PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 | FEBRUARY, 1926 | Number 1

CONTENTS

GENERAL INFORMATION

The PROCEEDINGS of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.50 per copy or $9.00 per year. To foreign countries the rates are $1.60 per copy or $9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

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

PUBLISHED BY
THE INSTITUTE OF RADIO ENGINEERS, INC.
37 WEST 39TH STREET, NEW YORK, N. Y.

OFFICERS AND BOARD OF DIRECTION, 1926

(Terms expire January 1, 1927; except as otherwise noted)

PRESIDENT
DONALD MCNICOL

JUNIOR PAST-PRESIDENTS
J. H. DELLINGER
(Term expires January 1, 1928)
J. H. MORECROFT

VICE-PRESIDENT
DR. RALPH BOWN

TREASURER
WARREN F. HUBLEY

SECRETARY
ALFRED N. GOLDSMITH

PUBLICATION OF "PROCEEDINGS"
ALFRED N. GOLDSMITH, editor
GEORGE R. METCALFE, assoc. editor

MANAGERS

(Serving until January 1, 1927)
LLOYD ESPENSCHIED
A. H. GREBE
GEORGE LEWIS
L. A. HAZELTINE
J. V. L. HOGAN

(Serving until January 1, 1928)
MELVILLE EASTHAM
A. E. REOCH

(Serving until January 1, 1929)
R. H. MARRIOTT
L. E. WHITTEMORE

WASHINGTON SECTION

CHAIRMAN
A. HOYT TAYLOR

SECRETARY-TREASURER
T. PARKINSON, Bureau of Standards, Washington, D. C.

BOSTON SECTION

CHAIRMAN
GEORGE W. PIERCE

SECRETARY-TREASURER
MELVILLE EASTHAM, 11 Windsor St., Cambridge, Mass.

SEATTLE SECTION

CHAIRMAN
CHARLES E. WILLIAMS

SECRETARY-TREASURER
R. H. BERKHEIMER, 1426 Elizabeth St., Bremerton, Washington

SAN FRANCISCO SECTION

CHAIRMAN
J. F. DILLON

SECRETARY-TREASURER
D. B. McGOWN, Custom House, San Francisco, Cal.

CHICAGO SECTION

CHAIRMAN
MONTFORD MORRISON

SECRETARY
L. R. SCHMITT, Morkrum Kleinschmidt Corporation, Chicago, Illinois

CANADIAN SECTION

C AIRMAN
C L RICHARDSON

SECRETARY
W. J. HEVEY, Radio News of Canada, 257 Adelaide St., W., Toronto

PHILADELPHIA SECTION

CHAIRMAN
STUART BALLANTINE

COMMITTEES OF THE INSTITUTE OF RADIO ENGINEERS, 1926

Committee on Meetings and Papers

R. H. Marriott, Chairman
J. H. Dellinger
Carl Dreher
D. K. Martin
Erich Hausmann
H. F. Dart
A. N. Goldsmith
R. A. Heising
W. R. G. Baker

Committee on Institute Sections

L. E. Whittemore, Chairman
L. F. Fuller
David H. Gage, Jr.
L. G. Pacent
M. C. Rypinski
M. B. Sleeper

Committee on Admissions

Ralph Bown, Chairman
E. H. Armstrong
A. H. Grebe
L. A. Hazeltine
R. H. Marriott

Committee on Revision of the Constitution

J. H. Dellinger, Chairman
J. V. L. Hogan
J. H. Morecroft

Committee on Publicity

W. G. H. Finch, Chairman
David G. Casem
Edgar Felix
Arthur Lynch
R. F. Yates

Committee on Standardization

L. E. Whittemore, Chairman
E. H. Armstrong
R. Bown
Edward Bennett
L. W. Chubb
J. H. Dellinger
A. N. Goldsmith
J. V. L. Hogan
C. B. Joliffe
Leslie McMichael
R. H. Langley
A. E. Reoch
T. R. Rosebrugh
H. M. Turner
L. A. Hazeltine
Bowden Washington

Committee on Membership

H. F. Dart, Chairman
M. C. Batsel
M. Berger
Stuart Ballantine
George Burghard
David G. Casem
Frank Conrad
F. A. Canavaciol
Dr. L. J. Dunn
A. R. Nilson
C. L. Richardson
Col. J. F. Dillon
W. G. H. Finch
S. Kruse
E. R. Shute
C. P. Edwards

Committee on Finance

Ralph Bown, Chairman
W. F. Hubley
M. C. Rypinski

INSTITUTE ACTIVITIES

Chicago Section

At the November meeting of the Chicago Section, held in the Monadnock Building, a paper on "Short Wave Transmitters and Antenna Models" was presented by Prof. J. T. Tykociner, of the University of Illinois. A second paper on the subject "A New Wavemeter for Radio Measurements" was presented by Prof. Tykociner and L. P. Gardner.

