on the roof of the main building of the Department of Terrestrial Magnetism. The receiving aerial was a small loop. This was connected to the first detector of a superheterodyne set having an intermediate frequency of 50 kilocycles. The second detector of the superheterodyne was fed into a resistance of 25,000 ohms connected between the filaments and grids of four 7.5-watt

* Original Manuscript Received by the Institute, December 31, 1927.

* Presented before the convention of the International Union of Scientific Radiotelegraphy, October 14, 1927.

[1] G. Breit and M. A. Tuve, *Phys. Rev.*, vol. 28, 1926, pp. 554–575.

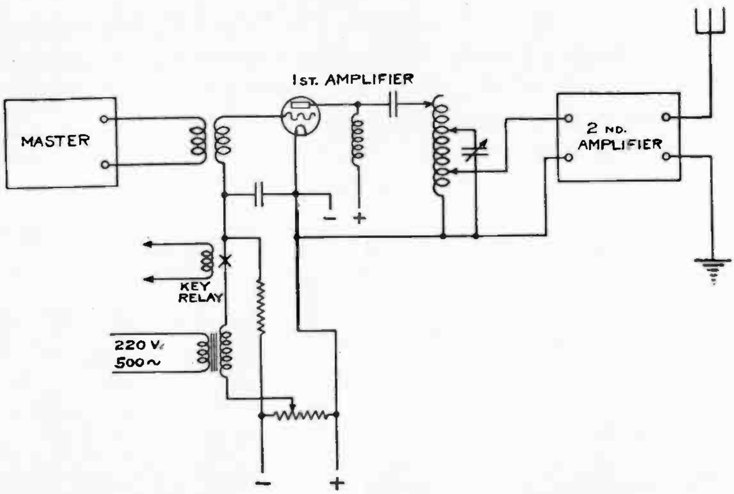


Fig. 1—Diagram of Transmitting Circuit, Crystal Control, 10 KW, 4,015 kilocycles.

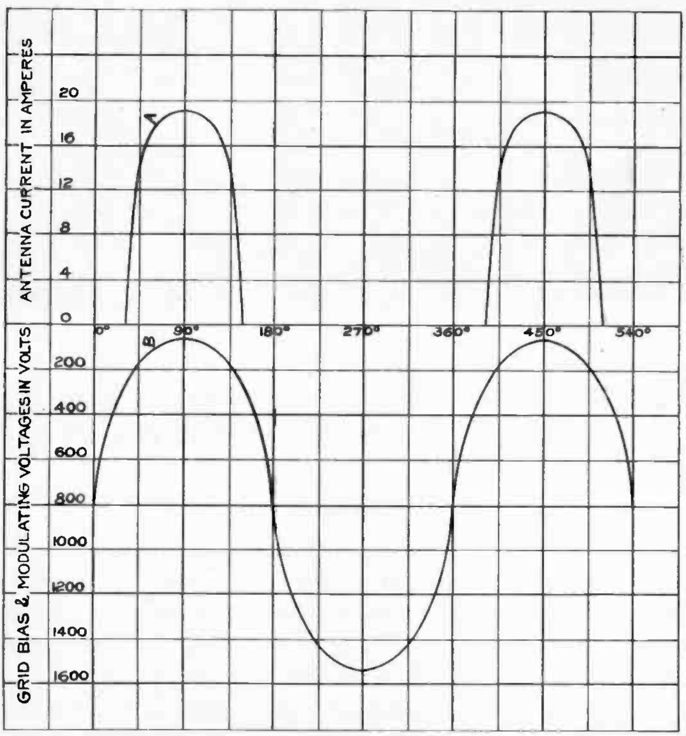


Fig. 2—Wave-form of Transmitter as Used in Experiments.

tubes (No. 210X) used in parallel. The output of these tubes was passed through a General Electric oscillograph with a proper balancing arrangement for the steady plate-current. The resultant wave-form was photographed and observed visually.

The idea of the method is to photograph on the same record the trains arriving directly over the ground from Bellevue as well

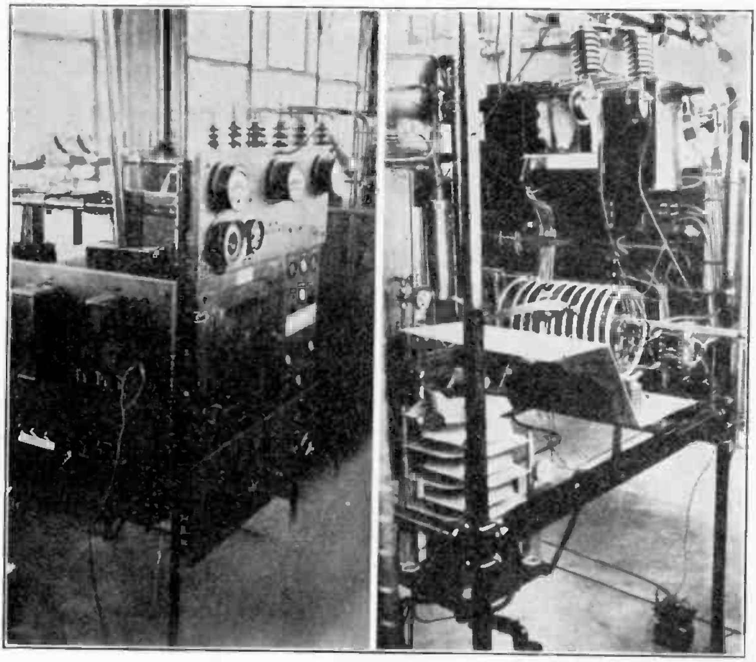


Fig. 3—Views of Transmitting Apparatus.

as their echoes arriving *via* the conducting layer. The lag between the arrival of the echo and the train which produced it gives the effective height of the layer.

Transmitter

Fig. 1 shows a diagram of the transmitter. A quartz crystal-oscillator was used as a master. Its output was first amplified by a 250-watt tube and then by a 20-kilowatt tube. Control and modulation were accomplished in the first, i.e., the 250-watt stage of the amplifier. In controlling, with the key up, a high negative voltage was placed on the grid. This stopped the amplifying action of the 250-watt tube. The same principle was used in modulating.

The modulation voltage was obtained from a 500-cycle generator fed through a transformer. The 500-cycle output of the transformer was passed through a voltage divider, and a proper part of the grid biasing voltage was superposed on a constant negative bias. Fig. 2 shows the actual relations. The constant negative voltage was 800 volts. The alternating 500-cycle voltage has an

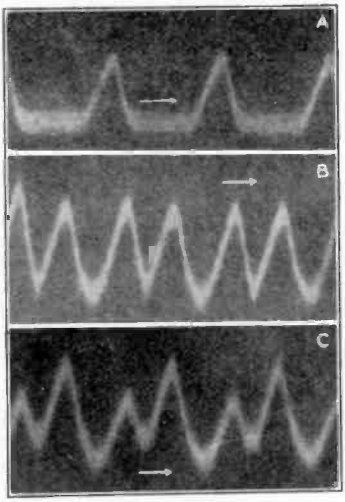


Fig. 4—Wave-forms Observed on August 25, 1927.
(A) Reflection absent, showing wave-form of transmitter. (B) Reflection approximately as strong as the ground-wave. (C) Reflection weaker than ground-wave.

effective value of 525 volts. Its graph against time is shown on curve *b*. The portions of time in which the 250-watt tube is operative are shown on *a*. The humps shown on *a* represent approximately the envelope of the antenna current.

Fig. 3 shows photographs of the transmitting apparatus.

Receiving Apparatus

The difference between the receiving apparatus used in these tests and in those of Breit and Tuve consists in the following items:

(1) Different location of the apparatus. The measurements were made on the roof of the main building, while in the summer of 1925 they were made in the small Experiment Building.

(2) The receiving aerial was a small loop 2 feet square instead of an antenna.

(3) 7.5-watt tubes were used in the power amplifier instead of the 5-watt tubes used previously. Four tubes in parallel were used in each case.

(4) A 7.5-watt oscillator loosely coupled to the superheterodyne was substituted for the 201A oscillator used previously.

Results

The results obtained are summarized in the following table.

Determination of Heaviside-Layer Heights

Date	Time	Height in miles	Transmitter
1927	h m h m		
Aug. 15	2:00– 2:15 P.M.	128 or 66	Antenna
16	10:00–10:15 A.M.	70 or 124	Antenna
16	2:00– 2:15 P.M.	62	Antenna
17	10:00–10:15 A.M.	60 and perhaps 110	Antenna
17	2:00– 2:15 P.M.	53	Antenna
19	....	No reflection	Antenna
22	2:00– 2:15 P.M.	112 or 80	Antenna
23	10:00–10:15 A.M.	103	Horizontal doublet
23	10:30–10:45 A.M.	104	Antenna
23	2:00– 2:15 P.M.	104	Antenna
23	2:30– 2:45 P.M.	124	Horizontal doublet
24	10:00–10:15 A.M.	92	Horizontal doublet (ground wave stronger than reflected)
25	10:15–10:30 A.M.	103	Horizontal doublet (reflected wave stronger than ground)

It must be noted also that not only did the reflected wave disappear on August 19 but also that the "ground" wave itself was received with difficulty. During the same period the reception of signals at the Naval Research Laboratory was decidedly below the average—some familiar stations not coming in at all.

Reports were received that the abnormal conditions caused a great deal of difficulty in copying on the San Francisco-Washington high-frequency circuit both day and night. For three days previous to and including the 21st much trouble was had in clearing traffic to London, it being the first time in over a month that London did not receive everything on the first transmission.

A report from London stated that during this period poor receiving conditions existed on all short-wave stations to the west of London, but that conditions were normal in receiving stations from other directions. Another London report stated that the same trouble was experienced with the Canadian Beam. The conditions, however, apparently did not affect the reception of Washington's 12,045 kilocycles frequency in San Francisco. On August 19, Lakehurst, New Jersey, was unable to receive Washington's 8:15 a.m. weather broadcast on 4,015 kilocycles, and

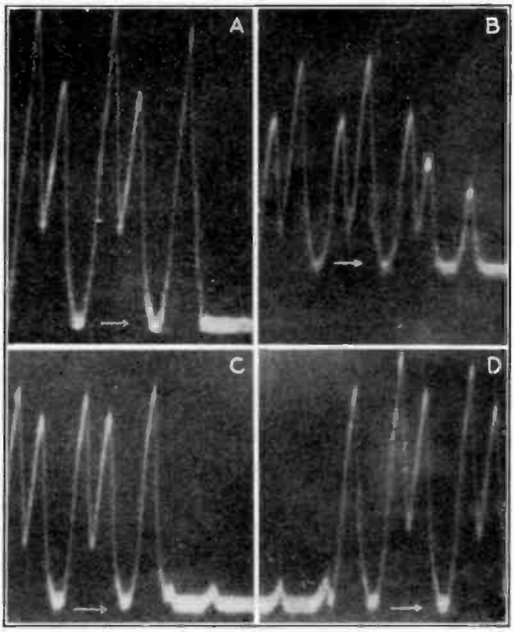


Fig. 5—Wave-forms Observed on October 8, 1927.
(A) End of dot, reflection bigger than ground-wave, no key-click. (B) End of dot, reflection smaller than ground-wave, last ground-hump weaker than preceding ones as also its reflection and in the right proportion. (C) End of dot, reflection slightly bigger than ground wave; note small key-click giving diminutive ground and reflected humps; time-separation between clicks same as between big humps. (D) Beginning of dot; key-click arrives first along ground, then as a reflection, then big ground-hump, its reflection, etc.; separation checks as in (C). Note that amplitude of ground-hump is constant for all.

Pensacola, Florida, could not copy this broadcast on 8,030 kilocyles. The failure of these two stations to get the broadcast was considered unusual, and could not be accounted for since the weather broadcast had been properly transmitted.

Several people reported to the Naval Research Laboratory that during the disturbance broadcast signals in the 550-1,500 kilocycles band also showed abnormalities.

We attempted to ascertain whether this unusual condition was definitely connected with a visible disturbance on the sun. No sufficiently definite information could be obtained because, even though there was an unusual spot in the southwestern quadrant of the sun, it had been active several days before August 19.

Fig. 6—H-alpha image of sunspot-group photographed at Mount Wilson, August 19, 1927, 14^h44^m Greenwich mean time.

However, our information seems fairly definite to the extent of indicating that just before the disturbance the layer height was around 50 miles, while after the normal condition had been reached again the layer height was increased to 100 miles and more.

Figs. 4 and 5 give reproductions of typical wave-forms observed during this period. The first of these was taken on August 25 and the second on October 8. Fig. 6 is a reproduction of the photograph of the sun on August 19 kindly put at our disposal by S. B. Nicholson of the Mount Wilson Observatory.

CORRELATION OF LONG WAVE TRANSATLANTIC RADIO TRANSMISSION WITH OTHER FACTORS AFFECTED BY SOLAR ACTIVITY*

By

Clifford N. Anderson

(American Telephone and Telegraph Company, New York City)

Summary—*Phenomena usually thought of as being affected by solar activity are: Sun spots, solar constant, earth's magnetic field, atmospheric electricity, auroras, earth currents, and, as has been recently shown, radio transmission. In order to correlate these with each other, the daily character of each must be reduced to some single figure. The factors which lend themselves most easily to quantitative correlation are sun spots, solar constant, earth's magnetic field, daylight radio transmission and night radio transmission. For sun spots, the numbers as prepared by Wolfer are used and for variations in the solar constant, the measurements by Dr. Abbot. Several sets of character figures of the earth's magnetic field were available. Of these, the three figures show too great a contrast between disturbed and undisturbed conditions while the Van Dijk show too little. A set of figures which showed a contrast between the disturbed and undisturbed conditions of the same order of magnitude as that obtained between disturbed and undisturbed radio conditions was devised. This method consisted of obtaining from the hourly averages, the total variation of the horizontal and vertical components of the earth's field. Such a figure is easily computed although better results might be obtained if the variation were taken directly from the magnetogram.*

The diurnal characteristic of long wave transatlantic radio transmission can be divided into four parts: daylight over entire transmission path, darkness over entire path, and the sunset and sunrise transition periods. Because the transition periods are normally characterized by one or more dips of signal field, some of short duration, they do not lend themselves particularly well to correlation. For daylight transmission, the average daylight fields were used. For night transmission, a character figure was derived for each day indicating the extent to which the night fields were reduced from their assumed undisturbed values. These assumed undisturbed values were obtained from the maximum night values and approached values given by the inverse distance law as their limit.

By mathematical analysis as well as by inspection high correlation was found between the general trends of these factors (except for the solar constant) which shows a decided decrease in 1926 while the other factors maintain their maxima. Weekly, three-weekly or quarterly averages of deviations from this trend show only a small correlation.

High daylight radio field strengths (at 57,000 cycles) obtain during periods of marked magnetic activity. In most cases, the magnetic disturbance precedes the high radio values, but there is evidence of the abrupt rise to high values preceding the magnetic disturbance and at times a gradual rise to high values independent of the magnetic activity. One interesting fact is the unusually low field strengths and

*Original Manuscript Received by the Institute, November 10, 1927.

low magnetic activity existing for several weeks on either side of December 1, agreeing quite well with the date of December 7 when the sun's equator (region of low solar activity) is on the line of centers of the sun and earth.

High disturbance of the night radio field (57,000 cycles) consistently occurs simultaneously with the magnetic disturbances but with a recovery lasting sometimes as long as six to eight weeks instead of the few days as is the case with the earth's field. If a second disturbance occurs before recovery is complete the effects are added to the existing state. Although fewer data are available on 17 kilocycles and 25 kilocycles, indications are that the maximum disturbance is not so immediate and the recovery sooner than on 57 kilocycles.

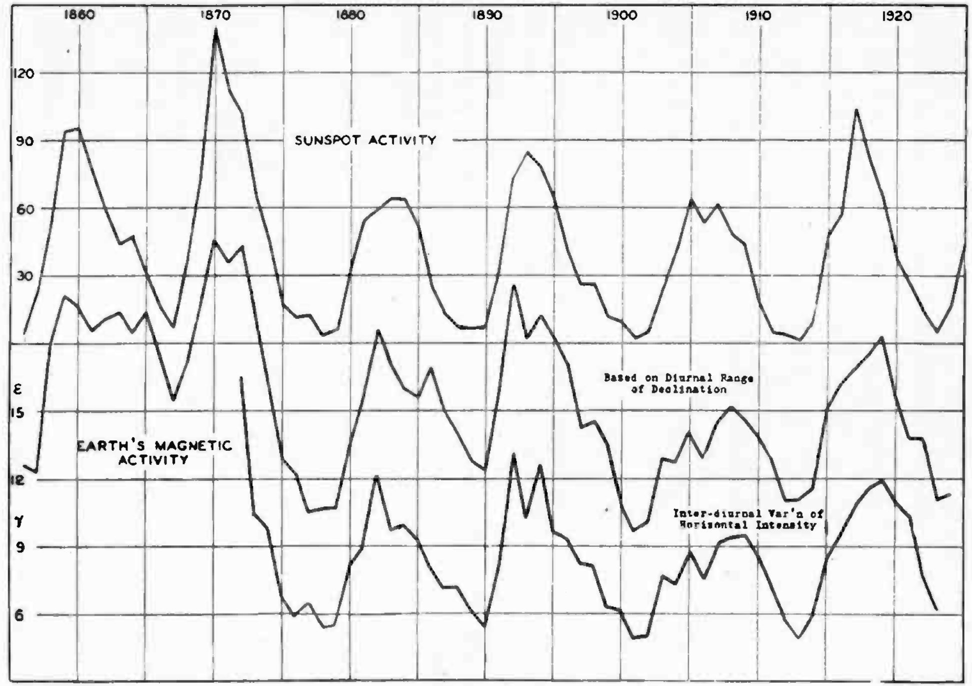
Qualitative correlation of disturbances on grounded telegraph lines indicates discrepancies in the times of beginning and in times of maximum disturbances in earth currents and earth's magnetic field which support conclusions reached by other investigators that these phenomena are not related in any simple way.

Such a statement in reference to all the phenomena examined is also appropriate as a general conclusion for this entire study.

I. Introduction

THE recent interest in the question of whether any significant relations can be established between variations in radio transmission and the activities of the sun has made it seem desirable to present in some detail the results of a study of long wave transatlantic radio transmission in its relation to a number of phenomena commonly thought to be manifestations of solar activity. In a paper presented before the Institute of Radio Engineers in May, 1925 (9), it was pointed out that there had been found a correspondence between times of abnormal radio transmission and the occurrence of severe magnetic storms. This is believed to be the first concrete evidence of an important relationship of this kind. Since that time not only has the transmission information obtained by the transatlantic radio telephone experiments been subjected to more careful examination, but also a considerable amount of additional information has been obtained.

In order to be reasonably certain that no possible factor of significance was being overlooked, it has seemed worth while to investigate these radio data in connection with data on the occurrence of sun spots, the variations of the sun's radiation (solar constant), disturbances of the earth's magnetic field, atmospheric electricity, the aurora, and earth currents. To carry out an examination of such interrelations as may exist on any simple basis it has seemed necessary to select for each of the phenomena some quantitative value which could be taken as representative of the conditions existing over an appreciable period of time such,



(Reproduced from *Terrestrial Magnetism and Atmospheric Electricity*, March, 1926.)

Fig. 1—The Activity of the Sun (sunspot numbers) and the Activity of the Earth's Magnetism as based upon absolute ranges of the magnetic declination at Kew and Cheltenham, 1856–1924, and upon the interdiurnal variability of the horizontal intensity at Bombay and Potsdam, 1872–1923.

for instance, as an entire day. To obtain such representative values as would be adaptable to the kind of analysis which has been made, it has been necessary to be somewhat arbitrary in choosing these "character figures." While an understanding and appreciation of the results of the entire study does not necessarily require

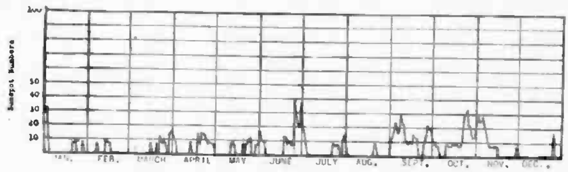


Fig. 2—Sunspot Numbers, 1923. These sunspot numbers are given by A. Wolfer, of Zurich, Switzerland, and published in *Journal of Terrestrial Magnetism and Atmospheric Electricity.*

an examination of the detailed information on which they are based, it has seemed desirable, not only for completeness, but as a possible aid to others interested in this kind of study and to those radio engineers who may wish to obtain an elementary acquaintance with the existing information relating to supposed solar phenomena, to include as a separate section of this paper the description of the available data and the methods which were

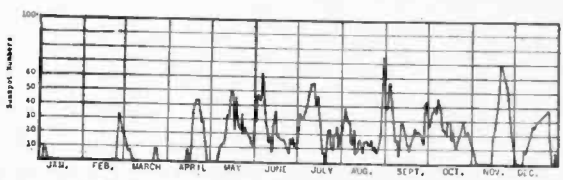


Fig. 3—Sunspot Numbers, 1924. These sunspot numbers are given by A. Wolfer, of Zurich, Switzerland, and published in *Journal of Terrestrial Magnetism and Atmospheric Electricity.*

used in bringing them into a form more easily handled. This material is included in Section II of the paper entitled "Description of Phenomena and Treatment of Data."

In the third section of the paper, entitled "Intercorrelation", is given the procedure of the study and a discussion of the results. The procedure was carried out along two general lines. The first was an examination of the information relating to the various phenomena intended to disclose whatever significant correspondences between abnormal conditions there might be. The second procedure was a strictly mathematical application of an intercorrelation formula to determine whether there were any relations capable of being recognized by the limited analysis which this formula permits. While this intercorrelation formula is capable of displaying in a quantitative and summarized manner the ex-

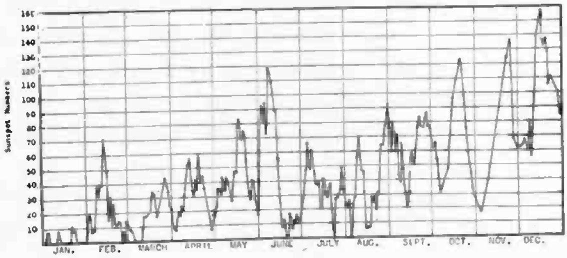


Fig. 4—Sunspot Numbers, 1925. These sunspot numbers are given by A. Wolfer, of Zurich, Switzerland, and published in *Journal of Terrestrial Magnetism and Atmospheric Electricity.*

tent to which any two sets of data are related in their point-by-point variations, it does not discriminate between differences in the duration of the disturbances in the two phenomena. Since the inspection of data disclosed many cases where apparent significant correspondences of abnormal conditions had a short period

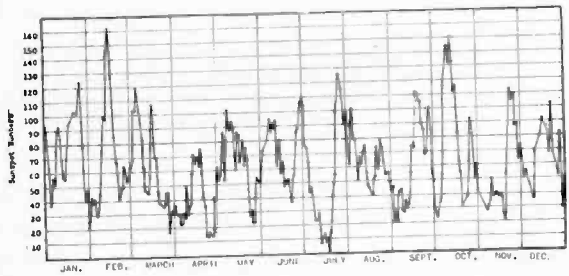


Fig. 5—Sunspot Numbers, 1926. These sunspot numbers are given by A. Wolfer, of Zurich, Switzerland, and published in *Journal of Terrestrial Magnetism and Atmospheric Electricity.*

of existence for certain of the factors but a relatively long period of recovery for others of the factors, it was not to be expected that the mathematical intercorrelation would give results of great significance for relatively short intervals of time. It is, however, capable of sifting out from a set of information which to the eye appears entirely random, general relationships which are of value.

The results of the study may be briefly abstracted as follows: The great reduction in night-time signal fields occurs essentially at the same time that a disturbance in the earth's magnetic field occurs. However, instead of reverting to normality within a day or so as is the case with the earth's field, the recovery of the high night radio fields is very gradual, sometimes requiring six to eight weeks before completion. If no allowance be made for this difference in the recovery, the mathematical correlation of day-to-day values of the two phenomena is not particularly large.