Board Meeting, December 1

The December meeting of the Board of Direction, held at Institute headquarters, New York, was attended by Dr. J. H. Dellinger, president; Donald McNicol, vice-president; Alfred N. Goldsmith, secretary; W. F. Hubley, treasurer; J. V. L. Hogan, L. A. Hazeltine, and Lloyd Espenschied, managers. Committee chairmen, making reports to the Board at this meeting, and who were present, were: Ralph Bown, L. E. Whittemore and R. H. Marriott.

Year Book

The Year Book for 1926 will be issued about the middle of February. This publication will contain a complete list of the members of the Institute, all grades; the Constitution, Section By-laws, and other matter of interest to all who are identified with the Institute, and who are interested in radio.

The publication is free to all Fellows, Members and Associates. A copy is being mailed to each member in these grades.

Price to others, fifty cents per copy.

Committees for Year 1926

In this issue of the PROCEEDINGS appears a list of working committees for the year 1926, appointed by the President.

Members of the Institute may communicate direct with committee chairman on matters pertaining to the work of the respective committees. The rapid increase in membership in the Institute in recent years will very likely continue throughout the present and coming years. With the membership as large as it is now, the work of the committees is of considerable proportions, and requires the continuous attention of the respective chairmen and of committee members.

Elections and Transfers

At the December, 1925, Board meeting, the following transfers and elections were approved: Transferred to grade of Fellow: Dr. Ralph Bown and Lester Jones. Transferred to grade of Member: D. Hepburn and Isaac R. Lounsberry. Elected to grade of Member: W. E. Branch, Walter J. Brown, George P. Bush, O. E. Dunlap, F. E. Eldredge, Walter H. Eller, J. H. Reyner.

At the January, 1926, Board meeting sixty applications for Associate grade and six applications for Junior grade were approved.

January Meeting of Board of Direction

At the regular monthly meeting of the Board of Direction, held January 5, the following members were present: Dr. J. H. Dellinger, Dr. A. N. Goldsmith and Messrs. Donald McNicol, Lloyd Espenschied, J. V. L. Hogan, Melville Eastham, W. F. Hubley, R. H. Marriott and L. E. Whittemore.

The count of the election ballots showed that the membership at large had elected as officers for the year 1926: Mr. Donald McNicol, President; Dr. Ralph Bown, Vice-president, and as Managers, Messrs. R. H. Marriott and L. E. Whittemore. The three appointive Managers, and one to fill the unexpired term of Dr. H. W. Nichols, deceased, are: Louis A. Hazeltine, Lloyd Espenschied, J. V. L. Hogan and George Lewis.

Certificates of Membership

At the January, 1926, meeting of the Board of Direction, proposal was approved to issue Certificates of Membership to Fellows and Members, and membership cards to Associates. The former will be suitably engrossed, will show the name of the member, and be signed by the President and Secretary of the Institute.

The certificates and cards will be ready for distribution about March 1, next, and may be obtained upon request to the Secretary.

Annual Meeting, 1926

The Annual Meeting of the Institute for 1926 was held in the form of a Convention on January 18, 19, in the Engineering Societies Building, New York. A paper on "The Polarization of Radio Waves" was presented by Mr. G. W. Pickard, and a paper on "The Present Status of Radio Atmospheric Disturbances," by Dr. L. W. Austin.

At the evening session, January 18, was presented a Symposium on "The Results of the Washington Radio Conference of November, 1925," the various viewpoints being discussed by Dr. Alfred N. Goldsmith, Dr. J. H. Dellinger, Mr. J. V. L. Hogan and Mr. R. H. Marriott.

Organized trips of inspection were made to the new high-power broadcasting station of the Radio Corporation of America at Bound Brook, N. J.; the trans-ocean radio telegraph office of the Radio Corporation of America in New York; Broadcast Station WEAF of the American Telephone and Telegraph Company; the Bell Laboratories Station WJZ, New York, of the Radio Corporation of America; the Studio and Station of WAHG, and manufacturing plant of A. H. Grebe Company, Richmond Hill, N. Y.

On the evening of January 19, there was a banquet at the Waldorf-Astoria Hotel, New York, at which the dinner music was received by radio, and at which the following radio engineers and executives delivered short addresses: Dr. Irving Langmuir, Dr. F. B. Jewett, Dr. A. E. Kennelly, Dr. E. F. W. Alexanderson, Prof. J. H. Morecroft, Mr. Edward J. Nally and Mr. A. H. Grebe.

Report of Standardization Committee

The Report of the Standardization Committee, to be known as the 1926 Report, is now ready for distribution. The Report contains a list of definitions of radio terms prepared by the Committee; also, approved symbols illustrating circuit elements and apparatus parts. Copies are included as a supplement to this issue of the PROCEEDINGS. Price to non-members, one dollar per copy.

Technical Papers for Presentation or Publication

It is important that all papers intended for presentation at meetings or for publication in the PROCEEDINGS be forwarded to the Chairman of the Meetings and Papers Committee at least sixty days before the date of presentation. This, in order to allow time for review, editing, making of illustrating cuts, printing, scheduling, etc. Illustrations must be clear enough to reproduce clearly as line cuts or half-tones, and must be of sizes such that they will still be clear when reduced to the width of the PROCEEDINGS page. Only sufficient illustrations must be used as are necessary to clarify the text.

TRANSATLANTIC RADIO TELEPHONE TRANSMISSION*

By

Lloyd Espenschied, C. N. Anderson, and Austin Bailey

(Department of Development and Research, American Telephone and Telegraph Company, New York)

Introduction

Signal Field Strength

Noise Strength

Signal-to-Noise Ratio

Directive Receiving Antennas

It will be recalled that something over two years ago, experiments in one-way radio telephone transmission were conducted from the United States to England.[1] In respect to the clarity

*Presented before The Institute of Radio Engineers, New York, May 6, 1925. Received by the Editor, May 28, 1925.

[1] "Trans-Atlantic Radio Telephony," Arnold and Espenschied, "Journal of the American Institute of Electrical Engineers," August, 1923. See also, "Power Amplifiers in Transatlantic Telephony," Oswald and Schelleng, Proceedings of The Institute of Radio Engineers.

and uniformity of the reception obtained in Europe, the results represented a distinct advance in the art over the trans-Atlantic tests of 1915. However, they were carried out during the winter, which is most favorable to radio transmission, and it was realized that an extensive study of the transmission obtainable during less favorable times would be required before the development of a trans-Atlantic radio telephone service could be undertaken upon a sound engineering basis. Consequently, an extended program of measurements was initiated to disclose the transmission conditions obtaining thruout the twenty-four hours of the day and the various seasons of the year. The methods used in conducting these measurements and the results obtained during the first few months of them have already been described in the paper previously mentioned. The results there reported upon were limited to one-way transmission from the United States to England upon the telephone channel. Since then measurements have extended to include transmission on several frequencies in each direction from radio telegraph stations, in addition to the 57 kilocycles employed by the telephone channel.

The present paper is, therefore, in the nature of a report upon the results thus far obtained in work currently under way. It seems desirable to make public these results because of the large amount of valuable data which they have already yielded, and because of the timely interest which attaches to information bearing upon the fundamentals of radio transmission. The carrying on of this extensive measurement program has been made possible thru the co-operation of engineers of the following organizations: in the United States—The American Telephone and Telegraph Company and the Bell Telephone Laboratories, Incorporated, with the Radio Corporation of America and its Associated Companies; in England—the International Western Electric Company, Incorporated, and the British Post Office.

Measurement Program

The scene of these trans-Atlantic experiments is shown in Figure 1. The British terminal stations will be seen to lie in the vicinity of London and the American stations in the northeastern part of the United States. The United States transmitting stations are the radio telephone transmitter at Rocky Point, Long Island, and the normal radio telegraph transmitters at Rocky Point and at Marion, Massachusetts. The measurements of these stations were made at New Southgate and at Chedzoy England. The British transmitting stations utilized in measuring the east-to-west transmission were the British Post Office telegraph stations at Leafield and at Northolt. The receiving measurements in the United States were initiated at Green Harbor, Massachusetts, and continued at Belfast, Maine, and Riverhead, Long Island.