High daylight radio fields accompany periods of high solar activity rather than individual storms. This is, in general, true

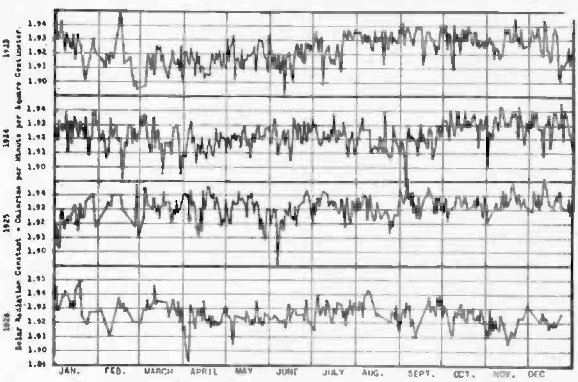


Fig. 6—Daily Variation of Solar Radiation Constant. Data taken by C. G. Abbot and colleagues of the Smithsonian Institution. These measurements represent means of measurements made at Harqua Hala, Arizona, and Montezuma, Chili. Measurements are made with a silver disk pyrheliometer.

of the intercorrelation of other phenomena associated with solar activity. In fact mathematical correlations of radio with those phenomena such as sun spots, disturbances in the earth's field and variations in the solar constant are higher than the corresponding correlations of these phenomena between themselves. Such correlations lie mainly in the broad movement corresponding to the 11-year cycle of solar activity and that with day-to-day, week-to-week, or even three-month averages of deviations from this trend the correlations are small.

Disturbances on grounded telegraph lines also occur chiefly during periods of high solar activity and although they usually accompany severe magnetic storms, discrepancies in the times of beginning and the times of maxima indicate that these phenomena are probably not related in any simple way.

The radio transmission phenomena associated with sunrise and sunset are of interest.

II. Description of Phenomena and Treatment of Data

Sun Spots

As it has been found in general that sun spots, solar constant, variations in earth's magnetic field, potential gradients of the atmosphere, earth currents, auroras or radio vary more or less together in periodic cycles, they have been collectively assumed

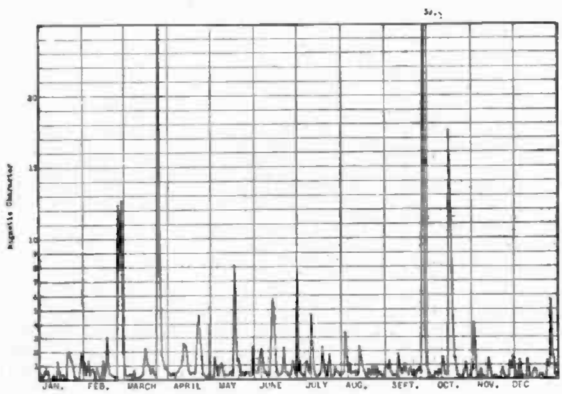


Fig. 7—Magnetic Character, Chree, 1923. These magnetic characters above are the sum of the hourly magnetic characters ($X\ 10^{-4}$) for each day as computed. The characters are proportional to the sum of the squares of extreme ranges of variation of declination and horizontal and vertical components of the earth's field. Because of the second power, they over-emphasize the disturbed days.

to denote the states of "solar activity." Of all the indices of solar activity, the observations of sun spots are probably most direct in that the measurements are made directly on the sun, weather conditions permitting.

Sun spots seem to be similar in nature to cyclonic areas which occur in the earth's atmosphere. The spots appear to consist of funnels of ascending gas, which cool on expanding at the higher levels and so appear darker than the surrounding vapors. They develop quite suddenly. Although they do have some motion of translation of their own, their movement as viewed from some fixed point in space is, in general, that due to the rotation of the sun about its axis. The period of this rotation varies with latitude on the sun, being 24.5 days at the sun's equator and 31 days at a latitude of 80 deg. Sun spots rarely occur at the equator or more than 35 deg. from the equator; and as the majority occur in the band from 10 deg. to 30 deg. on either side of the equator, the period is approximately 25 to 26 days. Allowing for the movement of the earth on its orbit, the average period is about 27.2 days. Their length of life is variable, ranging from a matter of hours to that of months. One has been recorded as having stayed in the same place on the sun's surface for 18 months.

Over a larger period of time, the number of sun spots varies in periodic cycles averaging 11.2 years. Since 1788 the interval

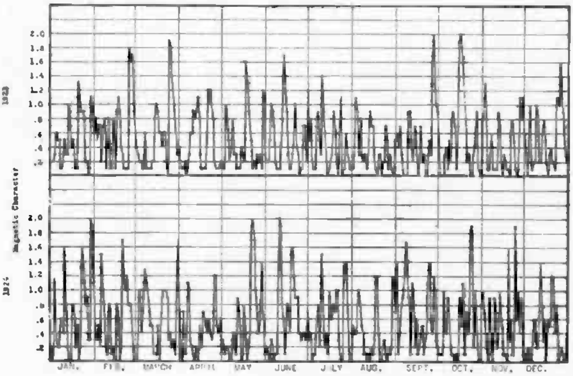


Fig. 8—Magnetic Character (Van Dijk), 1923-1924. The magnetic figures above are those given by Dr. Van Dijk and published in the *Journal of Terrestrial Magnetism and Atmospheric Electricity*. They represent results obtained at several observatories throughout the world. The figures are estimated from the character of the magnetograms. Because the maximum figure is 2 the tendency is not to give severe disturbances proper weight.

between maxima has varied, however, from 7.3 to 17.1 years. This periodic activity from 1856 to 1924 is shown in Fig. 1 (1). It has been suggested that the periodic occurrence of sun spots may be a tidal effect produced by the planets, of which Jupiter's influence predominates. Jupiter's period is 11.86 years.

The sunspot numbers referred to in this paper are those originally prepared by Wolf and continued by Wolfer. They are based in part on the number of spots and in part on their size. The formula used is $r = k\ (10\ g + f)$ where g is the number of groups and single spots observed, f the total number of spots which can be counted in these groups and single spots combined, and k a multiplier which depends on the conditions of observation and the telescope employed. The sunspot numbers cannot take into account sun spots on the sun's hemisphere away from the earth or disturbances, indications of which might not have reached the surface. The sunspot numbers for 1923 to 1926, inclusive, are shown in Figs. 2, 3, 4, and 5. These data extend essentially from a period of minimum sunspot activity to a period of maximum activity.

In the same category with sun spots are measurements of flocculas, faculas, solar prominences, magnetic fields of sun spots, etc.

Solar Constant

Another method which makes measurements of the sun itself is that of measuring the Solar Constant. This so-called *constant*

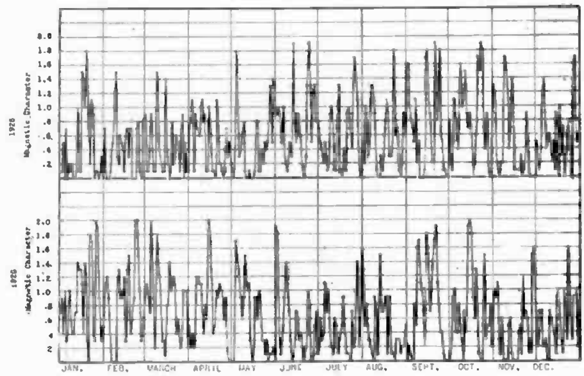


Fig. 9—Magnetic Character (Van Dijk), 1925-1926. The magnetic character figures above are those given by Dr. Van Dijk and published in the *Journal of Terrestrial Magnetism and Electricity*. They represent results obtained at several observatories throughout the world. The figures are estimated from the character of the magnetograms. Because the maximum figure is 2 the tendency is not to give severe disturbances proper weight.

is the energy received from the sun in calories per minute per square centimeter at the earth's surface assuming no atmosphere and that the earth is at its mean distance from the sun. Recent figures indicate the average to be about 1.94 calories. The extreme range of variation about this mean over a period of years is only a matter of $\pm$ $2\frac{1}{2}$ per cent. High solar radiation accompanies high solar activity. In addition there are superimposed periodic fluctuations of $25\frac{2}{3}$ months, 15 months and 11 months. Of these the first is the strongest. Most of the variation is localized in the ultra-violet region of the spectrum with a day-to-day range at 0.29 micron of probably as much as 100 per cent.

The measurements are made by Dr. C. G. Abbot and his colleagues of the Smithsonian Institution at Montezuma, Chili, and Harqua Hala, Arizona. The method is that of the silver disk pyrheliometer in which a silver disk is exposed to sunlight for several periods of 100 seconds each and the temperature rise noted. Knowing the thermal constants of the apparatus, the received energy can be computed.

The outstanding difficulty of this method is no doubt that of eliminating the effect of the atmosphere. Many of the radiation

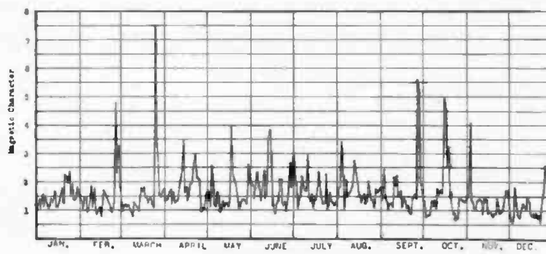


Fig. 10—Magnetic Character (Total Daily Variation). Data taken at Cheltenham, Md., U. S. Coast and Geodetic Survey, 1923. The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day and dividing by 100.

components never reach the earth's surface; and all are absorbed to a certain extent. Corrections are made for haziness and water vapor. The method does not admit of correction for volcanic dust, etc., and in general is satisfactory only for stations of excellent and uniform conditions. The data for the years 1923 to 1926 are shown in Fig. 6 (4).

Earth's Magnetic Field

General. As is well known, the earth acts like a magnetized sphere whose negative pole is near Boothia Felix approximately 71 deg. N. latitude and 96 deg. W. longitude and whose positive pole, although it has never been reached, is about 73 deg. S. latitude and 156 deg. E. longitude. At the earth's surface at Cheltenham, Maryland, the horizontal component is approximately 18,800 gammas (1 gamma = 0.00001 gauss) and the vertical component approximately 55,000 gammas. In equatorial regions the field is mainly horizontal and in the polar regions it is chiefly vertical. Because of the fact that the magnetic and geographical poles do not coincide, the horizontal magnetic field is not parallel to the geographical meridians but differs by an angle called the declination which varies for various geographical locations. For this reason, the horizontal field is sometimes divided into two components, the north (X) and the west (Y).

There is a daily variation in the various magnetic components which is a local phenomenon depending upon the altitude of the sun, the field being usually quite constant during the night. In the United States in summer, the compass needle points 10 min.

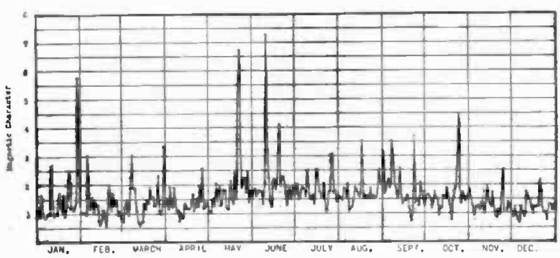


Fig. 11—Magnetic Character (Total Daily Variation). Data taken at Cheltenham, Md., U. S. Coast and Geodetic Survey, 1924. The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day and dividing by 100.

more to the west at 1 P.M. than at 8 A.M. The variation of horizontal and vertical components changes with latitude. At stations within 25 deg. or 30 deg. of the equator, the field *increases* during the morning to a maximum shortly before noon, after which it again decreases. For latitudes above 40 deg., the field *decreases* to a minimum shortly before noon. The normal range therefore depends upon the place of observation at Cheltenham, Maryland, being in the order of 0.1 per cent to 0.2 per cent.

From year to year the field drifts, sometimes increasing and sometimes decreasing. For example, the decrease in the total field at Cheltenham, Maryland, from 1905 to 1924 has been of the order of 1800 gammas or about 0.3 per cent of the total field.

The earth's field is also subject to disturbances of varying degrees, the range, however, for even the "violent" disturbances being for the middle latitudes only of the order of 1 or 2 per cent, although cases have been recorded involving a change in the horizontal component of as much as 5 per cent. The amplitude of the fluctuations is greater in high latitudes than in equatorial regions. There is no difference in intensity as regards the day and night hemisphere, although there seems to be some indication that the P.M. hemisphere is slightly more disturbed than the A.M. hemisphere.

In general, disturbances are characterized by rapid and excessive fluctuation in the earth's field with a net increase in the vertical field and a decrease in the horizontal field. These disturbances begin simultaneously, to within a minute over the whole earth's surface and are most intense the first day of the storm.

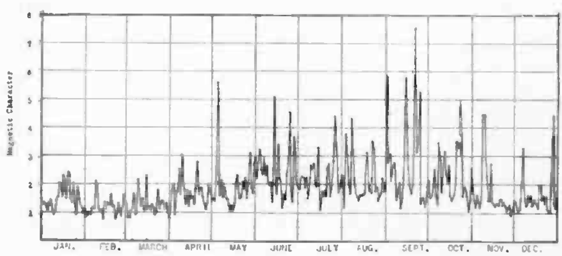


Fig. 12—Magnetic Character (Total Daily Variation). Data taken at Cheltenham, Md., U. S. Coast and Geodetic Survey, 1925. The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day and dividing by 100.

Then they gradually subside, reaching normality at the end of three or four days.

Theories. No proved theory has been developed to account for the existence and variation of the earth's magnetic field. Mathematical analyses indicate that about 96 per cent of the total field is due to internal forces, part to the vertical atmospheric conduction current and 2 to 3 per cent may be due to forces outside the earth. This latter amount is equivalent to approximately the total disturbance occurring at times of so-called magnetic storms. The correlation of magnetic storms and sun spots and the diurnal variation in the earth's field dependent upon local sun time rather than universal time suggest that the sun is responsible for part of the field. Practically all great magnetic storms occur simultaneously (to within a minute) over the entire earth; and because of the tendency to recur every 27 days, the explanation has been advanced that the storms are due to more or less sharply defined streams, at least on the advance front, of electrons emitted from disturbed localities on the solar surface. The angular velocity, of the sun is such that the velocity of a stream relative to the earth would be approximately 400 km. per second and a radius of the sun would cross the earth's disk in about 30 seconds. Assuming a disturbance with a duration of one day, the width of the stream would be of the order of 35,000,000 km.

An explanation given for the greater frequency of magnetic disturbances during the equinoxes as compared with the solstices is the relative positions of the earth and the solar latitude of greatest sunspot frequency and greatest latitude of assumed solar activity. The solar equator is inclined 7 deg. 15 min. to the

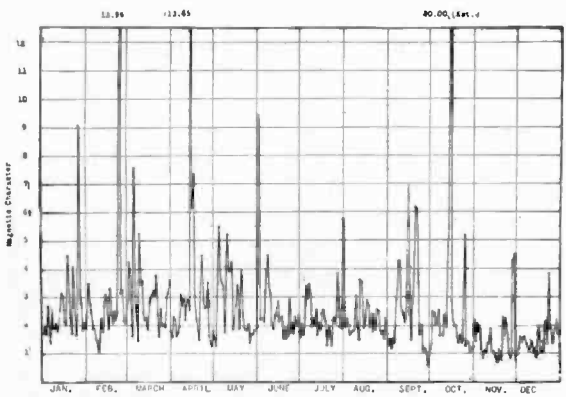


Fig. 13—Magnetic Character (Total Daily Variation). Data taken at Cheltenham, Md., U. S. Coast and Geodetic Survey, 1926. The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day and dividing by 100.

plane of the ecliptic as compared with 23½ deg. in the case of the earth. A line from the sun's center to the earth passes through the sun's equator on June 6, and December 7, and the maximum angle of 7 deg. 15 min. between that line and the equator occurs on September 8, and March 6.

The stream theory alone is not sufficient to account for the magnetic currents, but recourse has to be made to the idea of electric currents flowing in a conducting layer. One such theory (10) calls for a flow from west to east during the first phase of a storm when the horizontal field is slightly increasing and a current from east to west when the intensity of the storm increases and the horizontal field decreases. The interaction between these currents and the horizontal field of the earth is presumed to result in a vertical movement downward during the first phase of the storm and later an upward movement.

Measures of Magnetic Activity. Various schemes have been proposed for giving a single figure indicating the magnetic character of a day. A rough indication is given by dividing days into three classes designated respectively by 0, 1, and 2; 0 denotes quiet conditions; 2, severely disturbed; and 1, intermediate conditions. This is a very rough way of estimating. The results depend largely upon the judgment of the observer and may indicate different things during periods of great or little activity.

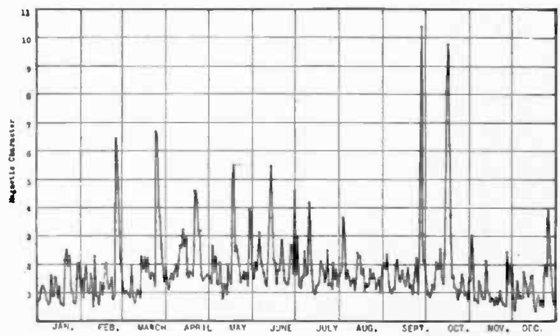


Fig. 14—Magnetic Character (Total Daily Variation). Data taken at Eskdalemuir, Scotland, 1923. The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day and dividing by 100.

Other methods for determining magnetic character figures have been devised and are given below—

Chree—Kew Observatory $R^2 = \frac{1}{100}(R_D^2 + R_H^2 + R_Z^2)$

Schmidt—Potsdam Observatory $A = A_D + A_H + A_Z)$

Van Dijk—De Bilt Observatory $R = (R_D + R_H + R_Z)$

Bauer—Carnegie Institute HR_H

where R = Absolute diurnal range or difference between extreme daily values.

A = Range of the hourly mean values.

H = Horizontal intensity

Z = Vertical intensity

D = Declination

The character figures obtained by the Chree formula were available for each hour of 1923. The total of the 24 figures for each day (proportional to arithmetic mean with constant base line) is plotted in Fig. 7. They could perhaps more justifiably be combined in some other way but this way will serve to indicate quite well the nature of the figures derived by the three formulas. As the character figures are proportional to the sum of the squares of extreme ranges of variation of declination and hori-

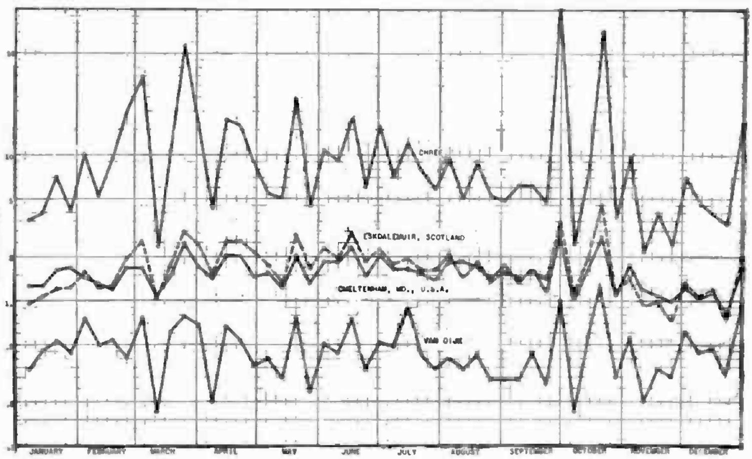


Fig. 15—Comparison of Weekly Averages of Magnetic Character Figures, 1923. This shows the good agreement between magnetic character figures by applying the total variation method to data from the observatories at Cheltenham, Maryland, and Eskdalemuir, Scotland.

zontal and vertical components, they over-emphasize the disturbed days.

The Van Dijk character figures as given in Figs. 8 and 9, are not computed by the formula attributed to Van Dijk in the table above but are estimates made by Dr. Van Dijk of the character of the magnetograms obtained from some 40 observatories throughout the world. Because the maximum figure is 2, the tendency is not to give severe disturbances proper weight.

The sum of the hourly variations for the 24 hours of the horizontal and vertical components has been found to be a convenient measure. As only the hourly means were available, the absolute total variation is, of course, greater in each case and such a measure determined from the magnetograms might be more significant. The computation is simple and for reasons shown later seems to have some value. The data for the years 1923-1926 inclusive are shown in Figs. 10 to 13, inclusive. The unit might be designated:

$$V = \frac{1}{100}(V_H + V_Z)$$

This has been found to be somewhat better than the other magnetic character figure for comparison with radio transmission.

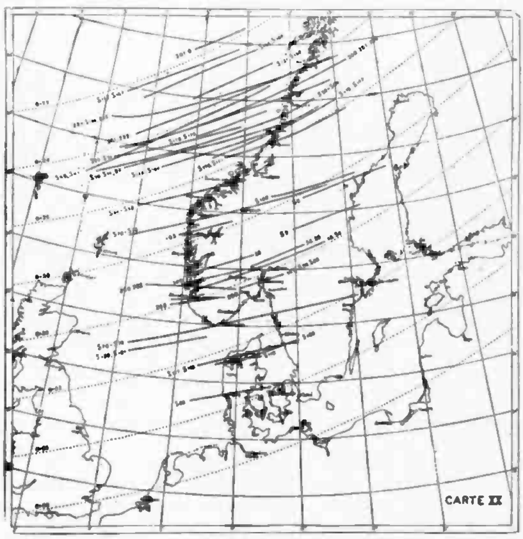


Fig. 16—Coincidence of Auroral Arcs with Magnetic Parallels.

Fig. 14 shows the above method applied to magnetic data obtained at the observatory at Eskdalemuir, Scotland. Comparison with Fig. 10 shows very good agreement indeed between disturbances in the earth's field on the two sides of the Atlantic. The character figures are computed for days beginning midnight to midnight local time so that if allowance were made for the 5-hour difference, the agreement would be even better. There seems to be a tendency for greater fluctuation in the field as measured in Scotland, and this is shown a little better in the weekly averages of Fig. 15. This figure shows also the Van Dijk and the Chree character figures for the same year. On account of the high correlation between the Scotland and the American data, no great error is introduced by using magnetic data at only one end of the circuit. Computed correlation figures show that the "total variation method" agrees better with each of the Chree and Van Dijk sets of figures than the two latter do between themselves. This is interpreted as meaning that the results obtained by the total variation method lie between those obtained by the other

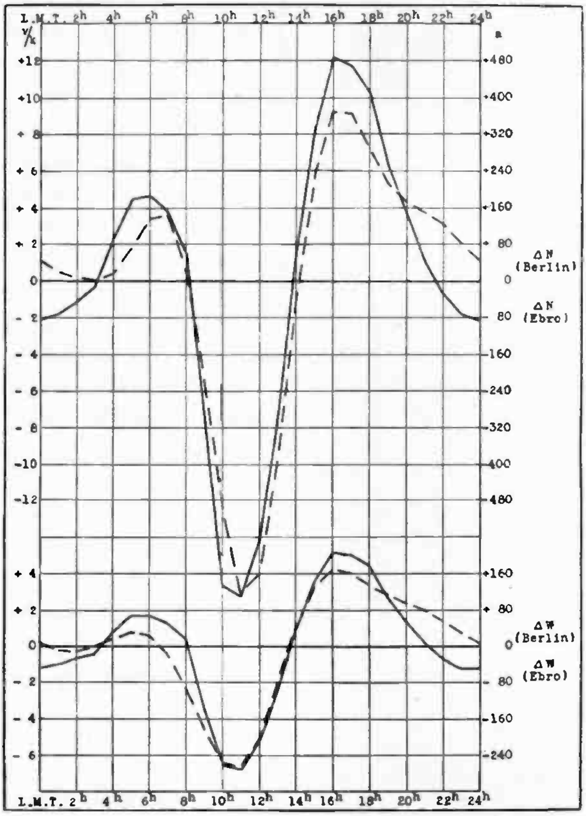


Fig. 17—Diurnal Variation of Earth-Current Components for the Ebro Observatory, 1914–1918, and for Berlin (Weinstein data, 1884–1887).

two methods. The Chree and Van Dijk figures have, however, been useful in checking conditions.

Atmospheric Electricity

Measurements of atmospheric electricity made at the bottom of the atmospheric sea are so affected by local conditions and factors unrelated to solar activity that it is difficult to draw con-

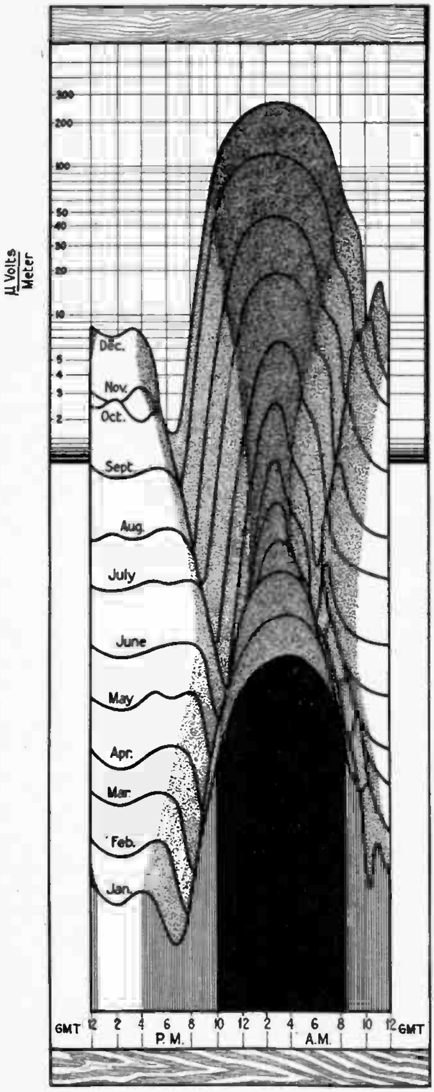


Fig. 18—Transatlantic Radio Telephone Transmission. Diurnal variation of assumed undisturbed signal field strength transmission. Rocky Point, Long Island to New Southgate, England. 5480 km., 57,000 cycles.

clusions as to the fundamental variations and as to what the effects of solar disturbances are.