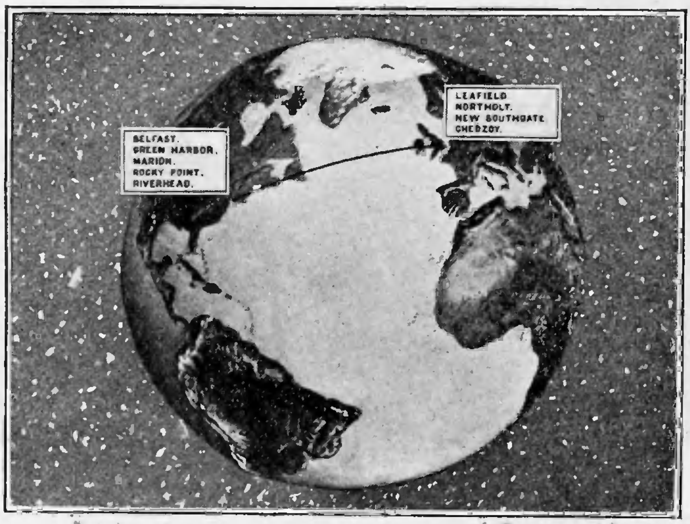


FIGURE 1

The Riverhead receiving station, shown in Figures 2 and 3, is typical of the receiving stations involved in the measurement program. The interior view of Figure 3 shows the group of receiving measurement apparatus at the right and the loop at the left. The three bays of apparatus shown are as follows: That at the left is the receiving set proper which is, in reality, two receiving sets in one, arranged so that one may be set for measurements on one frequency band and the other set upon another band. Th eset is provided with variable filters which accounts for the considerable number of condenser dials. The second bay from the left contains voice-frequency output apparatus, cathode ray oscilligraph and frequency meter. The third bay mounts the source of local signal and means for attenuating it, and the fourth bay contains means for monitoring the transmission from the nearby Rocky Point radio telephone transmitter.

The measurements made are of two quantities: (1), the strength of received field, and (2), the strength of received noise caused by static. The particular frequencies upon which the measurements were taken are given in the chart of Figure 4. They lie in a range between 15 and 60 kc. The arrows indicate the single frequency transmissions which were employed for signal

FIGURE 2

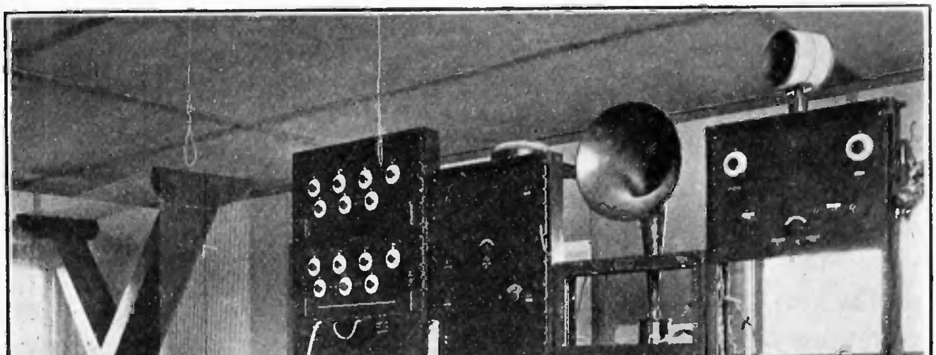


FIGURE 3

field strength meausrements, those at the left indicating the frequencies received in the United States from England, and those at the right, the frequencies received in England from the United States. The black squares in the chart denote the bands in which the noise measurements were taken. In general, the measurements of both field strength and noise have been carried out on both sides of the Atlantic at hourly intervals for one day each week. The data presented herewith are assembled from some 40,000 individual measurements taken during the past two years in the frequency range noted above. The transmitting antenna current has been obtained for each individual field strength measurement and all values corrected to a definite reference antenna current for each station measured. The data have been subject to careful analysis in order to disclose what physical factors, such as sunlight and the earth's magnetic field, affect radio transmission.