It is well known, however, that the earth is negatively charged with respect to the surrounding atmosphere, the potential gradient at the earth's surface being of the order of 100 volts per meter. The value decreases with altitude, as indicated by balloon measurements; and it is believed that above 10 km. the potential becomes uniformly of the order of 1,000,000 volts positive with respect to the earth. This field tends to drive negatively-charged particles upward and positively-charged particles downward, and from the conductivity of the atmosphere and the potential gradient the current which flows from the atmosphere into the ground can be computed. This amounts to approximately 2 microamperes per square kilometer, or of the order of 1000 amperes for the entire earth's surface. This value holds for several kilometers above the earth because, although the gradient is decreasing, the conductivity is increasing. (At 9.5 km. Kolhörster found the ionization had increased tenfold.)

Why the earth's charge is not soon neutralized by this current is not known. It is thought that this current might be compensated for by:

(a) Convection currents of charged air

(b) Rain (negatively charged)

(c) Upward conduction currents where potential gradient is negative. (During thunder storms the potential gradient often exceeds 10,000 volts per meter and may be either positive or negative).

(d) Radiations received from outside: β rays from sun to which auroras are attributed might cause a negative potential gradient in vicinity of poles (See "C"); or cosmic rays of

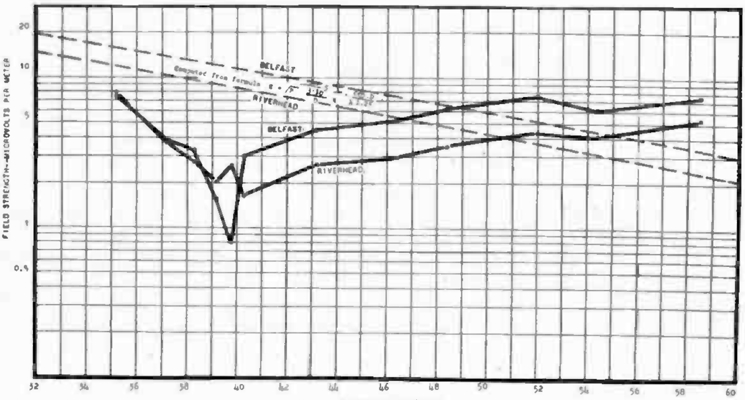


Fig. 19—Transatlantic Radio Telephone Transmission. Variation of daylight signal field with frequency transmission from Northolt, England (GKB)—2 kw. radiated power. Measurements made July to October, 1925.

Data on 58.5 kc. taken October 4, when, due to solar disturbances, field strengths were approximately twice those obtaining on the same frequency in July.

high penetration 15,000,000 volts as found by Hess, Kolhörster, Millikan and others, dissipating their energy in the production of β rays at the earth's surface.

In general the potential gradient decreases with the altitude of the sun, being lower at midday, in the summer time, and in the low latitudes (polar regions also low). In addition there seems to be in the diurnal variation, a variation not dependent on local time which consists of a minimum about 0400 GMT and a gradual increase to a maximum about 1800 GMT. The difference between land and sea values is small.

The correlation between variations of atmospheric electricity as measured at the earth's surface and other solar evidences is not so evident as it might be. However, for stations quite free from meteorological disturbances there appears to be in general an increase in the potential gradient with increasing solar activity.

AURORAS

Auroral displays are closely connected with other phenomena usually associated with solar activity. The displays take various

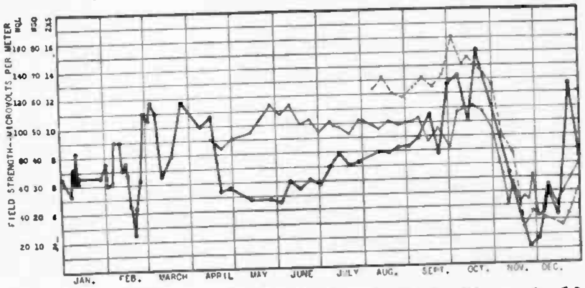


Fig. 20—Variation of Average Daylight Radio Field Strength, 1923.
———— Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc.
———— Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km., 600 amperes. Antenna current, 17.1 kc.
- - - - - - - Marion, Mass. (WSO) to New Southgate, England, 5280 km., 600 amperes. Antenna current, 25.7 kc.

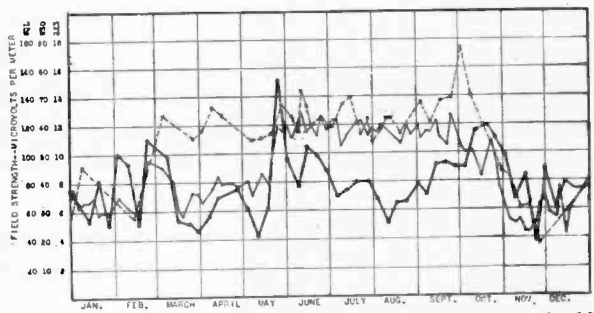


Fig. 21—Variation of Average Daylight Radio Field Strength, 1924.
———— Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc.
———— Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km., 600 amperes. Antenna current, 17.1 kc.
- - - - - - - Marion, Mass. (WSO) to New Southgate, England, 5280 km., 600 amperes. Antenna current, 25.7 kc.

forms such as foggy auroras, pulsating auroras, diffuse arcs, split bands, drapery-shaped arcs, draperies, rays, corona and intermediate types. The ray form is probably the structural element of the other forms. They appear most frequently in the polar regions with their distribution symmetrical with the magnetic axis rather than with the geographical axis. The isochasm (curve indicating same number of auroras) of maximum auroras is approximately 23 deg. from the intersection of the magnetic axis with the earth's surface. As this point is approximately 78 deg. N and 69 deg. W or not far from Etah, Greenland, the line of minimum aurora passes through the northern point of Norway (latitude 70 deg.) just south of Point Barrow, Alaska, (latitude 70 deg.) middle of Hudson Bay (latitude 60 deg.) and south of Greenland (latitude 58 deg.). In the United States auroras are seldom observed below the 30 deg. parallel and in Russia seldom

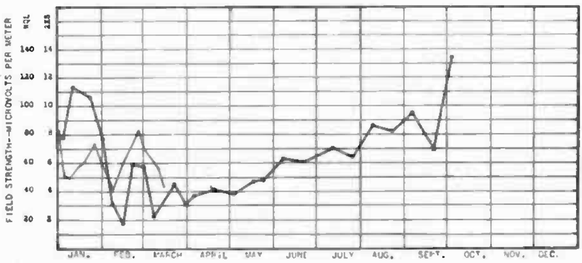


Fig. 22—Variation of Average Daylight Radio Field Strength, 1925.
———— Rocky Point, L.I. (2XS) to Chedzoy, England, 5300 km., 300 amperes. Antenna current, 57 kc.
———— Rocky Point, L.I., (WQL) to Chedzoy, England, 5300 km., 600 amperes. Antenna current, 17.1 kc.

below the 50 deg. parallel. The more severe the disturbance, the lower is the latitude at which the aurora is visible. Stormer reports that all the auroras observed at Oslo, Norway, during the years 1911–1922 were accompanied by magnetic disturbances with Van Dijk magnetic character figures of 2 with one exception—that of April 18, 1917, which had a character figure of 1. While the auroras observed at the lower latitudes follow in general the severe magnetic storms (most frequent during the equinoxes), the auroras observed near the auroral zone are most frequent in midwinter.

The more severe the disturbance, the greater are the higher and lower limits to which the aurora extends. By means of simultaneously photographing auroras against a background of stars from two observatories in the order of 30 km. apart, Stormer, Vegard, and Krogness (7) were able to determine the heights of auroras. In general the lower edge of the aurora occurred most frequently at an altitude of about 100 km. to 110 km., although at times as low as 80 km. and as high as 200 km. or even, in exceptional cases, 400 km. The upper part of the aurora usually fades away to invisibility so that generally a well-defined upper limit does not exist. Indications are, however, that the average upper limit of diffuse arcs is of the order of 140 km., draperies 175 km., and rays 230 km. It is not unusual for the latter to extend much higher, even up to 800 km. (March 22–23, 1920).

It was also found that the direction of the auroral arcs and bands coincide approximately with the magnetic parallels, i. e., at right angles to the earth's field. The angle is not, however, exactly 90 deg. as south of the auroral zone the western end is 10

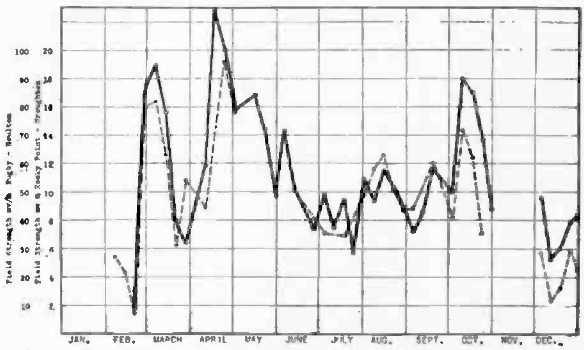


Fig. 23—Variation of Average Daylight Radio Field Strength, 1926.
———— Rocky Point, L.I. (2XS) to Wroughton, England, 5385 km., 300 amperes, Antenna current, 57 kc.
- - - - - - - Rugby, England (GBT) to Houlton, Maine, 4670 km., 250 amperes. Antenna current, 57 kc.

deg. north of the normal to the magnetic meridian. (Fig. 16) (8). Inside the auroral zone the directions become less constant and at the magnetic axis point all directions are equally probable. There is also a small diurnal variation in the mean direction of the arcs, the angle decreasing from evening to morning.

Birkeland assumed the auroral illuminosity to be caused by the bombardment of the rarefied atmosphere by negatively charged corpuscles from the sun. By exposing a magnetized sphere to cathode rays he was able to produce a similar phenomenon. Experiment and mathematical theory both show that the electron streams should follow curved paths. These paths will not, therefore, coincide with magnetic parallels, but deviate from them by a small angle. Assuming the charge to be positive, the deviation is in the opposite direction to that observed.

Earth Current

General. Another factor which has been found to accompany solar disturbances is that of earth currents. When a conductor is grounded at two separate points a current will flow, indicating a difference in potential between these two points. There is not a great amount of data available on earth currents, but indications are that there is always a current flowing in a greater or less degree and that it is affected at times of unusual solar activity.

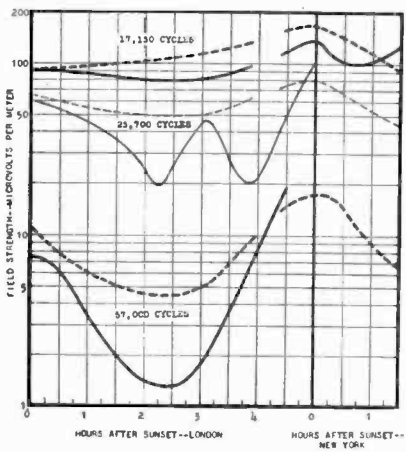


Fig. 24—Major Sunset Effects on Radio Transmission. Transmission from Rocky Point, L. I. (57 kc. to 17.1 kc.) and Marion, Mass. (25.7 kc.) to New Southgate, England. Solid line indicates undisturbed conditions, and dashed line disturbed conditions.

Measurements made in Spain by the Ebro Observatory at Tortosa indicate the current there to flow from a direction 29 deg. west of north with the north-south component of the gradient 0.2 volt per kilometer and the west-east component 0.11 volt per kilometer. The resultant, 0.23 volt per kilometer would increase to 0.8 to 1 volt per kilometer during electric or magnetic storms. As a relatively large part of the residual current is due to the electrochemical action at the contact between the electrode and the soil, the figures are to be taken only as indicating the approximate magnitude of the values involved. Fig. 17 shows the diurnal deviation from the mean of earth currents as measured at the Ebro, Spain, observatory and on telegraph lines between Berlin and Dresden (11). The minimum is seen to occur shortly before noon, a primary maximum in late afternoon and a secondary maximum in early forenoon. The diurnal variation is more severe along a meridian (north-south) than at right angles to it (east-west). It is maximum during the equinoctial months and lowest near the solstitial months and increases with increase in sunspot activity. A careful comparison, however, with the earth's magnetic field, as measured at the same observatory, indicates time phase and directional discrepancies, from which it is concluded that they are related in only a minor way and probably only through a common cause.

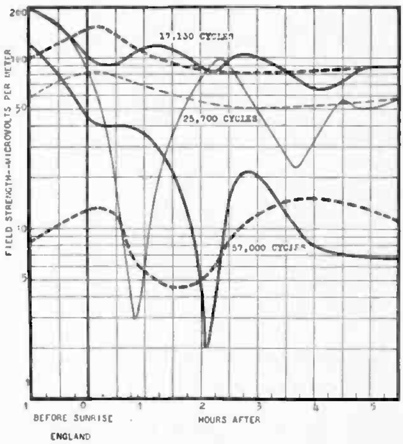


Fig. 25—Major Sunrise Effects on Radio Transmission. Transmission from Rocky Point, L. I. (57 kc. and 17.1 kc.) and Marion, Mass. (25.7 kc.) to New Southgate, England. Solid line indicates undisturbed conditions and dashed line disturbed conditions.

Earth Currents on Telegraph Lines. On days of severe solar disturbances, of the earth's magnetic field and the existence of aurora and sunspots, the potential gradients become so great that grounded wire lines are seriously affected. The potentials set up add or subtract from the usual line battery and as these voltages on long lines may in severe cases be 400-500 volts or more, there is not only the problem of maintaining service, but also that of insuring adequate apparatus and cable protection and eliminating fire hazard due to insulation breakdown.

For the most part, the voltages are in the order of 0 to 50 volts and may change from positive to negative within a few seconds. The duration may be from a few minutes to several days and the

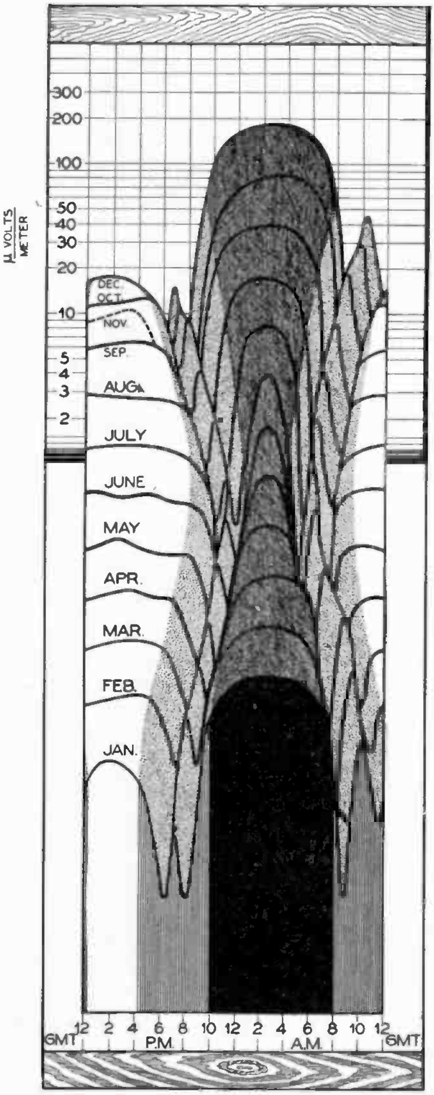


Fig. 26—Transatlantic Radio Telephone Transmission, Diurnal variation of assumed undisturbed radio field strength transmission. Marion, Mass. (WSO) to New Southgate, England. 5282 km., 25,700 cycles.

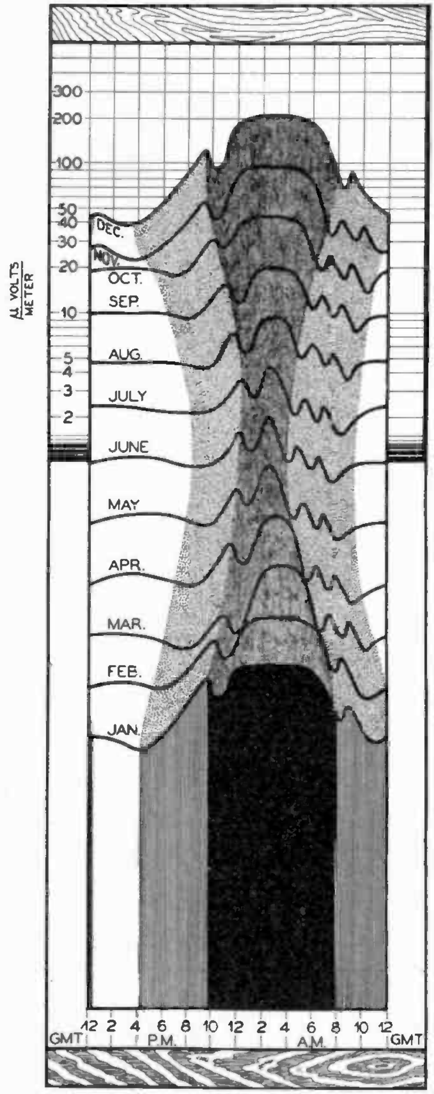


Fig. 27—Transatlantic Radio Telephone Transmission. Diurnal variation of assumed, undisturbed signal field strength transmission. Rocky Point, Long Island (WQL) to New Southgate, England. 5482 km., 17,130 cycles.

TABLE I

EARTH CURRENTS AND MAGNETIC AND SUNSPOT CONDITIONS

Date	Area Disturbed by Earth Currents	Severity	Time (EST) Beginning	Time (EST) End	Magnetic Character	Disturbance Beginning	Disturbance End (EST)	Provisional Sunspot Number
Apr. 28, 1921	Minneapolis Minn.	Mild	8:25 A.M.	10:00 A.M.	1.94	—	—	22
May 13–17, 1921	General—especially severe in New England	Periods of greatest intensity from 3 P.M. to 4 or 5 A.M. Disturbance most severe at about 9 P.M. May 14. Heat coils burned out, carbons grounded (operate on 350 volts), at Pittsburgh an arc of ¾ in. to 1 in. was noted between carbons. Condensers tested for 500 volts were broken down so that voltages in excess of this must have occurred. Cable insulation was broken down and a fire started in the Philadelphia office. Brilliant aurora on night of 14th.	8:50 A.M. (May 13)	12:30 A.M. (May 17)	20 Needle thrown out of adjustment so that complete record not available for May 13 to May 16. Character for May 12, 4.33. May 17, 3.32.	8:09 A.M. May 13	3:00 A.M. May 17	May 13–50 May 14–71 May 15–63 May 16–49 May 17–37
May 20, 1921	Pennsylvania to Missouri	Mild	12:55 P.M.	4:04 P.M.	5.50	9:33 A.M.	Midnight	18
Sept. 2, 1921	Pittsburgh, Pa.	Very mild	During night	to Sept. 2	3.99	11:00 A.M. Sept. 1	12:00 Noon Sept. 2	9
Feb. 13, 1922	Philadelphia to New York	Very mild	6:00 P.M.	8:00 P.M.	1.42	3:00 A.M. Feb. 14		63
Oct. 16, 1923	Indianapolis to Chicago	Mild	8:15 P.M.	9:40 P.M.	4.5	2:00 A.M. Oct. 15	2:00 A.M. Oct. 18	8
Oct. 27, 1923	Ohio	Mild	8:10 A.M.	9:14 A.M.	1.4	—	—	21
Jan. 29, 1924	N.E. quarter of Mississippi Valley	Quite severe with maximum disturbance the first hour.	1:00 P.M.	8:45 P.M.	5.8	12:24 A.M.	10:00 P.M.	0
May 9, 1925	Missouri	Mild	6:05 P.M.	9:25 P.M.	1.9	4:00 P.M. May 8	5:00 P.M. May 9	43
June 24, 1925	Wisconsin	Mild	3:18 P.M.	6:00 P.M.	4.55	8:00 P.M. June 22	6:00 P.M. June 25	7
Jan. 26, 1926	General — Except New England	Quite severe	11:19 A.M.	7:15 P.M.	9.1	11:17 A.M.	Midnight	105
Feb. 23, 1926	General — Except New England	Quite severe	9:05 A.M.	6:19 P.M.	5.1 (14 on Feb. 24)	11:26 A.M. Feb. 23	11:00 P.M. Feb. 24	48
Mar. 5, 1926	Middle West	Rather severe	9:25 A.M.	2:20 P.M.	7.55	5:03 A.M. Mar. 5	3:00 A.M. Mar. 6	119
Apr. 14, 1926	New England to Minnesota	Rather severe	9:45 A.M.	10:57 P.M.	13.65	9:00 A.M. Apr. 14	10:00 P.M. Apr. 17	71
Oct. 15, 1926	General	Very severe. At many observation points there was a lull between about 11:30 A.M. and 2:00 P.M. Aurora borealis display at night after disturbance had ceased.	8:45 A.M.	11:40 P.M.	20 (Estimated) Needle thrown out of adjustment	4:00 P.M. (Oct. 14) Most violent from noon to 4:00 P.M. Oct. 15	Midnight Oct. 15	112

P.M. hemisphere seems to be most affected. The disturbances may be comparatively local in character or may extend over the whole country with the effect about one-third as great on the

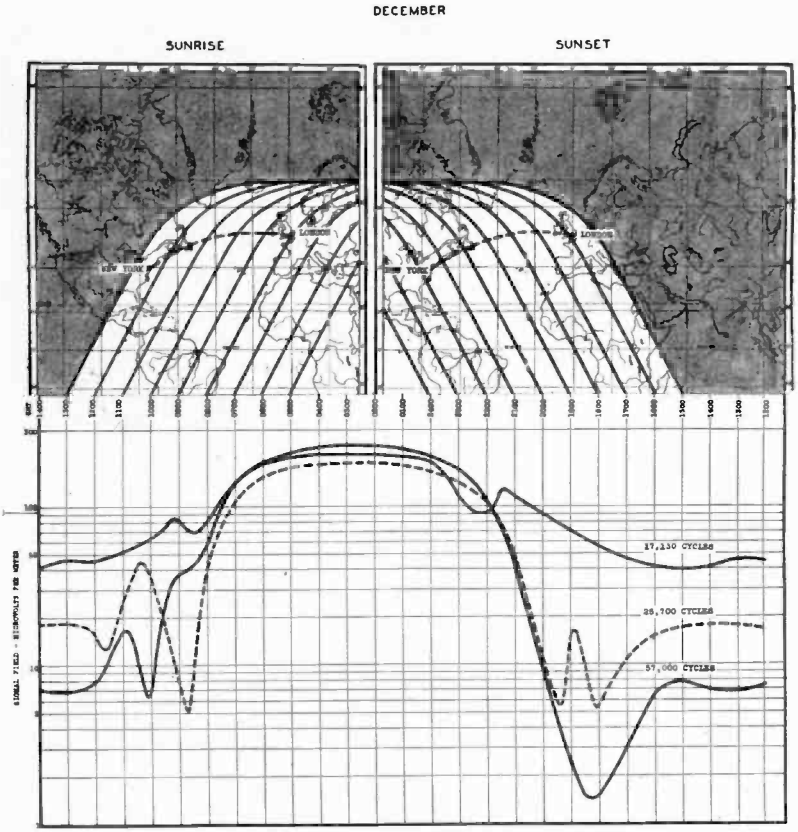


Fig. 28—Relation of Sunset and Sunrise to Transatlantic Radio Transmission, December.

east-west lines as on the north-south lines; the more severe the disturbance, usually the larger the area disturbed.

Table 1 gives the data on all disturbances which have been noted on the telegraph circuits of the American Telephone and Telegraph Company for the years 1921 to 1926, inclusive. The number of storms is, after all, comparatively small. The respective sunspot numbers range from 0 to 119, averaging possibly 50. The disturbance for the day with no sunspots was quite severe, and on the other hand, no disturbances were noted on 300 days during 1923 to 1926 when sunspot numbers have exceeded 50, even up to 160.