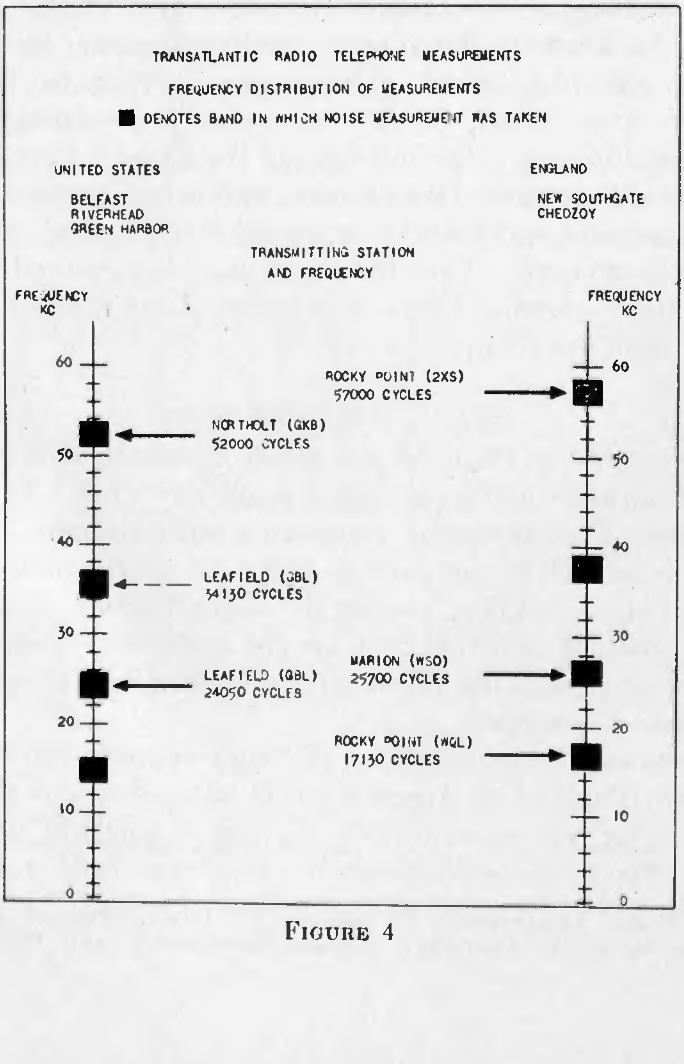


FIGURE 4

Measurement Methods

Altho it will not be necessary to describe in any detail the type of apparatus employed in making these measurements, as this information has already been published,[2] a reminder of the methods involved will facilitate an understanding of the data.

In general, the method employed in measuring the signal field strength is a comparison one. A reference radio-frequency voltage of known value is introduced in the loop antenna and adjusted to give the same receiver output as that from the distant signal. This is determined either by aural or visual means. Under such conditions equal voltages are introduced in the antenna from local and distant sources, and by calculating the effective height of the loop the field strength of the received signal is determined.

In the noise measurements, static noise is admitted thru a definite frequency band approximately 2,700 cycles wide. A local radio-frequency signal of known and adjustable voltage is then introduced. The radio-frequency source of this signal is subjected to a continual frequency, fluctuated so that the detected note has a warbling sound. This is done in order that the effect of static upon speech can be more closely simulated than by using a steady tone. The intensity of the signal is then adjusted to such a value that further decrease results in a rapid extinction. The comparison signal is then expressed in terms of an equivalent radio field strength. Thus the static noise is measured in terms of a definite reference signal with which it interferes and is expressed in microvolts per meter.

Signal Field Strength

The curves of Figure 5 are given as examples of the field strength measurements covering a single day's run. The curves have been constructed by connecting with straight lines, the datum points of measurements taken at hourly intervals. It will be evident that they portray the major fluctuations occurring thruout the day, but that they are not sufficiently continuous to disclose, in detail, the intermediate fluctuations to which the transmission is subject.

Diurnal Variation—The left-hand curve is for transmission from England to America on 52 kilocycles, and the right-hand one for transmission from America to England on 57 kilocycles. These curves illustrate the fact, which further data sub-

[2] "Radio Transmission Measurements," Bown, Englund, and Friis, Proceedings of The Institute of Radio Engineers, April, 1923.

stantiate, that both transmissions are subject to substantially the same diurnal variation. The condition of the trans-Atlantic transmission path with respect to daylight and darkness is indicated by the bands beneath the curves. The black portion indicates the time during which the trans-Atlantic path is entirely in darkness, the shaded portions the time during which it is only partially in darkness, and the unshaded portions the time during which daylight pervades the entire path.

The diurnal variation may be traced thru as follows:

1. Relatively constant field strength prevails during the daylight period.

2. A decided drop in transmission accompanies the occurrence of sunset in the transmission path between the two terminals.

3. The advent of night-time conditions causes a rapid rise in field strength to high values, which are maintained until daylight approaches.

4. The encroachment of daylight upon the eastern terminal causes a rapid drop in signal strength. This drop sometimes extends into a morning dip similar to, but smaller than, the evening dip. After this, relatively steady daylight field strengths again obtain.

Three or four curves similar to Figure 5 are obtained each month. By taking the average of such curves for the month of September, 1923, the lower curve on Figure 6 is obtained. The