Mild disturbances on telegraph lines have been noted with quiet magnetic conditions, but every severe disturbance has been

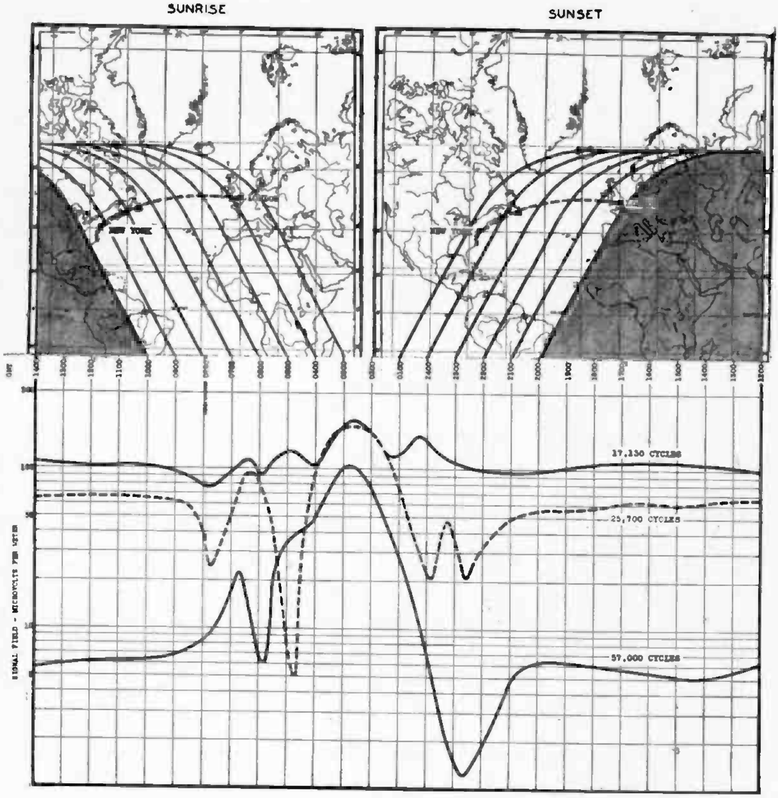


Fig. 29—Relation of Sunset and Sunrise to Transatlantic Radio Transmission, June.

accompanied by a severe magnetic disturbance. The extremely severe magnetic disturbances are also accompanied by earth current disturbances, but this does not hold for the less severe. For example, the magnetic character for January 29, 1924, with quite a severe earth current disturbance was 5.8. During the four years 1923-1926, 18 out of 23 days with magnetic character above 5.8 (some as high as 10) were unaccompanied by wire line disturbance. In most cases line disturbances occur during the period between the beginning and end of the magnetic disturbances. However, on February 13, 1922, the trouble on the wire circuits occurred between 6 P.M., and 8 P.M., while the magnetic disturbance, which was slight, did not begin until 3 A.M. the next morning. On January 23, 1926, the wire line disturbance began over two hours before the magnetic disturbance and was essentially over by 6

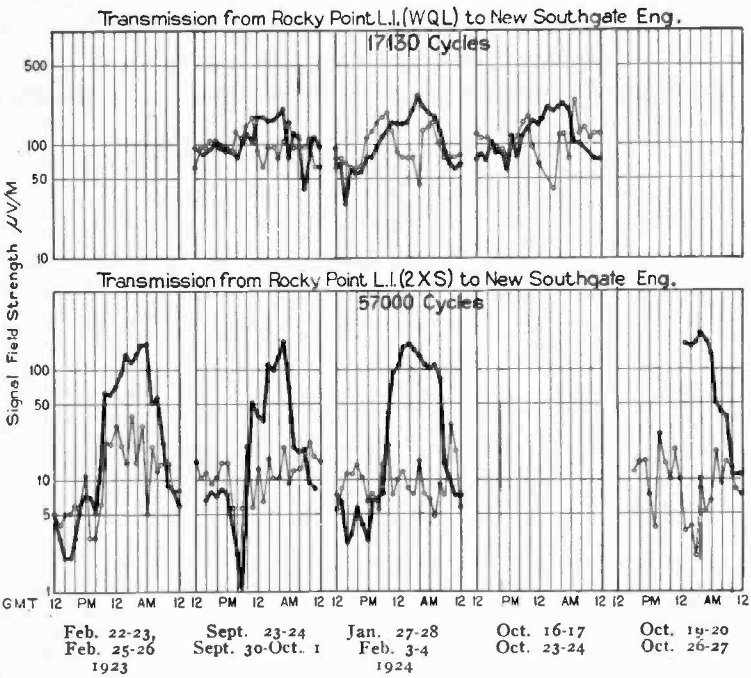


Fig. 30—Transatlantic Radio Telephone Measurements; Effect of Solar Disturbances on Radio Transmission.

——— More or less normal transmission week-end before disturbances occurred.

——— Abnormal transmission on following week-end, disturbance still in progress.

P.M., while the most violent disturbance in the earth's field occurred the next day, February 24, 1926. Another point of interest is that on October 15, 1926, the lull in the wire line disturbance from 11:30 A.M. to 2:30 P.M. occurred during the period of most violent disturbance of the earth's field-noon to 4:00 P.M.

The results seem to bear out the conclusions reached by the investigators of the Carnegie Institution.

Radio Transmission

General. In connection with the experiments prior to the establishment of a commercial radio-telephone circuit, considerable amount of data was accumulated on radio transmission across the Atlantic. Most of these data were on a frequency in the neighborhood of 60 kilocycles (5,000 meters) although some information was obtained at frequencies in the neighborhood of 25 kilocycles (12,500 meters) and 17 kilocycles (17,500 meters). The greater part of these data has already been published (9).

For convenience, transmission during the 24 hours may be divided into four periods: viz., the period when the entire trans-

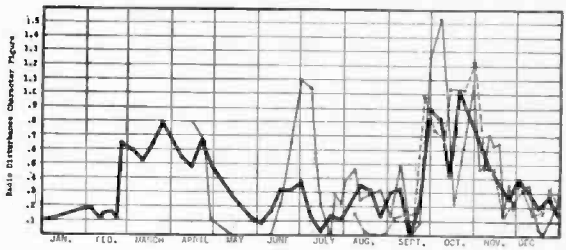


Fig. 31—Variation in Disturbance of Night Time Radio Field Strength, 1923.

———— Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc.

———— Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km., 600 amperes. Antenna current, 17.1 kc.

- - - - - - - Marion, Mass. (WSO) to New Southgate, England, 5280 km., 600 amperes. Antenna current, 25.7 kc.

These radio character figures are a measure of the extent to which night time signal fields are decreased from the assumed undisturbed value to the daylight value. If the radio character is zero, the night time fields are normal; if unity, the night fields are equal to the day fields; if greater than unity, the night fields are even less than the day fields.

mission path (great circle) is in daylight, the period when the entire path is in darkness, and the two transition periods, one in the morning and one at night. Fig. 18 shows the diurnal variations in signal field strength for the various months of the year for transmission from Rocky Point, Long Island, to New Southgate, England, on a frequency of 57,000 cycles. In order to show all the essentials, the figure lost its guide of perspective. One must visualize, therefore, a three-dimensional figure in which the vertical plane showing the field-strength grid is at the back. The months of the year are distributed along the base and the third dimension is the time of day. The shaded portions indicate the extent to which the transmission path is in darkness.

The night period is one of relatively high, and usually unstable, field-strength values. They are often thought of as representing the unabsorbed transmission and expressed by the Hertzian expansion formula $E(\mu v/M)=\frac{120\pi HI}{\lambda D}$ commonly spoken of as the Inverse-Distance Law.

The daylight period is one of relatively low, although as a rule quite stable, field-strength values. These are the values to which

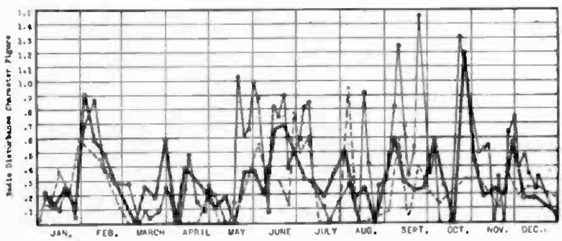


Fig. 32—Variation in Disturbance of Night Time Radio Field Strength, 1924.

———Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc.

———Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km., 600 amperes. Antenna current, 17.1 kc.

-------Marion Mass. (WSO) to New Southgate, England, 5280 km., 600 amperes. Antenna current, 25.7 kc.

These radio character figures are a measure of the extent to which night time signal fields are decreased from the assumed undisturbed value to the daylight value. If the radio character is zero, the night time fields are normal; if unity, the night time fields are equal to the day fields; if greater than unity, the night fields are even less than the day fields.

various transmission formulas apply. The more widely used of these formulas usually consist of the expression for the Inverse-Distance Law and an exponential factor representing the absorption encountered during the day.

During the transition periods, the change from daylight field to night field or vice versa is not a direct one, but passes through one or more periods of equivalent high attenuation.

Night-Time Radio Transmission. For the purpose of comparing radio transmission from day to day, the first requisite was to determine the standard for comparison. It has already been noted, during periods of solar disturbances, that the night fields were decreased greatly and that the daylight fields were somewhat increased. The first step, then, in attempting to generalize our data, was to obtain averages of 24-hour transmission for all days which might be characterized as not seriously disturbed. This was done for each individual month. It was next found that, for the night-time fields, smoother curves and more consistent results were obtained by plotting, for each month, the maximum values ever obtained for each particular hour. It is of interest to note in this connection that for frequencies of 17,000 cycles and 25,000 cycles as high night-time values were obtained during the summer months as during the winter months. This maximum value was

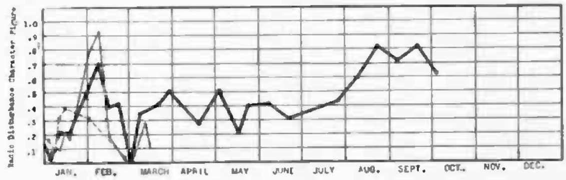


Fig. 33—Variation in Disturbance of Night Time Radio Field Strength, 1925.

———Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc.

———Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km., 600 amperes. Antenna current, 17.1 kc.

- - - - - - Marion, Mass. (WSO) to New Southgate, England, 5280 km., 600 amperes. Antenna current, 25.7 kc.

These radio character figures are a measure of the extent to which night time signal fields are decreased from the assumed undisturbed value to the daylight value. If the radio character is zero, the night time fields are normal; if unity, the night fields are equal to the day fields; if greater than unity, the night fields are even less than the day fields.

essentially that calculated by the Inverse-Distance formula. On 57,000 cycles, values as high as those calculated by that formula are obtained only during the winter months.

Daylight Radio Transmission. The above method appears to eliminate successfully the effect of disturbed transmission for the night period. For the daylight period, the average field for each hour was taken as computed from the "quiet" days referred to above. This minimizes, but, as seen later, does not entirely eliminate the effect of solar disturbances. As these daylight values are used only for computing the amount of night-time disturbance, and the difference between the "quiet" and "affected" daylight values is not a particularly large one, it was thought that the daylight values as obtained above, would represent conditions for the present at least, as well as any obtained by further assumptions.

As is well known, the daylight fields for equal radiated powers are higher, the lower the frequency. This relationship, based on measurements taken on three frequencies in the particular frequency range of 60 to 15 kilocycles and over the transmission path New York and London can be expressed by the empirical formula

$$E\mu v/M = \frac{120\pi HI}{\lambda D} e^{\frac{-0.005D}{\lambda 1.25}}$$

$$= \sqrt{\frac{P_{kw}3.10^5}{D}} e^{\frac{-0.005D}{\lambda 1.25}}$$

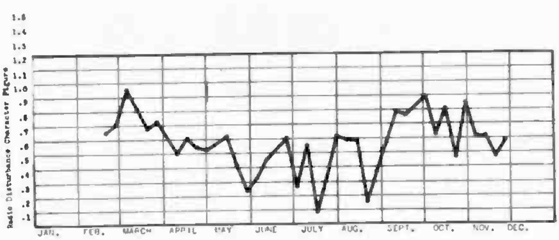


Fig. 34—Variation in Disturbance of Night Time Radio Field Strength, 1926. Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km., 300 amperes. Antenna current, 57 kc. These radio character figures are a measure of the extent to which night time signal fields are decreased from the assumed undisturbed value to the daylight value. If the radio character is zero, the night time fields are normal; if unity, the night fields are equal to the day fields; if greater than unity, the night fields are even less than the day fields.

This formula has also been found to represent quite well transmission data obtained by engineers of the Marconi Company on a trip around the world in 1922 and 1923 (13). One apparent exception, however, to increasing fields with decreasing frequency seems to be indicated by data obtained several years ago in which abnormally low field strengths were obtained on frequencies in the vicinity of 40 kilocycles (Fig. 19). The study was made during the summer months and was suggested by exceptionally low fields experienced during the spring months on a frequency of 43 kilocycles. The field measurements at 58.5 kilocycles were taken at a period during which the earth's field was disturbed and hence are somewhat higher than average.

Curves showing the variation in daylight field for such measurements as were made in 1923 to 1926, inclusive, on 60,000 cycles, 25,000 cycles and 17,000 cycles are shown in Figs. 20 to 23, inclusive.

Fig. 35—Photograph of Aurora at Oslo, Norway, May 12, 1921 (Stormer).

Sunrise and Sunset Effects on Radio Transmission. Some difficulty was encountered in obtaining a picture of the variation in field during the transition period due to the fact that a large part of the phenomena is of short duration as compared with the

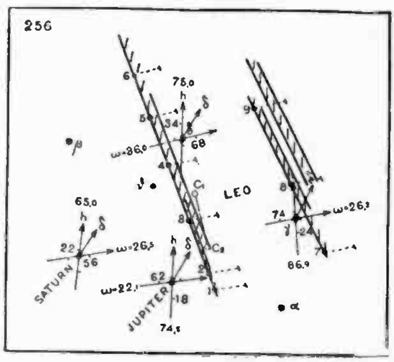


Fig. 36—Sketch of Aurora (Fig. 35) with Background of Stars.

interval between measurements. Accordingly, the data obtained were plotted with respect to sunrise and sunset instead of standard time.

Fig. 24 shows the results obtained for the transition period as daylight recedes from the transmission path. The assumed undisturbed variations for the three frequencies 17,130 cycles, 25,700 cycles and 57,000 cycles are shown by the respective solid lines. The major sunset dips occur approximately 2 hours and 30 minutes after sunset in London for the frequencies 17,130 cycles and 57,000 cycles and the two dips occur at about 2 hours and 15 minutes and 3 hours and 50 minutes after sunset in London for 25,700

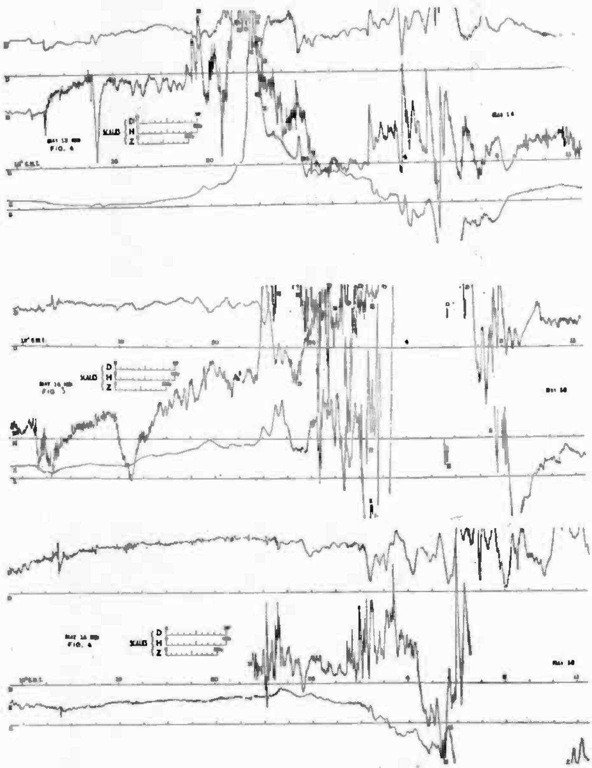


Fig. 37—Magnetograms of Earth's Magnetic Field, Cheltenham, Maryland. (From U. S. Coast and Geodetic Survey Report Serial 275).

cycles, irrespective of seasons. These are independent of season because the portion of great circle path between New York and London, which is being plunged into darkness during the first three or four hours after sunset in England, is at approximately the same latitude as London. In winter, sunset at New York occurs 5 hours and 40 minutes after sunset at London and in summer only 4 hours and 15 minutes after sunset at London. The phenomena associated with sunset at New York can thus be segregated. One of them is the dip in transmission (17 kilocycles)

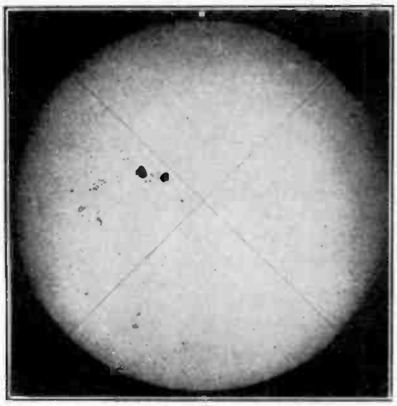


Fig. 38—Photograph of Solar Disk, May 13, 1921.

occurring approximately 30 to 50 minutes after sunset at New York.

The dotted curves indicate the transmission tendency during disturbed periods. For severe conditions this tendency is for the

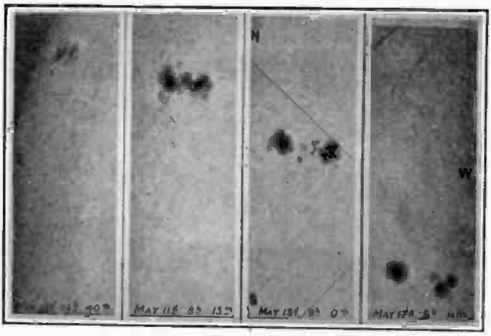


Fig. 39—Photograph of Solar Disk showing Progress of Sunspot Group.

sunset dip to be less pronounced and for the field strengths to drop to the low night values directly after sunset in New York.

Fig. 25 shows similar results obtained for the sunrise transition period. The same tendency to smooth out the peaks and dips is shown. In one case of severe disturbance, a complete reversal was found.

As many of the phenomena accompanying sunrise and sunset are of much shorter duration than those which the transmission schedules were designed to study, there are, no doubt, other variations which our data can only suggest. For example, one piece of evidence at hand shows a decrease in the field (57,000 cycles) by the factor of 3 over a period of only 5 to 10 minutes at sunset at New York. For the same reason, the magnitude of the dips is no doubt underestimated. One continuous record indicates a fall in field strength (57,000 cycles) to half value at sunrise England whereas our other data only warranted showing a small depression.

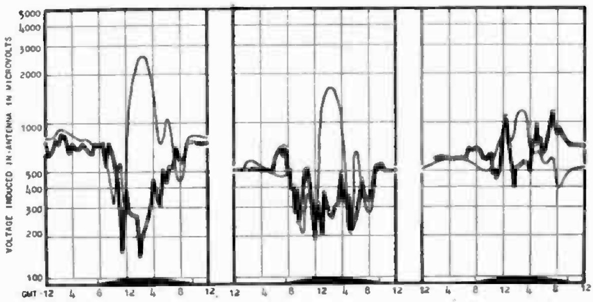


Fig. 40—Comparison of Radio Transmission During Disturbed Period in May, 1921 and Assumed Undisturbed Transmission Data at Chelmsford, England. Taken by Engineers of Marconi Wireless Telegraph Company, Ltd.

New Brunswick, N. J. to Chelmsford, England, 13.6 km. Distance 5420 km. May 13 to May 14, 1921. Light curve indicates assumed undisturbed transmission from Marion, Mass. to London, England, for May. Approximately same wavelength and distance.

Marion, Mass. to Chelmsford, England 11.6 km. Distance 5310 km. May 19 to May 20, 1921. Light line indicates assumed undisturbed transmission from Marion, Mass. to London, England, for May. Same wavelength and approximately same distance.

Tuckerton, N. J. to Chelmsford, England, 16 km. Distance 5520 km. May 23 to May 24, 1921. Light line indicates assumed undisturbed transmission from Rocky Point, L. I. to London, England, for May. Approximately same wavelength and distance.

Because radio transmission is so sensitive to light conditions during these transition periods, a study of this phase of radio transmission may prove to be quite profitable.

Generalized Diurnal Variation of Undisturbed Radio Transmission. With the night fields determined by the envelope of maximum values for each month, the day fields obtained by averages, and the major variations during the transition sunset and sunrise periods at least qualitatively known, composite curves of assumed undisturbed transmission could be constructed for each month of the year as shown in Fig. 18. Similar figures for transmission on 25,700 cycles and 17,130 cycles are shown in Figs. 26 and 27.

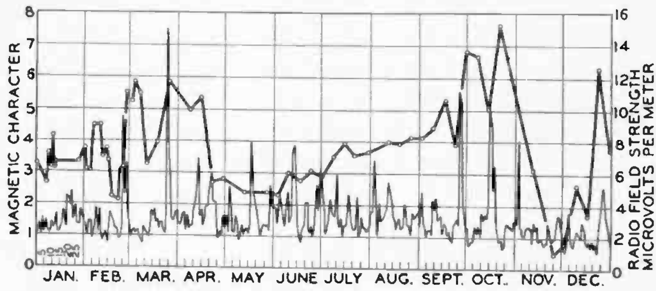


Fig. 41—Comparison of Average Daylight Field Strength with Character Figure of Earth's Magnetic Field.
———— Radio transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1923.

Fig. 28 shows the positions of the sunset and sunrise shadow walls for December in relation to the transmission path and the corresponding variation in the radio field while Fig. 29 shows similarly the conditions for June.

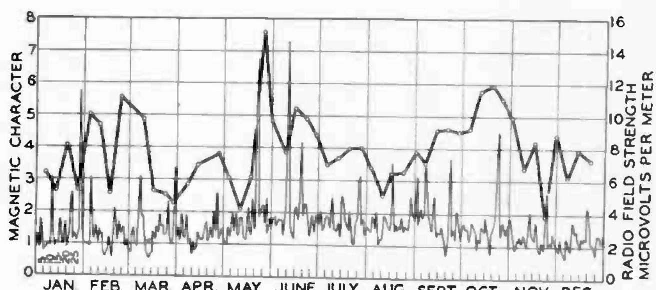


Fig. 42—Comparison of Average Daylight Field Strength with Character Figure of Earth's Magnetic Field.
———— Radio transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1924.

Measure of Night-Time Radio Disturbance. As shown in an earlier paper (9), there occur periods during which the night fields are very much reduced and subject to considerable fluctuation and change of direction. These periods were shown to coincide with periods of marked disturbance in the earth's magnetic field. Fig. 30 is reproduced from the earlier paper referred to.

In order to obtain radio transmission character figures which would be more or less independent of the frequency measured, the method suggesting itself was that of using the extent to which the night values were reduced to the normal daylight values. In order to minimize as much as possible the effect of fluctuations which would tend to make the measurements non-representative, the character figure finally decided upon was the ratio of which the area (semi-log coordinates) of the curve enclosed by the assumed undisturbed night values less the average daylight value

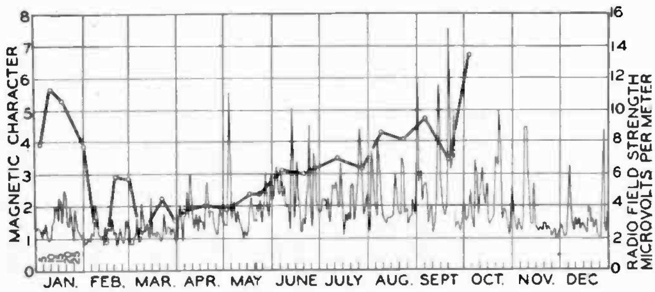


Fig. 43—Comparison of Average Daylight Field Strength with Character Figure of Earth's Magnetic Field.
———— Radio transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1925.

is the denominator and the area represented by the difference between the area of assumed undisturbed night values and the observed night values received is the numerator. The actual method of arriving at this figure was to obtain the sum of the logarithms of all the night ordinates of the disturbed N and the assumed undisturbed N curves and the log of the average daylight field d.

The radio character figure is then equal to $\frac{\log N - \log N'}{\log N - n \log d}$ where n is the number of ordinates. If the night fields are equal to those assumed undisturbed transmission, the character figure is zero; if night fields are reduced to the day fields, the character figure is unity; if reduced below the daylight value, the character figure is greater than unity. Because of the short period during the summer months in which the entire transatlantic path is in darkness, only 3 or 4 night-time values of field strength represent transmission conditions. As these fall on the side of the curve where field strengths are rapidly changing, considerable error may be introduced. A single experimental error or a measurement made at an unusually favorable or unfavorable moment might change altogether the radio character figure for that day.

Curves showing the variation of character figures for such measurements as were taken from 1923 to 1926, inclusive, on

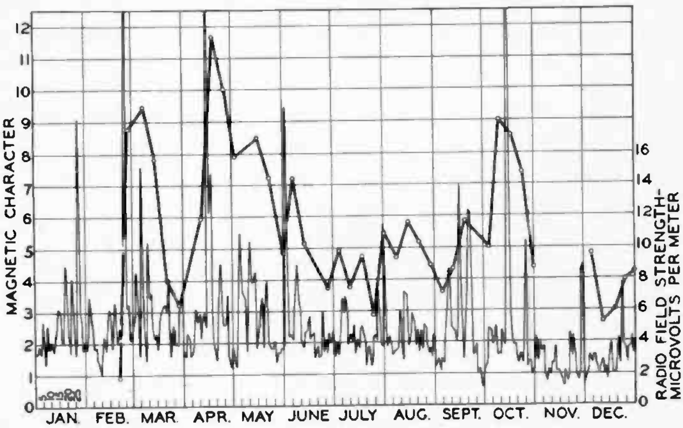


Fig. 44—Comparison of Average Daylight Field Strength with Character Figure of Earth's Magnetic Field.
———Radio transmission from Rocky Point, L.I. (57 kc.) to Wroughton, England.
———Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1926.

60,000 cycles, 25,000 cycles and 17,000 cycles over the transmission path between roughly New York and London are shown in Figs. 31, 32, 33, and 34.

III. Intercorrelation

Disturbance of May, 1921. One of the most severe disturbances of recent years occurred May 13–17, 1921. Auroras were particularly brilliant and observed at very low latitudes. One of the numerous photographs obtained in Norway (8) is shown in Fig. 35 and a sketch of its position against a background of stars is shown in Fig. 36. The calculated position is shown on the map (S-260) of Fig. 16 with a height extending from 103 to 460 kilometers. During the storm, grounded telegraph circuits were rendered inoperative due to excessive earth potentials which burned out line protectors, broke down condensers and insulation and even started fires in terminal offices.

The disturbance in the earth's field was also violent, with the magnetometer trace off scale for hours at a time at observatories in both England and America. At Cheltenham, Maryland, the needle was twice thrown out of balance. The magnetograms (2) at Cheltenham for May 13–16 are shown in Fig. 37 and indicate the nature of such disturbances.

Fig. 38 shows a picture of the solar disk taken at the Greenwich Observatory, London, at 0900 GMT on the day the storm began

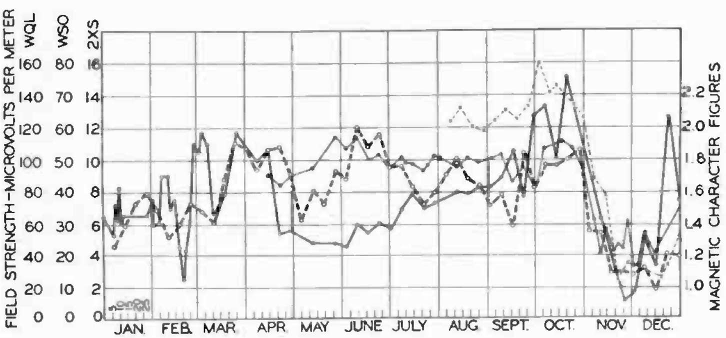


Fig. 45—Comparison of Average Daylight Field Strength and Weekly 3-Week Moving Averages of Magnetic Character Figures, 1923.
———— Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km.—300 amperes. Antenna current, 57 kc.
———— Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km.—600 amperes. Antenna current, 17.1 kc.
- - - - - - Marion, Mass. (WSO) to New Southgate, England, 5280 km. —600 amperes. Antenna current, 25.7 kc.

(12). It is to be noted that the end of the sun's axis is 21 deg. west of north and the sun's equator 2½ deg. north of the center of the disk. The sunspot group is on the sun's equator and the largest in this position, in the last half-century. The area is 1/1500 of the sun's surface or eight times the area of the earth.

The spot was nearest the center of the disk May 14 at 1600 GMT when it was within 3 deg. It was then nearly in line with the earth, but the magnetic storm occurred 27 hours earlier. At this time the leading spot was 11½ deg. east of the central meridian and the following spot 19 deg. The greatest intensity of the disturbance was about 0500 on May 15, at which time the following spot was 3 deg. past the central meridian. The second maximum occurred at 0800 GMT, May 16.

Fig. 39 shows the progress of the group across the sun's disk from the day when it first appeared—May 8.

Fortunately data on radio transmission for this period are also available. Fig. 40 shows variation in signal field from New Brunswick, N. J., Marion, Mass., and Tuckerton, N. J., as measured by the engineers of the Marconi Wireless Telegraph Company, Ltd., at Chelmsford, England, (13). Curves of assumed undisturbed radio transmission from Marion and Rocky Point of approximately the same frequencies and distances are also

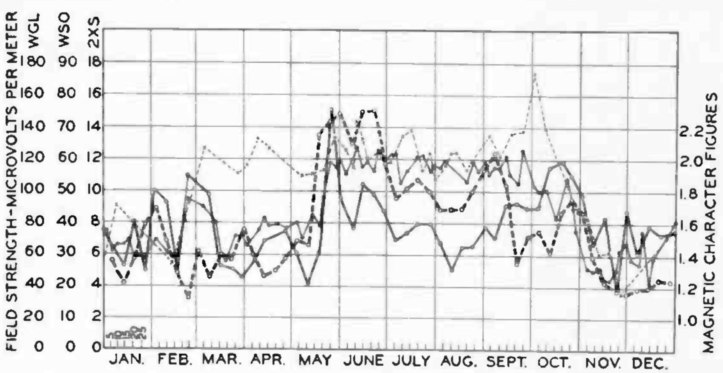


Fig. 46—Comparison of Average Daylight Field Strength and Weekly 3-Week Moving Averages of Magnetic Character Figures, 1924.
———Rocky Point, L.I. (2XS) to New Southgate, England, 5480 km.—300 amperes. Antenna current, 57 kc.
———Rocky Point, L.I. (WQL) to New Southgate, England, 5480 km.—600 amperes. Antenna current, 17.1 kc.
- - - - - - -Marion, Mass. (WSO) to New Southgate, England, 5280 km.—600 amperes. Antenna current, 25.7 kc.

drawn in for comparison. It is seen that the night-time transmission is reduced to one-half and one-third the values which might be expected.

Earth Currents. In the case just cited auroras, earth currents, sun spots, earth's field, and radio were all severely affected. The agreement is not, however, always so good. As previously pointed out in connection with earth currents on telegraph lines, severe disturbances may occur with no visible sun spots. On the other hand no disturbance occurred on 300 days in 1923 to 1926 on which the sunspot numbers exceeded the 50 which obtained on

May 13, when the most severe disturbance on record occurred on the telegraph lines. Discrepancies in the times of beginning and in times of maximum disturbances in earth currents and earth's magnetic field support conclusions reached by other investigators that these phenomena are not intimately connected.

Sun Spots and Magnetic Disturbances. Comparison of sunspot numbers (Figs. 2 to 5) and magnetic character figures (Figs. 10 to 13) for 1923 and 1926, inclusive, shows that the severe disturbances of February 25, 1923, and January 29, 1924, were unaccompanied by any sun spots. The severe disturbances of February 24, and April 15, 1926, as well as all others in the previous years (1923–1926) and including the severe disturbance of May, 1921, were accompanied by relatively low sunspot numbers as prevailed

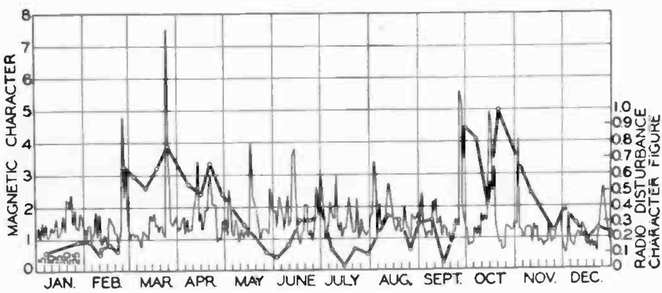


Fig. 47—Comparison of Disturbance in Night Time Radio Transmission with Character Figure of Earth's Magnetic Field.
———Radio Transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1923.

at other times in 1925 and 1926 when no severe magnetic disturbances occurred. It is true that these discrepancies might be explained by the fact that at times the sun spots were unfavorably situated with respect to the earth, i.e., not in or near that portion of the sun's surface cut by a cone of which the center of the sun is the apex and the earth's disk the base.

Daylight Radio Transmission and Magnetic Disturbances. Figs. 41 to 44 show the comparison of the average daylight radio field strength (57,000 cycles) with daily magnetic character figures. 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, however, the high fields follow the magnetic disturbance and then gradually fall off, although the gradual rise in field strengths during August and September in 1923 and during October in 1924 seems to be independent of magnetic disturbances. One outstanding case of the high field strength preceding the magnetic disturbances is that of October 10, 1926, where the magnetic disturbance did not commence until the third day after and did not reach its maximum until the fifth day after.

A comparison of radio transmission with three-week moving averages as in Figs. 45 and 46 does not show any great degree of correlation except in the major variation. The agreement with radio fields on the various frequencies is, however, about as good

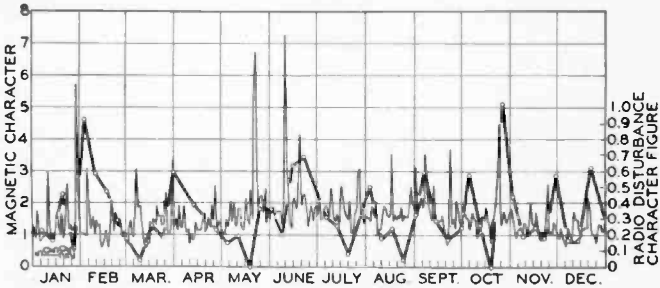


Fig. 48—Comparison of Disturbance in Night Time Radio Transmission with Character Figure of Earth's Magnetic Field.
———— Radio Transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1924.

as between transmission on various frequencies. One outstanding feature which is shared by transmission on all frequencies and magnetic characters alike is the low fields and low disturbance for the two to three weeks on either side of December 1. This may be of significance in view of the sun's equator (region of low activity) being on the line of centers of the earth and sun on December 7.

Night Radio Transmission and Magnetic Disturbances. The comparison of disturbances of night-time radio transmission and earth's magnetic field is shown in Figs. 47 to 50. As before, daily comparisons tell us little. There seems to be a close relation between the radio disturbances and the magnetic disturbances, however, in that the radio disturbances are consistently low preceding a magnetic disturbance, then there is an abrupt increase accompanying the magnetic disturbance and finally a gradual recuperation which may last several months depending on the severity. This "hang-over" effect is seen best in the figures for 1923 and 1924 where disturbances are less frequent, permitting recovery to take place. Disturbances occurring before recovery has taken place superimpose their effects upon conditions present at the time.

Because of this "hangover" effect it is not entirely correct to compare magnitudes of radio disturbances with magnitudes of magnetic disturbances as the latter might occur partly in one day and partly in the next so that although the magnetic character of both days may be relatively low, the magnetic character of the 24 hours including the period of maximum might be considerably

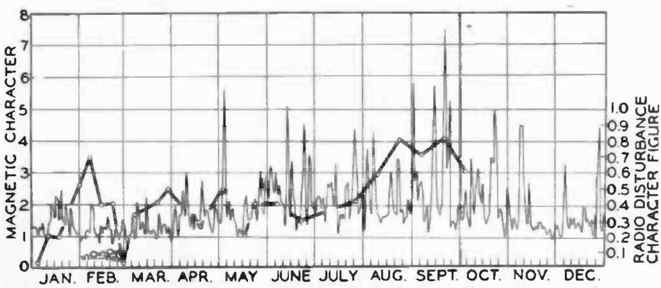


Fig. 49—Comparison of Disturbance in Night Time Radio Transmission with Character Figure of Earth's Magnetic Field.
———— Radio Transmission from Rocky Point, L.I. (57 kc.) to New Southgate, England.
———— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1925.

higher. Such is the case of September 26 and 27, 1923, with character figures of 5.6 and 5.2 respectively. Taking the 24 hours of maximum activity which in this case was from noon on September 26, to noon on September 27, the magnetic character is 9.3.

A better picture of the effect of a disturbance and the recovery is shown in Fig. 51. Each curve represents the diurnal variation of signal field for the 24 hours commencing at noon one day and ending at noon the next. Radio transmission on January 27–28 was quite normal with a radio character figure of 0.1. The disturbance in the earth's field occurred January 29, after which the first radio test schedule on February 3–4 showed a radio disturbance character figure of 0.92. The subsequent tests show the gradual recovery with character figures of 0.58, 0.47, 0.28, and 0.04. This process took approximately 5 weeks.

On the lower frequencies, the recovery appears to be more rapid and there is some evidence that there is a lag in the maximum radio disturbance behind the disturbance of the earth's field.

The disturbances of night-time radio fields can, therefore, be reasonably attributed to some cause which simultaneously affects the earth's field; but the rates of recovery in the two cases are different, being much more rapid in the case of the earth's field. Although the daylight radio fields are highest at periods of magnetic disturbance, they often increase toward these high values ahead of the magnetic and have been known to jump to

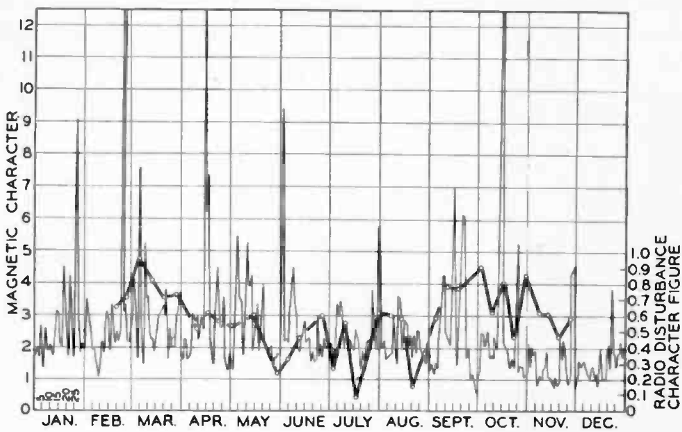


Fig. 50—Comparison of Disturbance in Night Time Radio Transmission with Character Figure of Earth's Magnetic Field.
——— Radio Transmission from Rocky Point, L.I. (57 kc.) to Wroughton, England.
——— Magnetic data taken at Cheltenham, Maryland. U. S. Coast and Geodetic Survey, 1926.
(The magnetic characters as represented above are determined by adding the total variation between hourly averages of horizontal and vertical field (gammas) for each day, and dividing by 100.)

the peak value several days before the magnetic disturbance. This would seem to indicate that the mechanism of the increased day fields and that of the decreased night values were different. The former might be affected by, say, corpuscular radiation but the latter by wave radiation.

It is seen that if for no other reason that than the rates of recovery are different, the mathematical correlation of day-to-day magnetic and radio conditions would probably not be high.

Fig. 52 shows three-week moving averages computed for every week for radio character (night), daylight radio fields, magnetic character solar constant and sun spot.

The dotted lines in each case represent the trend as computed from 18-month moving averages computed for every 6 months. The agreement of this trend is exceptionally good in all cases expect in the case of solar constant which shows a decrease in 1926 while the other factors maintain their maximum. As the data only extend over a part of the cycle of solar activity, no definite conclusions can be drawn as to whether this apparent

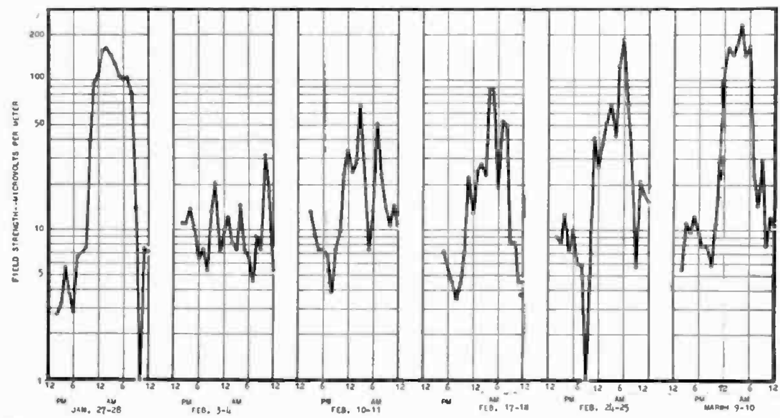


Fig. 51—Transatlantic Radio Telephone Transmission. Diurnal variation in signal field on successive week-ends showing recovery after disturbance January 29, 1924. Rocky Point, L. I. to New Southgate, England. 5480 km., 57,000 cycles.

phase displacement is real or not. The results of detailed mathematical correlation can best be summarized by Table II.

The Correlation Coefficients are computed by the formula developed by Pearson

$$r = \frac{\Sigma(d_1 d_2)}{\sqrt{\Sigma d_1^2 \cdot \Sigma d_2^2}}$$

where d_1 and d_2 are the deviations of the individual values of two sets of data from their respective means. They endeavor to assign numerical values to the correlation which the eye attempts to do by inspection of the plotted curves. If the coefficient is unity and positive, the correlation is perfect and an increase in one is accompanied by an increase in the other. If the coefficient is

TABLE II

INTERCORRELATION OF VARIOUS FACTORS AFFECTED BY SOLAR ACTIVITY

	Trend 6 Monthly 12-Month *Moving Averages*		4-Weekly 12-Week *Moving Averages*		4 Weekly 12-Week Moving Averages *(Trend Out)*		Weekly 3-Week Moving Averages *(Trend Out)*		Weekly Averages *(Trend Out)*	
					RADIO CHARACTER—NIGHT					
Magnetic Character	*+0.995*	(406)	*+0.725*	(15.4)	*+0.28*	(2.8)	*+0.39*	(9)	*+0.32*	(6.5)
Sun Spots	*+0.985*	(158)	*+0.664*	(12.5)	*+0.29*	(3.3)	*+0.22*	(4.6)	*+0.15*	(2.7)
Radio Fields—Day	*+0.975*	(86.2)	*+0.633*	(10.6)	*+0.55*	(7.7)	*+0.37*	(8.4)	*+0.34*	(6.8)
Solar Constant	*+0.44*	(2.5)	*+0.22*	(2.9)	*−0.04*	(0.4)	*+0.03*	(0.6)	*−0.01*	(0.2)
					RADIO FIELDS—DAY					
Magnetic Character	*+0.987*	(180)	*+0.695*	(13.4)	*+0.38*	(4.3)	*+0.41*	(10.5)	*+0.33*	(6.9)
Radio Character—Night	*+0.975*	(86.2)	*+0.633*	(10.6)	*+0.55*	(7.7)	*+0.37*	(8.4)	*+0.34*	(6.8)
Sun Spots	*+0.95*	(46.8)	*+0.54*	(7.7)	*+0.14*	(1.4)	*+0.16*	(3.4)	*+0.05*	(0.9)
Solar Constant	*+0.30*	(1.5)	*−0.07*	(0.8)	*−0.09*	(0.9)	*+0.03*	(0.6)	*+0.06*	(1.1)
					MAGNETIC CHARACTER					
Radio Character—Night	*+0.995*	(406)	*+0.725*	(15.4)	*+0.28*	(2.8)	*+0.38*	(9)	*+0.32*	(6.5)
Radio Fields—Day	*+0.987*	(180)	*+0.695*	(13.4)	*+0.38*	(4.3)	*+0.41*	(10.5)	*+0.33*	(6.9)
Sun Spots	*+0.98*	(127)	*+0.798*	(22.8)	*+0.21*	(2.3)	*+0.21*	(4.6)	*+0.20*	(4.3)
Solar Constant	*+0.39*	(2.1)	*+0.14*	(1.4)	*−0.46*	(6)	*−0.21*	(4.7)	*−0.14*	(1.4
					SUNSPOT NUMBERS					
Radio Character—Night	*+0.985*	(158)	*+0.664*	(12.5)	*+0.29*	(3.3)	*+0.22*	(4.6)	*+0.15*	(2.7)
Magnetic Character	*+0.98*	(127)	*+0.798*	(22.8)	*+0.21*	(2.3)	*+0.21*	(4.6)	*+0.20*	(4.3)
Radio Fields—Day	*+0.95*	(46.8)	*+0.54*	(7.7)	*+0.14*	(1.4)	*+0.16*	(3.4)	*+0.05*	(0.9)
Solar Constant	*+0.53*	(3.3)	*+0.39*	(4.9)	*+0.1*	(1.1)	*+0.23*	(5.2)	*+0.11*	(2.4)
					SOLAR CONSTANT					
Sun Spots	*+0.53*	(3.3)	*+0.39*	(4.9)	*+0.1*	(1.1)	*+0.23*	(5.2)	*+0.11*	(2.4)
Radio Character—Night	*+0.44*	(2.5)	*+0.22*	(2.9)	*−0.04*	(0.4)	*+0.03*	(0.6)	*−0.01*	(0.2)
Magnetic Character	*+0.39*	(2.1)	*+0.14*	(1.4)	*−0.46*	(6)	*−0.21*	(4.7)	*−0.14*	(1.4)
Radio Fields—Day	*+0.30*	(1.5)	*−0.07*	(0.8)	*−0.09*	(0.9)	*+0.03*	(0.6)	*+0.06*	(1.1)

Italic figures denote Correlation Coefficient.
Figures in parentheses denote ratio of Correlation Coefficient to Probable Error.

unity and negative, the correlation is perfect but an increase in the one is accompanied by a decrease in the other. If the coefficient is zero, the variations in both are random and independent of each other. In order to determine the significance of the Correlation Coefficients, one resorts to the ratio of the coefficients to the

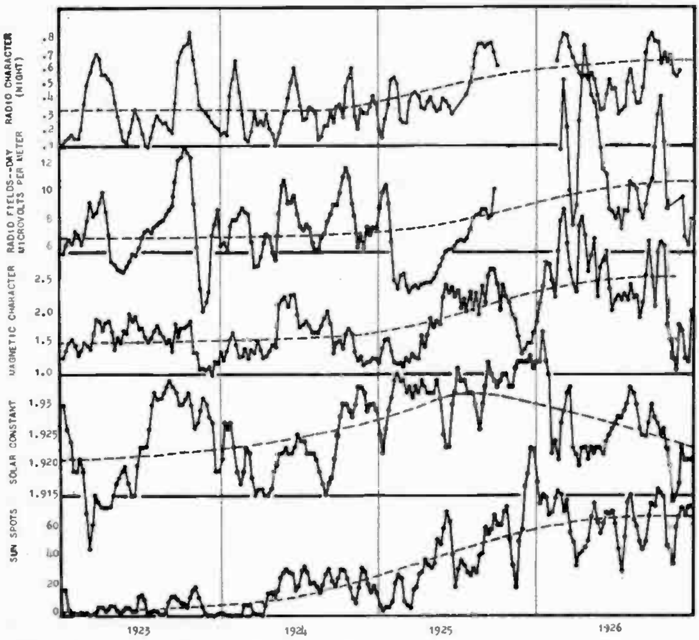


Fig. 52—Intercorrelation of Various Factors Affected by Solar Disturbances —Comparison of "Weekly" 3-Week Moving Averages.

Probable Error. The Probable Error is computed by the formula:

$$P.E = 0.6745 \frac{1-r}{\sqrt{n}}$$

where r = correlation coefficient.

n = number of observations.

For practical purposes it is assumed that if the Correlation Coefficient is less than the Probable Error, there is no evidence of correlation; if the Correlation Coefficient is more than 6 times the Probable Error, correlation is good. In addition when the Probable Error is relatively small, there is decided correlation if the correlation coefficient is greater than 0.5 but not at all marked if less than 0.3.

It is seen from the table that whatever correlation exists lies in the broad movement corresponding to the eleven-year cycle of solar activity and that with day-to-day, week-to-week, or even three-month averages (Fig. 53) of deviations from this trend, the correlation is small. It is of interest to note that although the correlation of the trend of variation of the solar constant is positive, the correlation of some of the shorter period fluctuations is negative. This is especially evident in the case with magnetic activity.

In connection with correlation of radio transmission with solar

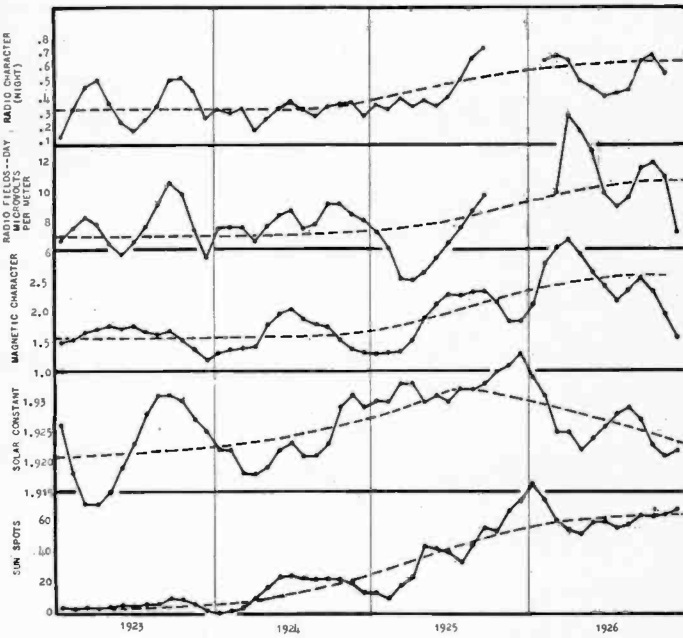


Fig. 53—Intercorrelation of Various Factors Affected by Solar Disturbances —Comparison of "Four Weekly" 12-Week Moving Averages.

activity for a complete cycle, there is only one set of consistent radio data in existence, that taken by Dr. Austin of the Bureau of Standards. Recently he has shown high correlation existing between the trends of radio transmission from Nauen for the years 1915 to 1926 inclusive and corresponding sunspot numbers.