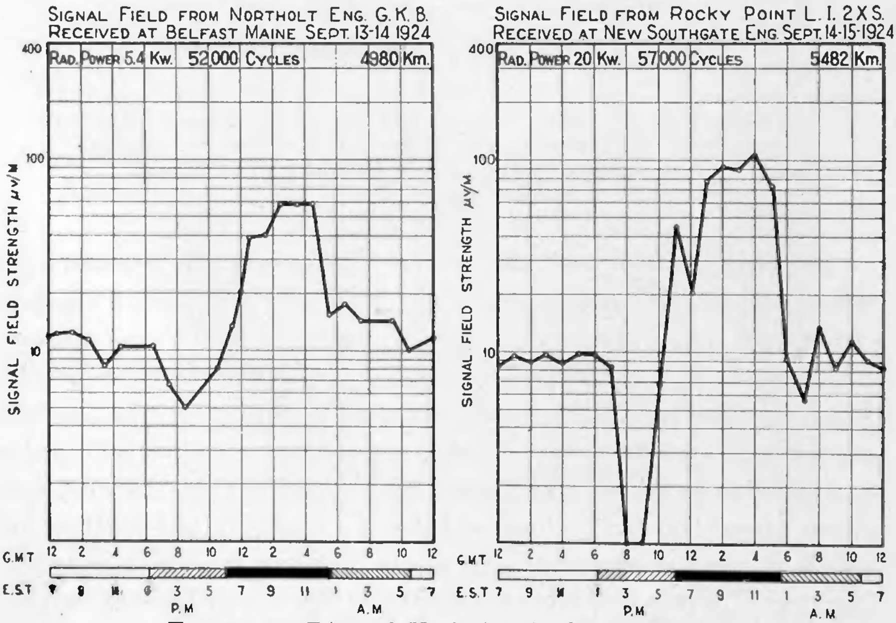


FIGURE 5—Diurnal Variation in Signal Field

upper curves are for similar averages of measurements made on the lower frequencies. These curves show clearly that the range of the diurnal fluctuation is less for the lower frequencies. This is because of the lesser daylight absorption.

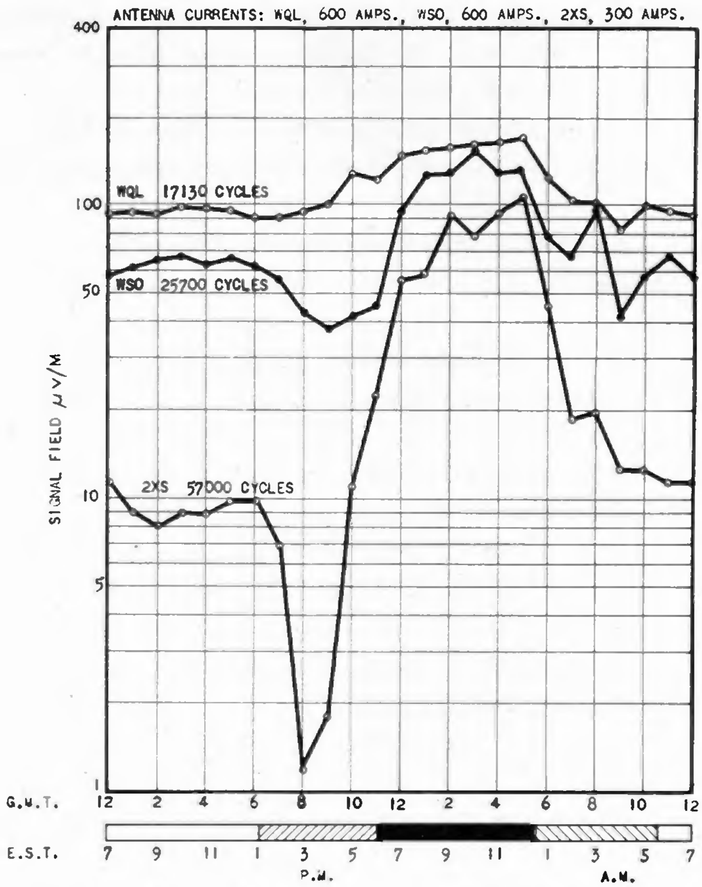


FIGURE 6—Monthly Average of Diurnal Variation in Signal Field Transmission from American Stations on Various Frequencies. Received at New Southgate, England. September, 1923

The mechanism by which the trans-Atlantic transmission path is subjected to these daily and seasonal controls on the part of the sun would be more evident were we enabled to observe the earth from a fixed point in space. We should then be able to see the North Atlantic area plunged alternately into daylight and darkness as the earth rotates upon its axis, and to visualize the seasonal variation of this exposure to sunlight as the earth revolves about the sun. Photographs of a model of the earth showing these conditions have been made, and are shown in Figure 7. The first condition is that for January, in which the entire path is in daylight. The curve of diurnal variation is shown in the