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REPORT OF THE CHAIRMAN OF THE COMMISSION ON RADIO WAVE PROPAGATION,* INTERNATIONAL UNION OF SCIENTIFIC RADIO TELEGRAPHY

By

L. W. Austin

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

The work of the Commission on Radio Wave Propagation appointed at the last General Assembly of the International Union of Scientific Radio Telegraphy at Brussels in 1922, covers such a wide field of investigation that it seems best to confine this report to a discussion of the subjects on which the various workers are not yet entirely in accord, or those in which the conclusions are not yet definitely established.

A considerable portion of the work to be discussed has not been done directly by the Union and some of the investigations mentioned have been carried out in countries not connected with the organization.

Theory of Wave Propagation

The theory of the propagation of radio waves has been greatly developed since the last meeting of the Union, through the work of Larmor[1] on ionic refraction, followed by that of Appleton and Barnett[2] in England, and Nichols and Schelleng[3] in America who have independently developed a theory of the action of the earth's magnetic field on the phase velocity of radio waves in an ionized medium such as the Kennelly-Heaviside layer is assumed to be.

From this it follows that the ionized layer acts in the same manner as a quartz crystal in optical phenomena; that is, there is a rotation of the plane of polarization for transmission in the direction of the magnetic field, and double refraction for transmission at right angles to it. If the carriers in the ionized layer are electrons, as seems most probable, it also follows that there should be an absorption band for a wavelength of about 214 m. A. Meissner[4] in Berlin has looked for this absorption band experimentally, but was unable to discover any large increase in absorption in this

* Original Manuscript Received by the Institute, January 5, 1928.
* Presented at the International meeting of the Union in Washington October, 1927.
Note: References will be found at end of paper.

exact neighborhood. It is known, however, that the daylight range of stations of wavelengths between 150 m. and 250 m. is less than the ranges at considerably longer or shorter wavelengths.

Field Strength Measurements

Absolute field-intensity measurements at distances too great for the use of simple measurement instruments, thermoelements, etc., appear to be among the most difficult in physics. In practically all the methods used a comparison is made between the signal to be measured and an artificial signal from a local high-frequency oscillator. This is true even in the long-wave measurement system of the Bureau of Standards; for though in this case the direct comparison is made with artificial audio signals, the calibration for absolute determinations must be carried out by means of a local radio-frequency oscillator.

The great difficulty in all the various methods used lies in the production of a sufficiently weak known local signal in the antenna for comparison with the signal to be measured. The specific possibilities of error, in addition to the difficulties of definite attenuation of the artificial signal by resistance nets, current transformers, or mutual inductances, lies in the possible presence of false couplings either due to inductance or capacity, which can in general be removed only by careful shielding. It is to such errors in calibration, which often are most difficult to detect, that the large differences (sometimes more than five to one) in the results obtained by various experimenters, are almost certainly due.

It would seem that a direct comparison of the different types of apparatus in measuring the same signal offers the best means of decreasing the possibility of error. Such comparisons[5] have already been made between the long-wave apparatus of the Radio Corporation of America, the Bell Telephone Laboratories, and the Bureau of Standards; and it seems desirable to carry on such intercomparisons of all the types of field-strength measurement apparatus at present in use.

Signals at Moderate Distances (below 1500 km.)—The daylight work by Austin[6] (Brant Rock and Arlington experiments) indicated a regular falling off in field strength with the distance over salt water for wavelengths of 1000 to 4000 m. which could be approximately expressed by the Austin-Cohen transmission formula.

The recent daylight experiments of Hollingworth[7] in England and Scotland on Ste. Assise (FT), wavelength 14,000 m., which were carried on mostly over land have shown, on the other hand, evidences of interference between ground and reflected waves resulting in well-marked maxima and minima of intensity with increasing distance; so that the receiving field at Aberdeen at a distance of 1000 km. was about three times as great as at Manchester at 650 km.

The measurements which have been made in Washington on the transatlantic stations of the Radio Corporation of America in New Brunswick, N. J., (281 km.), Tuckerton, N. J., (251 km.) Rocky Point, L. I., (435 km.) and Marion, Mass., (660 km.), all of which have wavelengths between 11,500 and 16,100 m., have not shown any definite periodic change of intensity with distance at least in the daytime.[27] At night there is plenty of evidence of interference as the signals from the stations at 435 km. and 660 km. have fallen with considerable regularity far below their day values during the past summer, while those from the two stations at 281 km. have risen slightly at night or remained fairly constant. The conditions of experiments are of course somewhat different from those in England, inasmuch as the signals are measured at one point and the transmitting stations at the various distances transmit on somewhat different wavelengths. Nevertheless, since these experiments, some of which have been continued over many years, indicate a regular falling off of intensity with the distance in the daytime, it would seem that they must be held to be in disagreement with the results of Hollingworth. Therefore it would seem very desirable to carry out further measurements in other places, some of which might well be on signals over water as over land of different characteristics.

The English committee[27] has reported the following in regard to the differences in the behavior of transmitting stations at distances between 300 km. and 1000 km. and between 100 km. and 300 km.

Distances 300 to 1000 km.—(1) No abnormal polarization during daylight in summer. (2) A definite sunset cycle lasting 2 to 3 hours. (3) Night values in general very different from day values. (4) No marked effect of magnetic storms.

Distances 100 to 300 km.—(1) Abnormal polarization always present. (2) No sunset cycle. (3) Night and day values nearly the same. (4) Distinct magnetic storm effects.

The Washington observations[27] on long-wave stations have given the following corresponding results in the same ranges: Between 300 km. and 1000 km. (1) Insufficient observations. (2) Fairly regular sunset cycle of reception. (3) Night values very different from day. (4) Distinct solar and magnetic effects, the same as at shorter distances. Between 100 km. and 300 km. (1) Abnormal polarization usually present day and night. (2) No regular sunset reception cycle. (3) Night values generally not very different from day values, at least in summer. (4) Distinct solar and magnetic effects.

The English and American observations are therefore in agreement on (2) and (3) at the longer distances, while at the shorter distances there is general agreement in all four items. The only positive disagreement is in respect to (4) at the longer distances. In regard to the effect of magnetic storms on transmission at distances of from 300 to 1000 km. the French observations at Meudon on the transmitting stations at Bordeaux and Nantes (310 and 360 km. distant, respectively) are in agreement with the British and at variance with the American observations. Our impression is, however, that the conclusions which can be drawn from the American observations are somewhat less positive in regard to all these statements than those expressed in the British report. There also seems to be greater variability in the signals in America during the summer months than in England, while there is at the same time no very great increase here in variability as winter approaches, such as is indicated by the English report although there is a considerable general increase in strength of signal. The maximum variability in summer may amount to 40 per cent in contrast to the 10 per cent variability of the English observations. Below are given the average percentage variations from the monthly means of WII for June, September, and December, 1925, and these may be compared with the average percentage deviations for the year of three long-distance stations received in Washington. It is seen that the American station at only 281 km. has almost the same variability of day signals as the stations at great distances.

New Brunswick, WII, Distance 281 km.

1925	Variability of 10 A. M. Signals
June	17.6 per cent
Sept.	15.6 per cent
Dec.	19.4 per cent

Average Variability for the year—10A.M. signals	
Bordeaux (LY)	19.5 per cent
Ste. Assise (FT)	20.0 per cent
Buenos Aires (LPZ)	19.0 per cent

Another effect, which has been observed in America but apparently not in the other countries of the Union, is the tendency for signal intensities to rise both by day and night when the temperature falls.[8] This has been especially noticeable in the case of long-wave stations at distances under 1000 km. during the extreme cold of the so-called cold waves when the intensity often rises to two or three times its average strength.

Field Intensity Measurements at Great Distances.—Long-continued signal measurements at great distances and on the longer wavelengths have been carried out by a number of observers in recent years. Among the more important of these are the observations of Mesny[9] in France, the Marconi Co.[10] in England, Baumler[11] in Berlin, the Indian Post Office[12] in India, and the American Telephone & Telegraph Co.,[13] the Radio Corporation[27] and the Bureau of Standards[14] in America. The Marconi Co.[10] has also sent an experimental expedition around the world, and the French Navy has carried out measurements on a voyage from France to Tahiti.[15]

This mass of observations, while it has revealed many interesting phenomena and has suggested many interesting problems, has brought out the fact that the results obtained by the different methods of measurement are not by any means always in accord, and that even with the same type of apparatus there are dangers of differences in results when it is used under slightly different conditions.

It also appears that the actual variations in signal intensity from day to day, and month to month renders difficult the comparison of observations which are not continued throughout long periods of time.

Ultra Short Wavelengths.—Ultra short-wave intensity observations can hardly as yet be considered in general to be reduced to a quantitative basis. The Bell Telephone Laboratories[16] have, however, developed measurement apparatus for this purpose which in expert hands is capable of fairly exact measurements.

The changes in the signal intensity with changing wavelength and hour of the day are so great, however, that even with purely qualitative observations much information has been gained regarding the behavior of these high frequencies.

The observations of Taylor and Hulburt[17] covering several years, and the work of various members of the French Committee both in France and in the colonies have thrown much light on the subject. The observers are in general in agreement that the short-wave signals after being heard for a moderate distance from the transmitting station, become inaudible over distances depending on the wavelength, and then at greater distances are again heard with great intensity. The only scientific observations contradicting this have been made by Captain Staut[27] in Senegal. This absence of skip distance also seems to be confirmed by the commercial stations in tropical Africa.

The whole matter of the variation in strength, varying skip distance, etc., with changing wavelength, hour and season, may apparently be explained broadly as due to varying penetration in the Kennelly-Heaviside layer, and its varying height.

Transmission Formulas.—Empirical formulas for transmission on the longer waves have been given by Eckersley[10] (based on the theoretical work of Watson) and by Austin and Cohen[6] (based on the Hertzian expression for the field intensity at some distance from an oscillator with the addition of an empirical exponential absorption term). Fuller[18] and Espenschied, Anderson and Bailey[13] have also given formulas in which different values have been given to the constants in the exponential term of the Austin-Cohen formula.

Since the discovery of the great variability of the signal intensity at different times, the general interest in transmission formulas has been much diminished, as it is evident that any formula laying claim to general accuracy would be so complicated that it could hardly be of practical value even if our knowedge of the subject were sufficient to derive it. The most that can be claimed for any of the formulas thus far suggested is a very rough approximation to the actual results averaged over very long periods. Thus far there has been no attempt to produce a formula applicable to the ultra short waves.

Evidences of Reflection or Refraction from an Ionized Atmospheric Layer

Dr. Smith-Rose and Mr. Barfield[19] have made experiments in England on the angle of the wave front of the received wave. The first experiments, made on very long waves, showed that the wave front was practically vertical, in agreement with the earlier work of Austin.[20] This may be explained as due to the action of the earth as a reflector, due to its high conductivity, which neutralizes the effect of any horizontal components in the electric field of the arriving wave. When these experiments were repeated at broadcasting wavelengths (300–500 m.), a considerable deviation from the vertical was found.

Observations were also made at the same time on the relative strengths of the signals on vertical and closed coil antennas. These measurements on a 386 m. wave at a distance of 124 km. showed that the downcoming wave might make any angle between 13 deg. and 34 deg. with the vertical. 34 deg. would correspond to a height of the reflecting layer of 88 km., which is in agreement with the estimates from other measurements, while the smaller angles might be due to multiple reflections, or perhaps reflections from another layer.

The measurements also indicate that the intensity of the downcoming wave is of the same order as that of the ground wave.

Further research into the nature of the electromagnetic field at a receiving station has been carried out in England by Appleton and Barnett.[21] Their experiments were based on the fact that fading is greater on a loop than on a vertical antenna, since the horizontal component of a wave coming down at an angle would affect a loop, but would not affect a vertical antenna. From the ratio of the fading effects observed on the loop and on the vertical antenna it is possible to calculate the angle of the downcoming wave. Experiments between London and Cambridge gave an angle of 60–70 deg. with the ground. Experiments between Bournemouth and Oxford, in which the wavelength was gradually changed from 385 m. to 395 m., gave seven successive interference maxima and minima. This would indicate a reflecting layer at a height of from 80 to 90 km. In later experiments photographic records of the signal maxima and minima were obtained. In this case observations were continued throughout the night and showed that the height of the reflecting layer increased gradually from soon after sunset until just before dawn. After sunrise it fell rapidly and the intensity of the downcoming wave gradually diminished until it was inappreciable.

In order to determine the attenuation of the ground wave for comparison with the wave reflected from the ionized layer, day measurements on the variation of signal intensity with distance have been made in England by G. A. Ratcliffe and M. A. F. Barnett[22] on the transmissions from Daventry (1600 m.) and from 2LO (260 m.). These observations were in close agreement with Sommerfeld's theory of over land transmission for distances beyond 10 wavelengths, though deviations from the theory were found at shorter distances. In the calculations the ground resistivity, previously found by Smith-Rose and Barfield[19] was used. These experiments in conjunction with the fading experiments already described, indicated a refraction attenuation coefficient in the reflected wave of 30 per cent.

Work on the polarization of radio waves has also been carried out recently in America by Pickard[23] and by Alexanderson[24] who, using tilting rods and horizontal and vertical receiving antennas, have found for the shorter ranges of wavelength, that the horizontal wave component at a distance may become much stronger than the vertical component. They have also found that this effect is quite independent of the horizontal or vertical position of the transmitting antenna. Mr. Alexanderson also reports periodic changes in the ratio of the horizontal and vertical fields, as the distance is increased. These correspond to the interference fringes of Appleton.

Extensive experiments on ultra short waves at great distances by Taylor and Hulburt,[17] based on the skip distances of signals at different wavelengths both by day and night, and experiments by Breit and Tuve[25] employing 70 m. modulated continuous waves in daylight at a distance of only 8 miles and using an echo effect, have given further information on the height of the ionized layer.

All the observations taken together indicate that the paths of the waves in the upper atmosphere are lower, the longer the wavelength; that they are lower in the day time than at night; and lower in summer than in winter. Taylor and Hulburt's observations indicate heights for ultra short waves on winter nights of more than 500 km; and for summer nights of roughly 300 km., with the corresponding day values considerably lower. Breit and Tuve find for the 70 m. wave in summer, daylight heights of 80–230 km. Appleton's results in the broadcasting range give night heights of about 90 km. in summer. In a recent letter to *Nature*[26] he reports winter night heights of 250–350 km., falling to 90 km. at daylight. This, he thinks, may indicate a second layer.

Apparent Direction Variations in Radio Signals

The British, French and American committees[27] have all carried on extensive observations covering several years on the variations in apparent direction of transmitting stations.

Effect of Wavelength on the Variations.—Leaving out of account the ultra short waves and considering only those from 300 m. upwards, the English committee reports no certain variations in the amount of deviation due to wavelength, although differences are observed in the behavior of certain stations, which may, however, be due to the character of the ground over which the signals pass. The French and American observations are not entirely in agreement with this, as both have found what has seemed to them sufficient proof of a greater tendency to variation as the wavelength is increased. In this connection the French committee reports that the observations at Meudon show for Bordeaux, distance 510 km., at a wavelength of 23,400 m. general weekly maximum deviations of 20 deg. to 25 deg. in some cases even going to 90 deg.; while at 18,900 m. the weekly maxima have ranged between 10 deg. and 15 deg. In the case of Nauen, distance about 900 km., the 13,000 m. wave gives maximum weekly deviations of 7 deg. to 15 deg. and the 18,000 m. wave 0 deg. to 30 deg. There is, I think, general agreement that slight changes in wavelength often produce great changes in bearing variation.

Effect of Distance.—According to the English observations, for distances up to 15 or 20 miles, night variations are slight and not very different from those observed by day. Above 30 miles overland large variations are observed at all wavelengths, which increase up to about 150 miles. Over sea these respective distances are increased by approximately three times. For still greater distances there seems to be a tendency for the variations to decrease, until at 3000 miles or more, the variations amount to only about 3 deg. both day and night. American observations on very long-wave European stations indicate night variations of 6 deg. to 12 deg. with day variations of 2 deg. or 3 deg. The French report mentions a tendency for night variations on the long waves to continue over considerable periods on the same side of the true bearing.

The Cause of the Variations.—It seems to be now generally accepted that night variations are caused by a wave which comes down at an angle from the upper atmosphere with its wave front so tilted that the lines of magnetic force cut the top and bottom as well as the sides of the direction-finding coil. Proof of a descending wave of this character has already been given under the discussion of the ionized layer, and recent English experiments have shown that night variation is almost entirely eliminated by a direction-finder composed of four vertical Hertzian rods with connections from the breaks at their middle points to the observing house in the center of the system where they are connected to the crossed primaries of a Bellini Tosi goniometer. This is a development of the Adcock system and is equivalent to a rotating loop without top or bottom.

Experiments of the English committee have also shown that the shape of the transmitting antenna plays no important part in the production of night direction deviation.

Solar Activity, Magnetic Storms and Radio Phenomena.

In America the work of Espenschied, Anderson and Bailey[13] has shown a connection between magnetic storms and transatlantic radio transmission, causing frequently a reduction of signal at night and probably a slight increase in the daytime.

More recently Pickard,[28] using his own observations in the broadcasting band of wavelengths as well as the observations of others, and employing moving and periodic averaging methods for the analysis of his material, has produced striking evidence of the dependence of radio phenomena on solar activity. His work indicates a decrease in night signal with increasing sunspot numbers at broadcasting wavelengths and an increase on the ultra short waves.

Austin,[29] using field intensity observations made at the Bureau of Standards since 1915, has shown that the long wave transatlantic daylight signals when averaged by months follow in a general way the sunspot numbers with the changing eleven-year cycle. This conclusion can be stated only as probable from 1915 to 1922, on account of possible errors in the signal measurements; but since the beginning of 1922, the increase of signal intensity with increasing solar activity seems certain.

In England, a relationship between magnetic storms and signals has been noticed on stations at a distance of 100 km. to 300 km., but not at greater distances. In France no relationship has been observed either with solar activity or magnetic storms.

Some of the questions which have been suggested by the experimental material are:

1. Does transmission from east to west differ from that from west to east, as indicated by the results of the Marconi expedition?
2. Is there a limit in wavelength beyond which transmission over land is practically identical with transmission over water?
3. Does the over water transmission in certain parts of the world differ materially from that in other parts?
4. Is there a difference in transmission along and across the earth's magnetic field?
5. What are the causes of the ionization of the reflecting layer?
6. Do the waves above a certain frequency fail to return to the surface of the earth?
7. There also remains the question of the amount of correlation betweeen radio transmission, solar activity, and variations in the earth's magnetic field; and how this may differ at various wavelengths and in various portions of the earth.

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DISCUSSION ON LONG DISTANCE RADIO RECEIVING MEASUREMENTS AT THE BUREAU OF STANDARDS IN 1925* (L. W. Austin)

B. H. J. Kynaston: G. W. Pickard[1] in commenting on K. Sreenivasan's discussion[2] of Dr. Austin's paper states that the observations

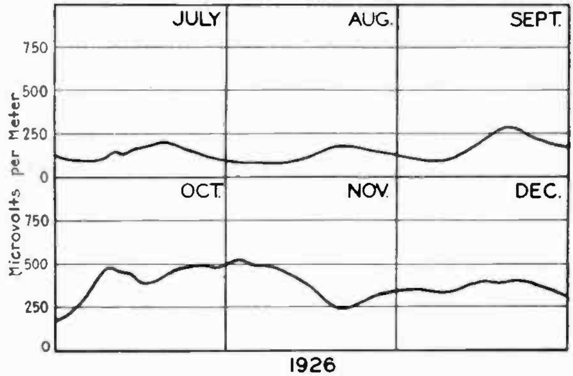

Fig. 1

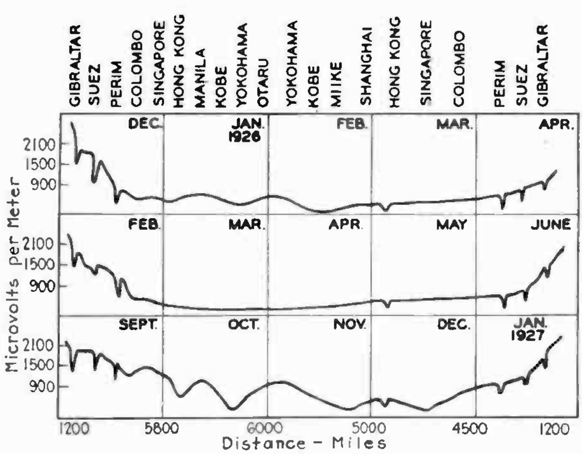

Fig. 2

on Madras (Fort) Radio are too brief for a good comparison with terrestrial and cosmic elements. My own observations taken in the Far East on Rugby's transmissions cover rather longer periods

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* Proceedings of the Institute of Radio Engineers, 14, 663: 1926.
[1] Proceedings of the Institute of Radio Engineers, 15, 539: 1927.
[2] Proceedings of the Institute of Radio Engineers, 15, 155: 1927.

than those given by K. Sreenivasan and may perhaps be useful to other investigators.

The curve in Fig. 1 is for moving weekly averages of observations of Rugby's midnight (G.M.T.) transmission on 18,750 metres. It is interesting to note that the curve for October and November shows intensity changes similar to K. Sreenivasan's observations of Madras.

The various curves given in Fig. 2 were taken during three voyages from Liverpool to Japan and back (via Suez) and cover a period of fifteen months, the time and wavelength of the transmission being the same as in Fig. 1. Many of the sudden and rapid changes in the curves were obviously due to screening by nearby land. This was most noticeable as would be expected in places like Gibraltar, Perim, Suez, and in the Formosa Channel between Hong Kong and Shanghai. In all these places large masses of land are on both sides of the ship.

NOTES ON THE DESIGN OF RADIO INSULATORS*

By

T. Walmsley

THE purpose of these notes is to amplify and apply existing knowledge upon the design of some types of radio insulators, used for transmission purposes. There seems to be no general appreciation of the fact that better results can usually be obtained by proportioning insulators correctly than by increasing the quantity of material used. Increased thickness of a dielectric, having a high dielectric constant, frequently causes a reduction in the breakdown voltage of the insulator. In illustration of this contention, the old experiment of introducing a sheet of glass into an air gap between two electrodes is cited. Previous to the intrusion, the air gap successfully resists the application of a certain maximum potential difference, but as soon as the glass plate is inserted, the air space breaks down.

Problems of design may be conveniently considered under the main headings: (1) quality of material, (2) shape and arrangement of material.

Quality of Material

Under the first heading, attention is directed to the mechanical and electrical properties, and the behavior of the material under sustained mechanical and radio-frequency electrical stresses, applied separately and simultaneously.

The quality of porcelain and glass has, during the past few years, been improved considerably. The most recent tests on glass made by the author show that a potential gradient of 8,000 volts r.m.s. per inch at radio frequencies can be taken by a suitable sample for long periods. Similar samples tested by the National Physical Laboratory for cracking compressive loads gave a minimum value of 13.8 tons per sq. in. The samples were in the form of circular disks 3.0 in. diam., 1.62 in. thick, which for the electrical tests had been previously soaked in pure water.

Porcelain shows about the same results as glass, both in compression and under the application of radio-frequency electrical differences of potential. Glass does not appear to stand the test of time so well as porcelain, but as far as the author is aware

* Original Manuscript Received by the Institute, September 21, 1927

exhaustive tests upon different qualities of glass have not been made to decide this point.

The tensile strength of glass and porcelain is somewhat uncertain. Porcelain, in the author's view, is more reliable than glass. Tubes of porcelain having a proof load of 0.6 tons per sq. in. are used at Rugby Radio Station for aerial suspension. The breaking tensile load is known to be considerably in excess of this value.

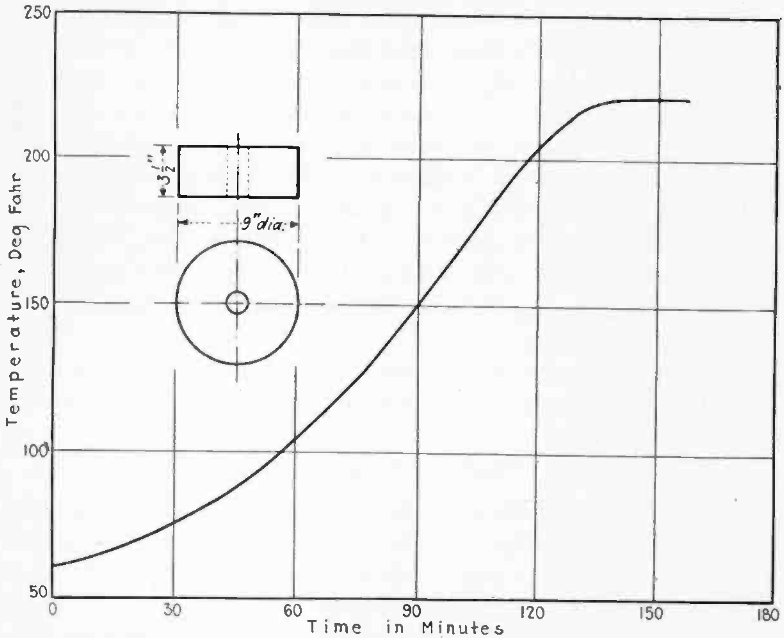

Fig. 1a—Material—Porcelain. Distance between Electrodes—$3\frac{1}{2}$ in. Voltage (R.M.S.)—15,000. Frequency per sec.—50,000. Atmospheric Temperature—50 deg. F.

Makers of a certain propriety type of glass claim a tensile breaking load of over 0.95 tons per sq. in. for their products. The figures, however, are based upon tests onvery small sections. The flexural mechanical strength of suitable types of porcelain is superior to that of glass. In addition to the usual electrical, mechanical, and moisture absorption tests to ascertain the quality of material, a heating test to show the behavior of the material under the application of radio-frequency potential gradients comparable to but more severe than the working conditions of the insulator, is considered essential. It is frequently asserted that a power factor test made with low voltages under ordinary laboratory conditions, by enabling the energy loss to be ascertained, will yield all the information required. The assumption underlying this contention is that the dielectric constant does not change with increase of potential gradient. It frequently happens, however, when an insulator has not been thoroughly vitrified, that the material is not homogeneous. This is particularly true of solid insulators having minimum dimensions of several inches.

Pockets of insufficiently vitrified material exist within the insulator, surrounded by well-vitrified material. The ordinary power factor test may not disclose any great electrical imperfection, but the application of an intense electric field at radio frequency produces local heating. The moisture of the imperfectly vitrified portion is converted into steam, which, if confined within the boundaries of the well-vitrified walls, causes high mechanical

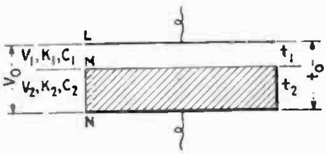

Fig. 1

pressures internally. In consequence the insulator cracks. A typical curve of the temperature rise of an insulator under the application of radio frequency difference of potential is shown in Fig. 1a.

The fall in temperature when the insulator had attained a temperature slightly in excess of that of steam at atmospheric pressure suggests that the vapor in this case was able to escape.

Shape and Arrangement of Material

Several principles are involved in deciding upon the shape of material. Consider Fig. 1. LM and MN are two elementary condensers in series, having a dielectric constant, K_1 and K_2; capacity C_1 and C_2; thickness t_1 and t_2 respectively.

The potential difference across the two condensers in series $= V_0 = V_1 + V_2$

The potential gradient across

$$LM = \frac{V_0 K_2}{K_1 t_2 + K_2 t_1}$$

When the dielectric is air, the potential gradient across $LM=$

$$\frac{V_0K_2}{t_2+K_2t_1}$$

In the limit when the thickness of air dielectric $=0$, that is, when the tap plate is just touching the solid dielectric, the potential

$$\text{gradient}=\frac{V_0K_2}{t_2}. \tag{1}$$

This simple expression (1) enables an explanation to be given of the cause of sparking between the surface of a loosely fitting

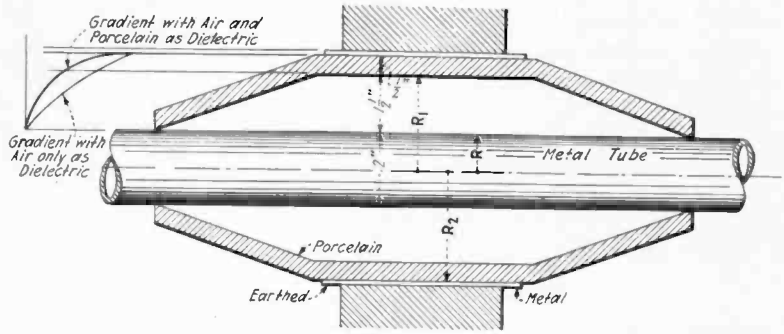

Fig. 2

metal plate and insulator, since the potential gradient across the minute air gap is K_2 times the average potential gradient across the plates. Many cases of breakdown of insulators are attributable to the ionization set up in small air gaps between conducting and insulating surfaces. The cure obviously lies in a correct design of insulator, but the application of graphite to the loosely touching surface is frequently productive of beneficial results.

The type of insulator shown in Fig. 2, frequently found in radio transmitting stations, is bad.

Assuming the material to be porcelain having a dielectric constant K of 5, and regarding the potential difference between internal tube and metal bush as unity, the average potential gradient across the $1\frac{1}{2}$-inch air gap is represented by 0.64 and across the porcelain by 0.078. The average potential gradient in the air gap when the porcelain is removed $=0.56$. Thus the porcelain has caused the average potential gradient in the air gap to be increased by 15 per cent. The criterion of design is not the average but the maximum potential gradient within the space. This occurs at the surface of the inner conducting tube and is approximately equal to

$$\frac{V_0 K}{R}\left[\frac{1}{K \log_e \dfrac{R_1}{R} + \log_e \dfrac{R_2}{R_1}}\right]$$

where R, R_1, R_2 = the radii of inner conducting tube, inside of insulator and outer tube (Fig. 2).

The application of this formula shows that the potential gradient at the surface of the inner conducting tube is increased

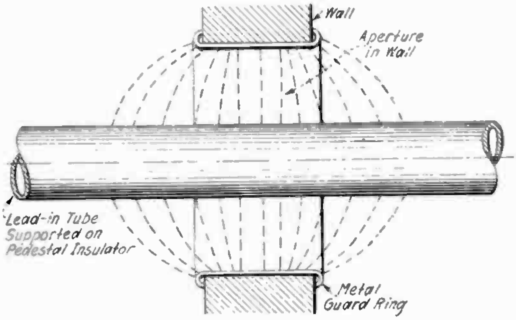

Fig. 3

by about 15 per cent by the introduction of the porcelain bush. Matters could be improved by filling the air space between tube and insulator with a high grade insulating oil, thereby increasing the breakdown voltage and reducing the voltage gradient in the space.

For a lead-in insulator from aerial to transmitter loading coils, an almost ideal arrangement is that shown in Fig. 3.

A similar arrangement for leading high-tension cables into sub-stations and power houses is used on the continent of Europe. Lack of protection against adverse weather conditions is, however, a great disadvantage of this type of lead-in. The aperture might be replaced by a glass or porcelain disk, Fig. 4.

Surface Leakage

This would not greatly disturb the stress distribution. The question of surface leakage, however, must be considered. In the following arguments

R_l = radius of disk on outside diameter of tube.
R_0 = outside radius of disk.
P = a co-efficient denoting surface resistance constant of the material considered.

Then surface resistance of ring δr wide at distance r from center (Fig. 5.) $= \frac{\delta r}{2\pi r} \cdot P$

therefore total surface resistance of disk $= \int_{R_l}^{R_0} \frac{\delta r}{2\pi r} \cdot P = \frac{P}{2\pi} \cdot \log_e \frac{R_0}{R_l}$

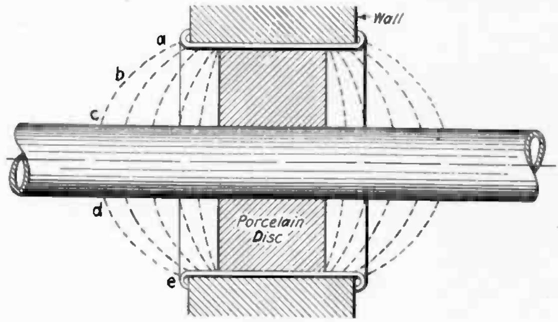

Fig. 4

The correct ratio $\frac{R_0}{R_l}$ for maximum spark over voltage in air is about 3. Curve 1 shows the rate at which the leakage resistance increases as the ratio $\frac{R_0}{R_l}$ increases from 3 to 27. Thus, although the radius of the disk is increased from 3 to 9 times the radius of the tube, the leakage resistance is only doubled. For a threefold increase in leakage resistance, it would be necessary to have a ratio of $\frac{R_0}{R_l} = 27$

In manufacturers' catalogues, leakage length between electrodes is usually quoted. It does not appear to be recognized sufficiently that length alone, without regard to the leakage area, has little value. The subject will be discussed further when the question of sheds is reviewed. From the figures just quoted two conclusions are formed:

(1) The installation of large-sized glass plates for lead-in windows does not necessarily greatly increase leakage resistance.

(2) An insulator following the contour lines of *abcde* in Fig. 4 will offer a greater leakage resistance than a flat disk of equal diameter.

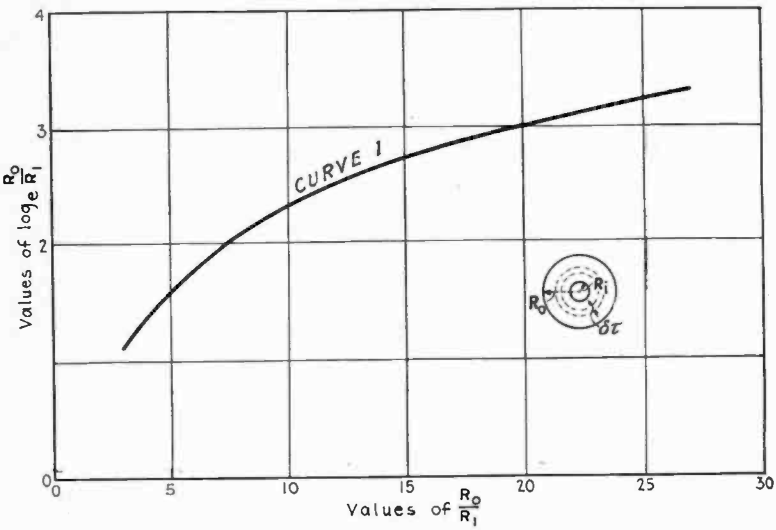

Fig. 5 Curve Showing Relation Between R_o/R_i and $\log_e R_o/R_i$.

Dome Insulators

A natural development from conclusion (2) is the insulator shown in Fig. 6(a), the dome being attached to the walls or glass plate by bolted flanges. A simple insulator which permits a better mechanical arrangement than Fig. 6(a) is that shown in Fig. 6(b). It will be observed that the insulator is placed inside the building. In designing this type of lead-in insulator, the size of tube and aperture would first be decided.

The formulas given by Peek[1] will give sufficiently accurate results:

$$-g_v = g_0\left(1 \div \frac{0.301}{\sqrt{R_i}}\right) \text{ also } g_v = \frac{E}{R_1 \log_e \frac{R_0}{R_i}} = g_0\left(1 \div \frac{0.301}{\sqrt{R_i}}\right)$$

where $g_0 = 30$ kilovolts per centimeter.

[1] "Dielectric Phenomena in High Voltage Engineering."

g_v = gradient in volts per cm. at surface of tube at visible corona.

E = maximum peak voltage between electrodes.

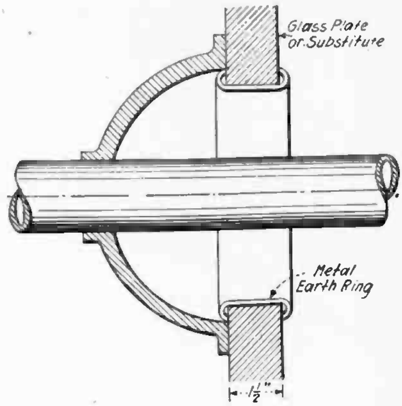

Fig. 6a

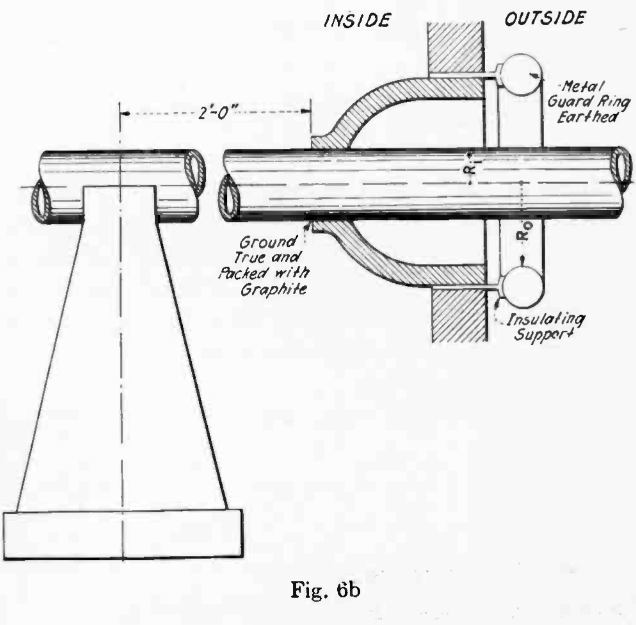

Fig. 6b

SHEDS

Although the ideal insulator has smooth surfaces following the contour lines of stress, sheds are frequently used to increase the leakage length.

The sheds should preferably be part of the main body, and *not* cemented on. Many cases have recently been brought to the

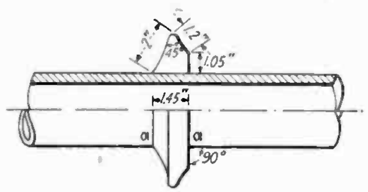

Fig. 7

author's attention of breakages of aerial insulator drip rings due to heating of the cement.

Cement is an imperfect insulator for radio-frequency voltages. In thin layers where the voltage gradient is low it may be used.

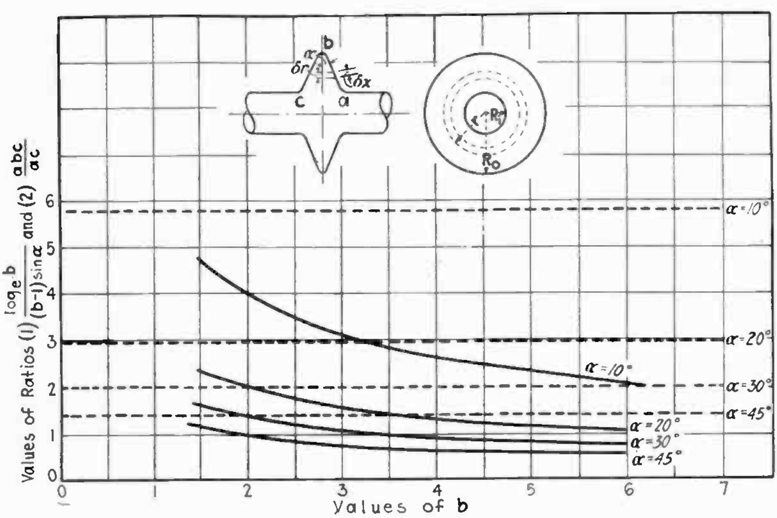

Fig. 8—Curve Showing Relation Between (1) b and $\log_e b\ /(b-1)\ \sin\alpha$ shown thus ——— (2) b and ratio abc/ac shown thus - - - - - -

For example it is used without ill effect, between the compression insulators supporting the Rugby masts. It connects the metal caps of the aerial supporting insulators to the porcelain insulator. The metal cap, however, completely encloses the cement, and guard rings protect the insulators. A porcelain drip ring (Fig. 7) cemented along *a a* of a tube insulator will have no such protection and will heat up if subjected to a certain potential gradient. Even though the ring is an integral portion of the body the extra leakage resistance cannot be measured simply by taking the differences between the lengths *abc* and *ac*.

In Fig. 8 a symmetrical ring is shown as an integral part of a tube insulator. To ascertain the value of the surface leakage resistance of the ring in comparison with that due to the plain tube of the same width, i.e., to compare the leakage along *abc* with *ac*, consider a small strip δx

$$\text{Surface leakage resistance of } \delta x = P\frac{\delta x}{2\pi r} = P\frac{\delta r}{2\pi r \cos\alpha}$$

$$\text{therefore total surface resistance of ring} = \frac{2P}{2\pi\cos\alpha}\int_{R_i}^{R_0}\frac{dr}{r}$$

$$= \frac{2P}{2\pi\cos\alpha}\log_e\frac{R_0}{R_i}.$$

Also surface resistance of cylindrical path *ac* with ring removed

$$= P\cdot\frac{ac}{2\pi R_i} = \frac{2P(R_0 - R_i)\tan\alpha}{2\pi R_i}$$

$$\text{therefore}\quad \frac{\text{Surface Resistance of ring leakage path}}{\text{Surface Resistance of cylinder leakage path}}$$

$$= \frac{R_i\log_e\frac{R_0}{R_i}}{\cos\alpha(R_0 - R_i)\tan\alpha}$$

$$= \frac{R_i\log_e\frac{R_0}{R_i}}{(R_0 - R_i)\sin\alpha}$$

$$= \frac{\log_e b}{(b-1)\sin\alpha}\quad\text{where } b = \frac{R_0}{R_i}$$

Curve 2 shows this ratio for various values of b and α. It also shows the *apparent* ratio of the resistance path *abc* to *ac* when no allowance has been made for the increased area of the ring. It will be observed that in some cases, the presence of sheds actually decreases the value of surface resistance.

For example, when $\alpha = 30$ deg., the surface resistance ratio of ring leakage path and cylinder leakage path when b is greater than

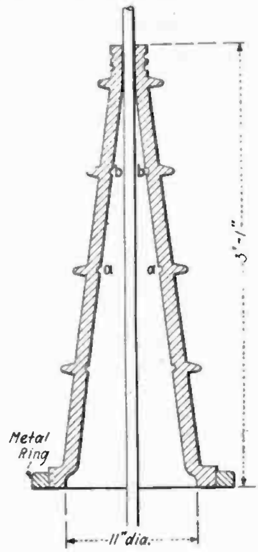

Fig. 9

3.5 is less than unity. It is thus obvious that corrugations on insulators, to be effective, must have a low value of α, i.e., they must be narrow. Further, the ratio $b = \frac{R_0}{R_i}$ must be low. It may, of course, be argued that sheds and corrugations keep portions of the insulator dry in wet weather. The author's experience, however, is that fog and snow are more troublesome than rain. Moreover, tube insulators supporting aerials are almost horizontal. In this position the rings offer little shelter from rain, although they break up the stream of water that tends to flow along the tube. This ability to break up the stream is a dubious advantage since it prevents natural washing of the tube. Sheds on dome insulators, the main body of which follow closely the lines of electric stress, should be avoided if possible. Their effect is to produce local concentrations of electric stress which may cause flashover. In this connection some account of tests made upon a pedestal porcelain insulator by the author, for the purpose of ascertaining the effect of grooves are of interest. A steel tube $\frac{7}{8}$ in. external diameter was passed through the neck and along the axis of the insulator (Fig. 9). The broader extremity of the insulator was surrounded by a metal cap, earth connected. An increasing difference of potential at 16,000 cycles per second was then applied between the bar and cap. When about 50,000 volts r.m.s. had been reached brushing around the groove *aa* inside the insulator was observed. This finally resulted in an arc over at 54,000 volts r.m.s. *inside* the insulator, the arc travelling down the insulator to the metal cap.

The internal $\frac{7}{8}$ in. pipe was then covered by a steel pipe $1\frac{1}{4}$ in. external diameter and a difference of potential again applied. Brushing was observed around the groove *bb*, higher up the insulator than previously, but a flash-over did not occur until 90,000 volts r.m.s. (127,000 volts peak value) had been reached. The breakdown was between rod and guard as far as could be observed. The tests illustrate two main facts: (1) the necessity of correctly proportioning the size of axial conductor to diameter of guard ring, (2) the necessity of making the insulator with ungrooved internal walls. Due to its location within porcelain, the groove was subjected to an increased electric stress.

This would account for the corona. The insulator, previous to the tests, had been soaked in water for several hours.

THE MEASUREMENT OF CHOKE COIL INDUCTANCE*

By

C. A. Wright and F. T. Bowditch

(Research Laboratory, National Carbon Company, Inc.)

Summary—*The investigation described has emphasized the facts that:*

(1) The inductance of the choke coil depends upon the degree to which its core is magnetically saturated because of direct current flowing through its winding.

(2) With a given direct current flowing through the winding of a choke coil, the inductance varies to a marked extent with the magnitude of the alternating current flowing through the winding. Methods of measurement which do not take into account or measure the magnitude of the alternating current are, therefore, unreliable.

(3) The inductance for given conditions may be determined from the saturation curve of the coil. It is determined by the average slope of the saturation curve over the range within which the current varies.

Three modifications of the ammeter-voltmeter method of measuring inductance are presented:

(1) The circuit used in the first modification of this method is applicable where only a few approximate measurements are to be made and where simplicity of connection is of the greatest importance.

(2) The second modification of the method involves simplicity of connection and permits of greater accuracy of measurement than does the first modification, but where a large number of measurements are to be made, it involves inconvenience of manipulation.

(3) The third modification of the ammeter-voltmeter method of measuring the inductance of choke coils involves the use of apparatus not always available, but permits of accuracy of measurement and convenience of manipulation.

Introduction

There has been a considerable amount of discussion recently concerning the measurement of the inductance of the choke coils used in *B* power circuits. The methods employed by various investigators do not give comparable results. For example, one company manufacturing choke coils proves by measurements that one of its coils has an inductance of 25 henrys while carrying 50 milliamperes of direct current, while another such company reports a value of about 12 henrys for this same coil, carrying the same direct current. Other investigators report other values, differing from the above and from each other.

The present study of the measurement of choke coil inductance has therefore been undertaken in order to develop a reliable method suitable for the comparative rating of such coils. This paper presents three modifications of such a method, together with a series of measurements exemplifying them. The reasons for the variations noted above are also developed.

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The Function of a Choke Coil in a Filter Circuit

A choke coil consists of a number of insulated turns of wire, wound around and insulated from an iron core. Such a coil may be designed to present a very high impedance to the flow of alternating current, while it provides simultaneously a comparatively low resistance to the flow of a steady direct current. For example, one well-known choke coil under certain typical conditions offers an impedance of over 15000 ohms to the passage of 120-cycle alternating current, and, at the same time, has a direct-current resistance of only 350 ohms.

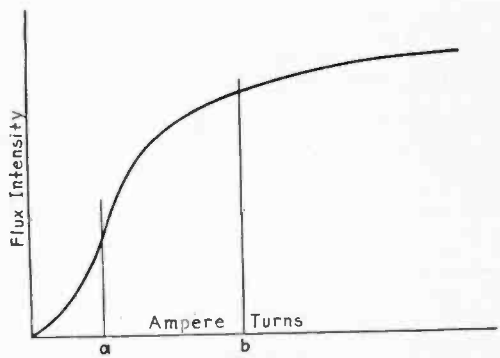

Fig. 1—Typical Magnetization Curve of Transformer Iron.

The choke coil is, therefore, particularly useful in filter circuits in which it is desired to separate the direct current from the alternating current in the pulsating current delivered by a rectifying source. By providing a shunt path of low alternating current and high direct-current impedance (such as the shunt condensers in a filter circuit) the alternating current is induced in large part to take the lower resistance shunt path, while the direct current passes through the choke coils to the load. The higher the inductance of these choke coils, and the higher the capacity of the shunt condensers, the more perfect is this separation of alternating from direct current.

The impedance of a choke coil to alternating current is approximately (the resistance of the coil being neglected) equal to $2\pi fL$, in which f is the alternating current frequency and L is the inductance, which is dependent upon the geometry and character of the iron core and the number of turns and character of the currents flowing in the winding. It is this inductance, L, effective under the current conditions existing in the filter mesh, which determines the filtering or "choking" value of the coil for the given frequency. The determination of L for a given coil, and the influence of various factors on it therefore constitutes the problem of this investigation.

The Saturating Effect of Direct Current

It is a well-known fact that one of the most important factors affecting the inductance of choke coils is the saturation of the core by the direct current flowing in the winding. Fig. 1 shows a typical saturation curve, in which the magnetizing forces are plotted as abscissas, and the resulting fluxes as ordinates. The magnetizing force for a given coil is directly proportional to the current flowing through the winding, and the resulting flux is dependent upon the number of turns and the nature, size, and shape of the iron core. When the value of magnetizing force (or coil current) exceeds a given amount, the iron core becomes "saturated," and increases in magnetizing force above this point produce but little additional flux. In general, the larger the core and the better its material magnetically, the greater is the direct current which is required to produce this state of saturation.