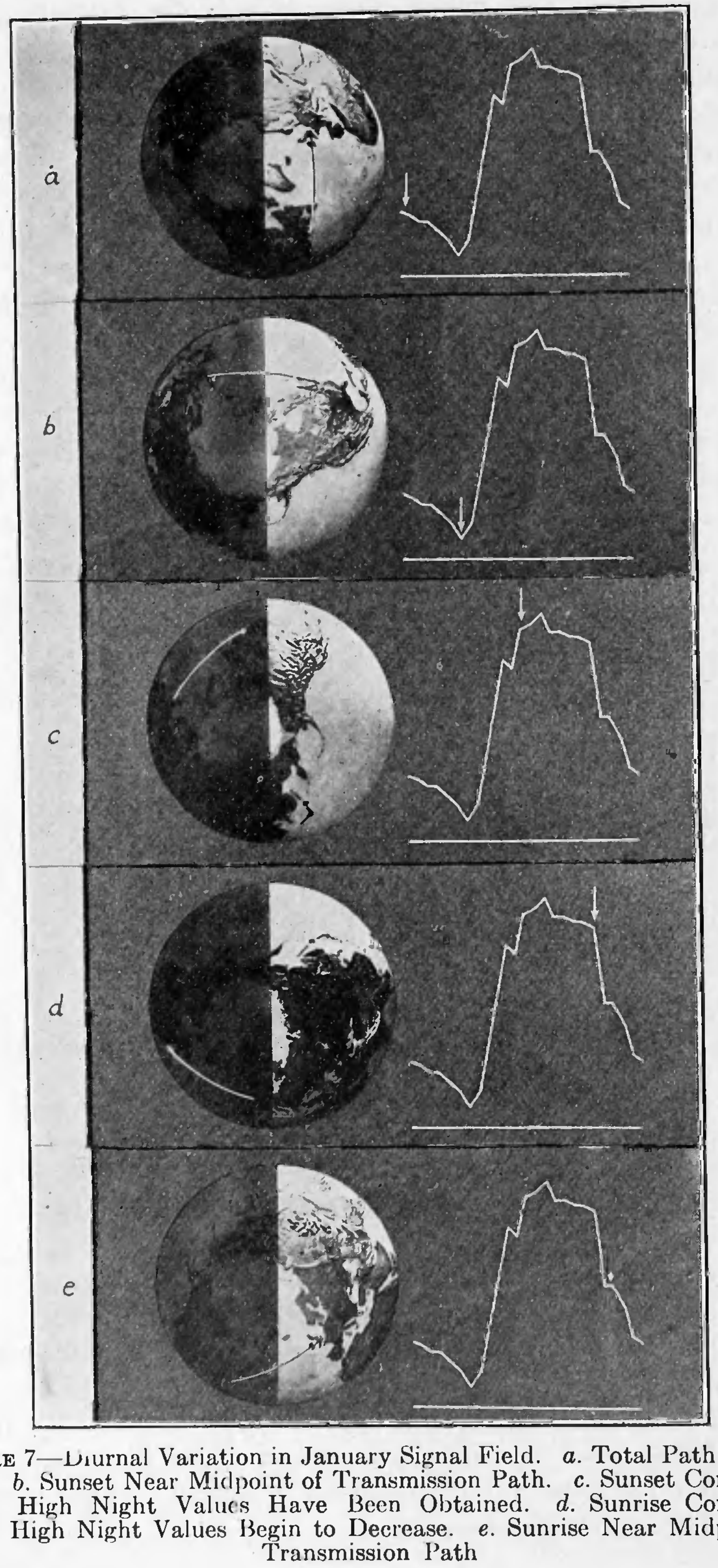


Figure 7—Diurnal Variation in January Signal Field. *a*. Total Path in Sunlight. *b*. Sunset Near Midpoint of Transmission Path. *c*. Sunset Conditions When High Night Values Have Been Obtained. *d*. Sunrise Conditions When High Night Values Begin to Decrease. *e*. Sunrise Near Midpoint of Transmission Path

picture and that part which corresponds to the daylight condition is indicated by the arrow. In the next position the earth has rotated so that the London terminal is in darkness while the United States terminal is still in daylight. This corresponds to the evening dip, the period of poorest transmission. With the further rotation of the earth into full night-time conditions for the entire path, the received signal rises to the high night-time values. These high values continue until the path approaches the daylight hemisphere, as indicated in the fourth position. As the path enters into sunlight, the signal strength drops with a small dip occurring when sunrise intervenes between the two terminals.

Seasonal Variation—By assembling the monthly average curves for all months of the year, the effect of the seasonal variation on the diurnal characteristic becomes evident. This is shown in Figure 8, the data for which actually cover two years.