The inductance of the coil, and therefore, its choking action, is determined by the magnitude of the flux changes produced by the alternating current flowing through it. In other words, *it is determined by the average slope of the saturation curve over the range within which the current varies.* The zero point about which this a-c. variation occurs is determined by the value of direct current which flows through the coil. Thus, if the direct current which fixes the zero point about which the current varies, has a value a in Fig. 1, at the center of the steepest part of the curve, the inductance for moderate values of alternating current will be a maximum. If, however, the direct-current component is of sufficient magnitude to bring the zero point above the knee of the curve (as at b) the inductance is much lower. It is thus apparent that the magnitude of the direct current carried by the coil has a great influence on the effective inductance.

The Effect of the Magnitude of the Alternating Current on the Inductance

A fact which has been overlooked by many investigators and which is responsible for much of the disagreement among them is that the magnitude of the alternating as well as that of the direct current component affects the inductance of the coil. As the inductance is determined by the average slope of the saturation curve within the limits of a-c. variation, it is apparent that on any but the straight part of the curve, and particularly in the region of the knee of the curve, this average slope is determined largely by the range of the a-c. fluctuation about the zero point. For very low or high values of alternating current, the average slope and consequently the inductance may be lower than it is for intermediate values. It is important in any method of measurement, therefore, that the magnitude of the alternating current as well as the magnitude of the direct current be considered. *In*

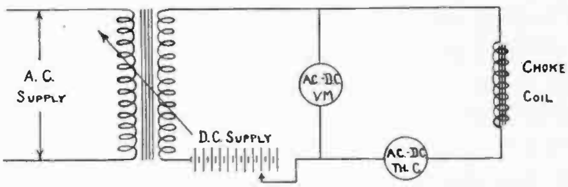

Fig. 2—The Ammeter-Voltmeter Method of Measuring Choke Coil Inductance; First Circuit Modification. (For use where simplicity of connection is important.)

other words, the currents, both alternating and direct, which flow through the coil while it is being measured must be of a magnitude comparable to those which flow through it in the circuit in which it is to be used. Otherwise a false rating is obtained which has no practical application to the problem at hand. Actual measurements taken on a filter circuit of a typical *B* power supply unit show that the first choke coil carries about five milliamperes of alternating current in addition to the direct current furnished to the load. The combination of 5 milliamperes (RMS) of alternating current and 50 milliamperes of direct current through the choke coil has therefore been chosen in this investigation as a standard in measuring coil inductance for comparative purposes.

It is in failing to take account of the magnitude of the alternating current that many bridge, ammeter-voltmeter, three-voltmeter, substitution, and fluxmeter methods of inductance measurement are unreliable. In many cases, the value of this a-c. component is not known, and it is frequently very low. In this investigation, however, there have been developed three modifications of the ammeter-voltmeter method which necessitate the measurement of the alternating current, and in which it, as well as the direct current, may be adjusted to any values desired. A discussion of these methods follows.

First Modification of the Ammeter-Voltmeter Method of Measurement

The circuit used in the first modification of the ammeter-voltmeter method is shown in Fig. 2. It is applicable where only a few approximate measurements are to be made, and where simplicity of connection is of the greatest importance. Observations are made as follows: With the a-c. source open-circuited at the transformer primary, sufficient B batteries are connected in series with the secondary of the transformer, a thermocouple ammeter, and the coil under test, to produce the desired amplitude of direct current in the coil. The direct voltage required and the direct current are read by means of the a-c., d-c. voltmeter and the thermocouple ammeter. Then sufficient alternating voltage is applied, by means of the variable voltage transformer, to increase the reading of the thermocouple ammeter materially, and the meters are again read.

The inductance calculation is then made in the following manner. When both direct and alternating currents flow simultaneously through an a-c., d-c. ammeter, a deflection is produced which is equal to $\sqrt{I_{ac}^2+I_{dc}^2}$. Similarly, when both alternating and direct voltages are simultaneously applied to an a-c., d-c. voltmeter, the deflection is equal to $\sqrt{E_{ac}^2+E_{dc}^2}$. Having determined, therefore, both the d-c. and the combined deflections, it is possible to solve for E_{ac} and I_{ac}. Knowing that $E_{ac}=(2\pi fL)\times I_{ac}$ the inductance L of the choke coil may be readily obtained by the solution of the equation in which L is now the only unknown quantity. The inductance value so obtained is the value when the measured direct current is flowing through the coil. The resistance of the choke coil is ordinarily neglected in the computation, since it is low in comparison with the reactance and, in addition, is added vectorially to it.

Second Modification of the Voltmeter-Ammeter Method of Measurement

A disadvantage of the method of Fig. 2 is that in order to obtain differences in current readings sufficient to permit of accuracy in the computed vector differences, comparatively large values of alternating current must be passed through the coils, probably larger than those met with in actual practice. This disadvantage may be avoided by connecting in parallel with the thermocouple ammeter a circuit consisting of a variable resistance, a choke coil, batteries, and a d-c. ammeter, as shown in Fig. 3. If the variable resistance and batteries are so connected in parallel with the thermocouple ammeter that they will send a current through it in the reverse direction, and if the batteries and variable resistance are properly adjusted, all of the direct current may be by-passed around the thermocouple ammeter so that it will not interfere with the measurement of the alternating current passing through the circuit. If the impedance of the choke coil in this shunt circuit is sufficiently large in comparison with the impedance

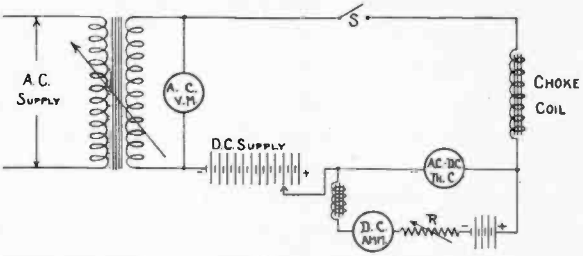

Fig. 3—The Ammeter-Voltmeter Method of Measuring Choke Coil Inductance; Second Circuit Modification. (For use where accuracy rather than simplicity of connection is important.)

of the thermocouple ammeter, the alternating current will not be by-passed around the thermocouple ammeter by this shunt circuit, and will be read accurately by that meter.

If the resistance of the a-c. ammeter is low, an observation is made in the following manner: First, with the a-c. source open circuited, and with the switch S also open, the rheostat R (in the shunt circuit) is adjusted until the ammeters read the desired value of direct current. Then, still leaving the a-c. circuit open the switch S is closed, and the voltage of the d-c. source is adjusted until the reading of the a-c., d-c. ammeter is reduced to zero. The reading of the d-c. meter, however, will be undisturbed, reading the initially chosen direct current which is now being entirely by-passed around the a-c., d-c. instrument.

This latter meter may now be replaced by a more sensitive one, or, if a multi-scale instrument is being used, the switch is thrown to a more sensitive range. The a-c. voltage is now applied and the variable transformer is adjusted to give the desired alternating current through the choke coil. The current is read on the a-c., d-c. ammeter, undisturbed by the direct current component in the circuit. The a-c. voltmeter is connected directly across the a-c. source as shown, where it reads only the a-c. voltage since the d-c. resistance of the transformer winding is so low that no appreciable direct voltage drop is impressed on the meter. Thus, with both alternating voltage and current readings taken separately from the d-c. readings, the accuracy of the method is good.

If, however, the resistance of the a-c., d-c. ammeter is so high as to form an appreciable part of the total resistance in the circuit

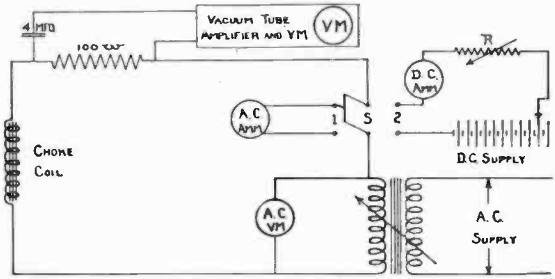

Fig. 4—The Ammeter-Voltmeter Method of Measuring Choke Coil Inductance; Third Circuit Modification. (For use where ease of manipulation and accuracy are important).

(as is likely to be the case if a high resistance thermocouple ammeter is employed) it will be necessary to modify the procedure slightly in order to obtain the desired d-c. balance. A short-circuiting switch is provided around the meter, which is closed initially. The resistance R is adjusted (with the switch S, Fig. 3, open) to give the desired current through the d-c. meter. Then S is closed, and the battery voltage is adjusted until a second d-c. meter, connected in the main circuit, reads exactly the same current. The short circuiting switch around the a-c., d-c. or thermocouple ammeter is now opened, and, if the balance is not perfect, both the rheostat R and the d-c. source must be simultaneously adjusted. Such procedure is necessary only in extreme cases, however, in which it is desired to hold the direct-current constant at a certain definite magnitude, and where a low value of alternating current necessitates the use of a high resistance ammeter. Having obtained the d-c. balance, the remaining operations are made exactly as before.

It is apparent that the method of Fig. 3 has the advantages of accuracy and simplicity of connection, but the disadvantage of difficulty of manipulation.

Third Modification of Ammeter-Voltmeter Method of Inductance Measurement

The method of inductance measurement of Fig. 4 is a special adaptation of the ammeter-voltmeter method which is accurate and which provides convenience of manipulation. It is to be preferred when a sensitive amplifier and vacuum-tube voltmeter are available. Observations are made in the following manner: With the switch S in the No. 1 position, the alternating voltage is adjusted to give the desired alternating current through the choke coil as registered on the a-c. ammeter connected across the switch terminals. The d-c. source, connected across the other end of the switch, is not in the circuit and only alternating current flows through the meter and choke coil. A portion of this alternating current flows through the input transformer of the vacuum-tube amplifier, and produces a deflection proportional to the alternating current flowing through the choke coil. From the value of alternating voltage and current so obtained, the inductance of the coil with no direct current flowing through it may be calculated.

The switch S is now thrown over to the No. 2 position, removing the delicate a-c. ammeter from the circuit and superimposing the direct current upon the alternating current already flowing in the circuit. The rheostat R is now adjusted to give the desired value of direct current, indicated on a D'Arsonval type d-c. ammeter which is not affected by the a-c. component of current which it carries. The alternating voltage is next adjusted to give the same reading on the vacuum-tube amplifier as before, and this new value of alternating voltage, together with the value of alternating current initially chosen, is used to compute the inductance of the coil with the measured direct current flowing through it. In making this calculation, the series resistances in the circuit are ordinarily neglected, since they are low in comparison with the coil reactance, and, in addition, are added vectorially to it.

The reading of the vacuum-tube amplifier is not influenced by the magnitude of the direct current flowing in the circuit and furnishes a convenient method of adjusting the alternating current to the accurately measured initial value flowing when there was no direct current in the circuit. The method lends itself

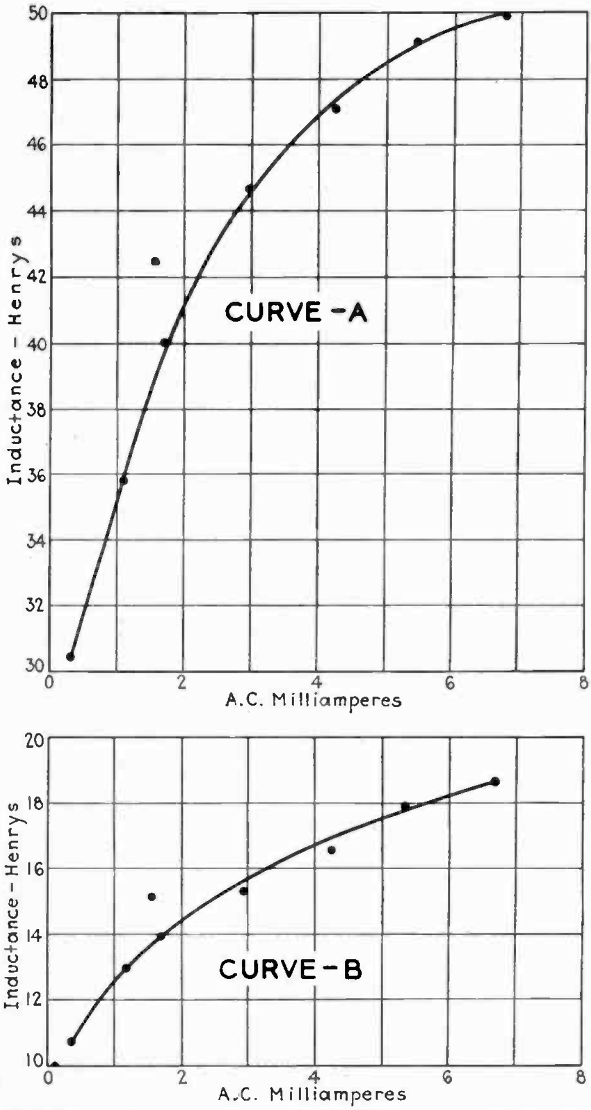

Fig. 5—Variation in Inductance of a Typical "B" Circuit Choke Coil with the Magnitude of Alternating Current.

Frequency 60 cycles. Curve *A*—with no direct current. Curve *B*—with 50 milliamperes of direct current flowing.

readily to manipulation, and permits the adjustment over a wide range of both the a-c. and d-c. components.

Inductance Measurements

In the curves plotted as Figs. 5 and 6, certain characteristic data have been chosen for presentation. Fig. 5 illustrates the variation in inductance of a choke coil with the magnitude of alternating current flowing through it. Curve *A* shows such a curve when no direct current is present, indicating that any inductance rating from 30 to 50 henrys might truthfully be claimed

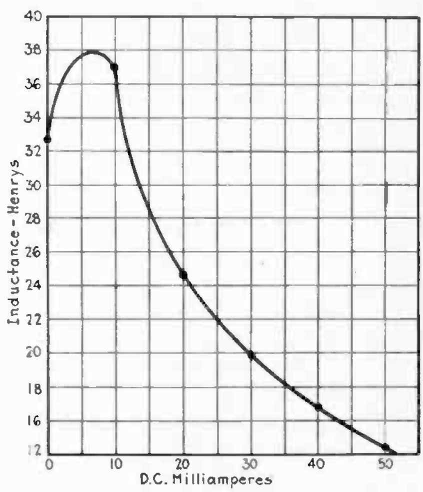

Fig. 6—Variation in Inductance of a Typical "B" Circuit Choke Coil with the Magnitude of Direct Current.
Frequency 60 cycles; 5 milliamperes of alternating current.

for this coil, provided no mention was made of the alternating-current magnitude. This increase in the inductance with current corresponds to the lower bend in the saturation curve shown in Fig. 1. As the magnitude of the a-c. variation about the zero point is increased, the average slope of the included portion of the saturation curve likewise increases with a corresponding rise in the value of the inductance. Curve *B* illustrates the same variation for the same coil, but with 50 milliamperes of direct current flowing. The inductance values are decreased by the saturating effect of the direct current to almost a third of the values in curve *A*, but the increase with the increase in magnitude of the alternating current is still apparent. If the magnitude of the alternating current is not recognized in the measurement of this coil, therefore, values ranging from less than 12 to over 20 henrys might be claimed as its effective inductance in a filter circuit carrying 50 milliamperes of direct current.

Fig. 5 shows the variation in inductance of a typical choke coil with the magnitude of the direct current, the alternating current being held constant at 5 milliamperes. Starting from zero, the inductance rises at first, as the zero line of a-c. fluctuation is advanced to the point of maximum slope of the saturation curve (at *a* on the curve of Fig. 1.) As the direct current is further increased beyong this point which gives a maximum value, the knee of the saturation curve is approached, and the inductance decreases as a result. The effectiveness of this coil in a filter circuit would therefore be a maximum if it carried but 6 or 7 milliamperes of direct current, and it would be less than four-tenths as effective if it carried 50 milliamperes of direct current.

It is because of this saturation at high direct currents that a suitable air gap is included in the magnetic path of a well-designed choke coil. Referring to Fig. 1, a similarly plotted curve for air alone would be a straight line, passing through zero, and rising with increasing ampere turns. The slope of this line is less than that for the iron alone at the point *a* but considerably greater than the slope above the saturation point as at *b*. The combined saturation curve for the iron and air gap together is a proportional addition of the two curves, decreasing the slope of the iron over its steepest range, but materially increasing the slope above the saturation point where the iron is usually "worked" in a *B* filter circuit. The effect of the air gap, therefore, is to increase the inductance of the coil over the range within which it is to be used, even though it does decrease the maximum value obtainable at lower direct-current loads.

Inductance measurements showing the variation in inductance of various types of choke coils with the alternating-current frequency were made. In making these measurements, a substitution method was employed in the following manner. In parallel with the choke coil and ammeter, a variable non-inductive resistance and a second similar ammeter were connected. The output of an audio-frequency oscillator was then connected across the terminals of the two parallel circuits, and the variable resistance in one was adjusted until the currents in both branches were identical. The magnitude of the resistance in ohms is then equal to the impedance, $2\pi fL$, of the choke coil in the parallel circuit, and the inductance L may be readily calculated.

The inductance values obtained at 60 and 120 cycles were in close agreement in all cases. Since 120 cycles is the predominant frequency in double-wave rectification, it is thus permissible to make measurements using the much more convenient 60-cycle source with the assurance that the values so obtained will be a reliable indication of the operation of the coil in a filter circuit. There seems to be a slight tendency for the inductance to rise at the higher frequencies, probably due to the increase in eddy current and hysteresis losses.

Although most of the measurements have been made of the inductance of choke coils to be used in radio B filter circuits, the methods have also been satisfactorily applied to choke coils designed for use in radio A filter circuits.

BOOK REVIEW

Applied Magnetism, BY T. F. WALL. D. Van Nostrand Company, 268 pages, cloth bound. Price $8.00

This book should serve admirably either as a textbook for engineering students or as a reference book. The first part, "The Principles of Applied Magnetism," includes chapters on "Magnetic Theory," "Definitions," "The Characteristics of Magnetic Substances." Common methods for magnetic testing of materials. The author is the head of the Electrical Engineering Department of the University of Sheffield, England.

It is an easily read presentation of magnetic principles although very little data has been included that cannot be found elsewhere. Both parts take up permanent magnet steels and transformer sheets. Other chapters are devoted to the electron theory of magnetism, magneto-striction, and the generation of intense magnetic fields (the order of half a million gauss). The author's method of generating such fields should prove of interest to the workers of many lines of research.

R. R. BATCHER

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February 1, 1928

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DIGEST OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY

The membership of the Institute is asked to refer to page 236 of this issue and supply information relative to the publication of Patent Digests. Answers to the following questions will be appreciated by the Board of Direction:

1. Shall the Institute discontinue the publication of any Patent Digests?

2. Shall the Institute continue to publish Patent Digests such as have been published during the past year?

3. Shall the Patent Digests be published to include one illustration, or drawing, plus one or two claims?

4. Shall the Institute publish a short summary, or abstract of each radio patent?


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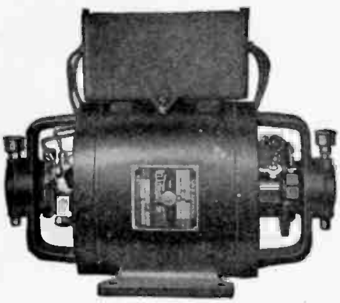

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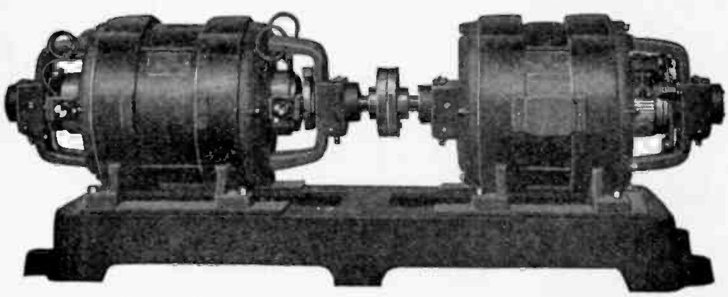

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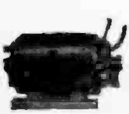

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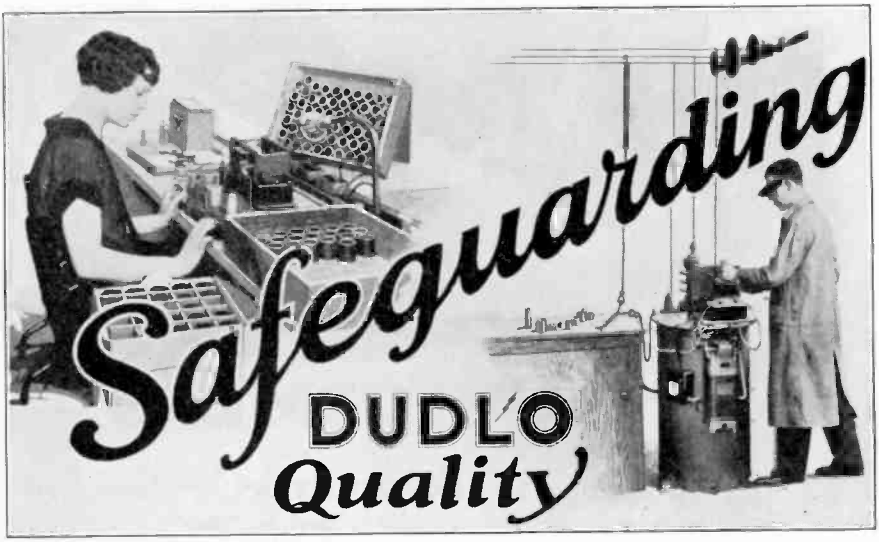

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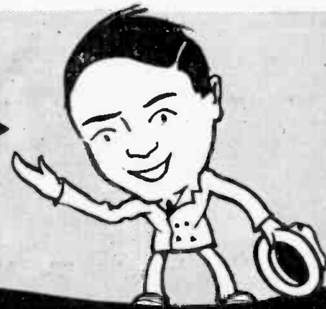

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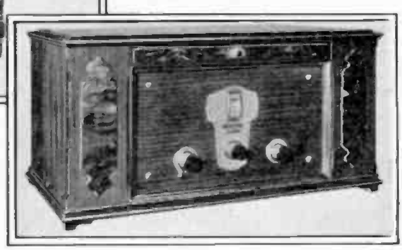

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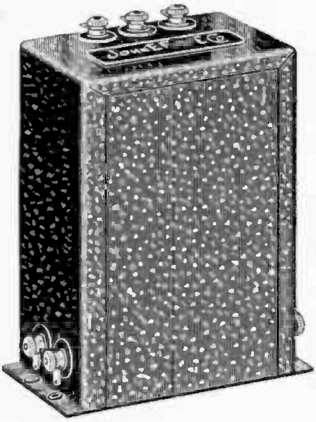

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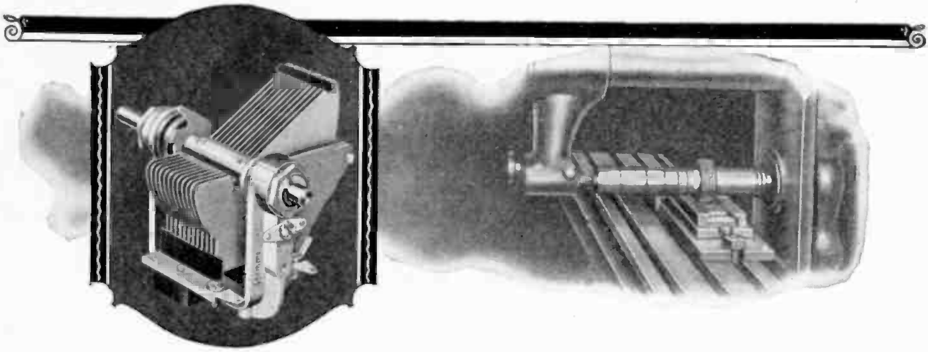

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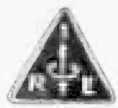

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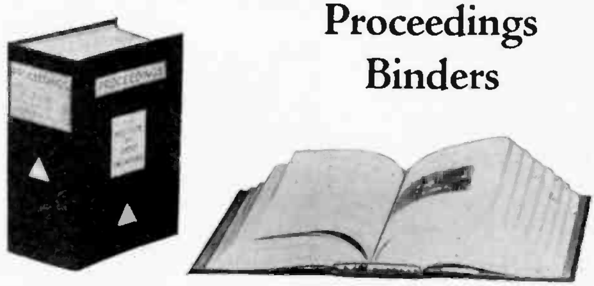

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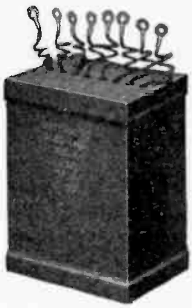

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