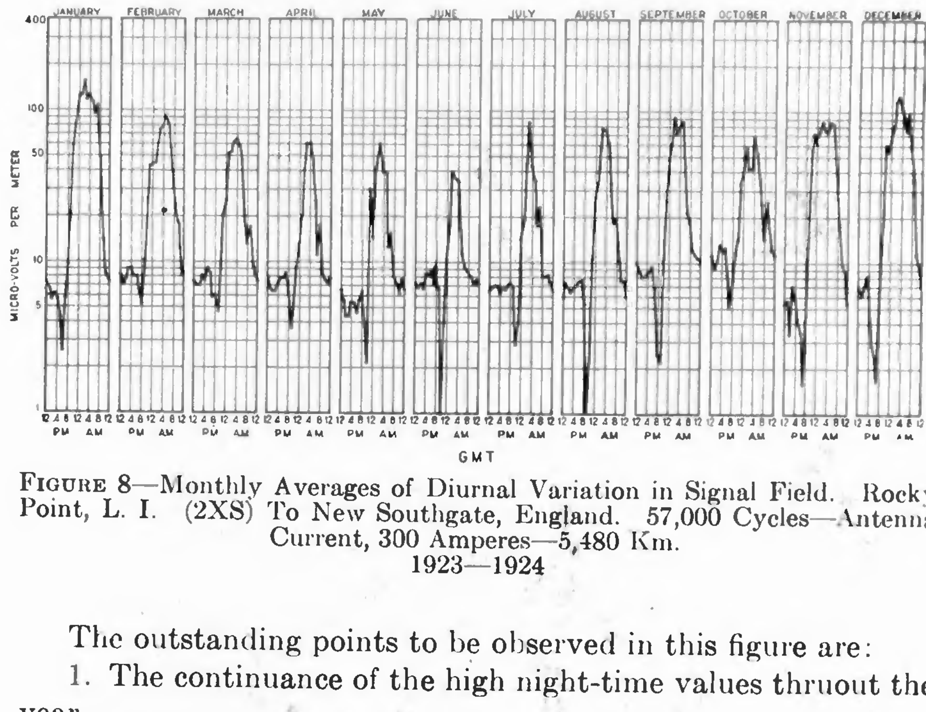


Figure 8—Monthly Averages of Diurnal Variation in Signal Field. Rocky Point, L. I. (2XS) To New Southgate, England. 57,000 Cycles—Antenna Current, 300 Amperes—5,480 Km.
1923—1924

The outstanding points to be observed in this figure are:

1. The continuance of the high night-time values thruout the year.

2. The persistence of the high night-time values for a longer period in the winter than in the summer months.

3. The daylight values show a comparatively small range of variation.

4. The extreme range of variation shown between the minimum of the sunset dip and the maximum of the high night-time values is of the order of 1-to-100 in field strength. This is equivalent to 1-to-10,000 in power ratio.

It will be recalled that the cause of the seasonal changes upon the earth's surface resides in the fact that the earth's axis is inclined and not perpendicular to the plane of its orbit about the sun. As the earth revolves about the sun, the sunlit hemisphere gradually extends farther and farther northward in the spring months and by the summer solstice reaches well beyond the north pole, as indicated in Figure 9. As the earth continues to revolve

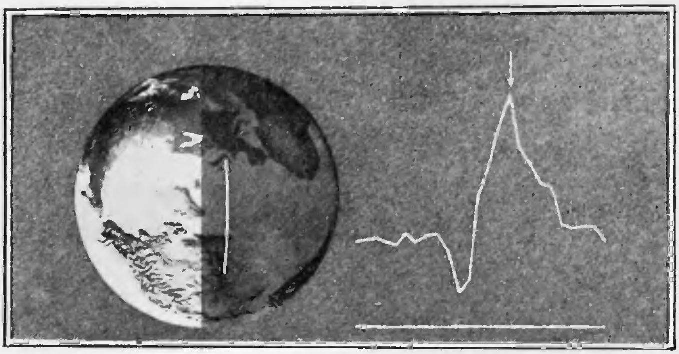


FIGURE 9—Night Conditions in June. Sunlight 170 Km. Above Great Circle Path Between New York and London

about the sun, the sunlit hemisphere recedes southward until at the winter solstice it falls considerably short of the north pole and extends correspondingly beyond the south pole. Since the trans-Atlantic path lies fairly high in the northern latitude, it is not astonishing that the transmission conditions disclose a decided seasonal influence. The effect of this seasonal influence in shifting the diurnal transmission characteristic is better shown in Figure 10. This figure consists of the same monthly average diurnal curves as are assembled in Figure 8, arranged one above the other instead of side by side.

In particular, there should be noted:

1. The time at which the sunset dip occurs changes with the change in time of sunset.

2. Similarly, the time at which the morning drop in field strength occurs changes with the time of sunrise.

3. The period of high night-time values, bounded between the time of sunset in the United States and the time of sunrise in England, is much longer in the winter than in the summer months.

It is also to be observed that, as a rule, full night-time values of signal field strength are not attained until some time after sunset at the western terminal and that they begin to decrease before sunrise at the eastern terminal. In other words, the day-

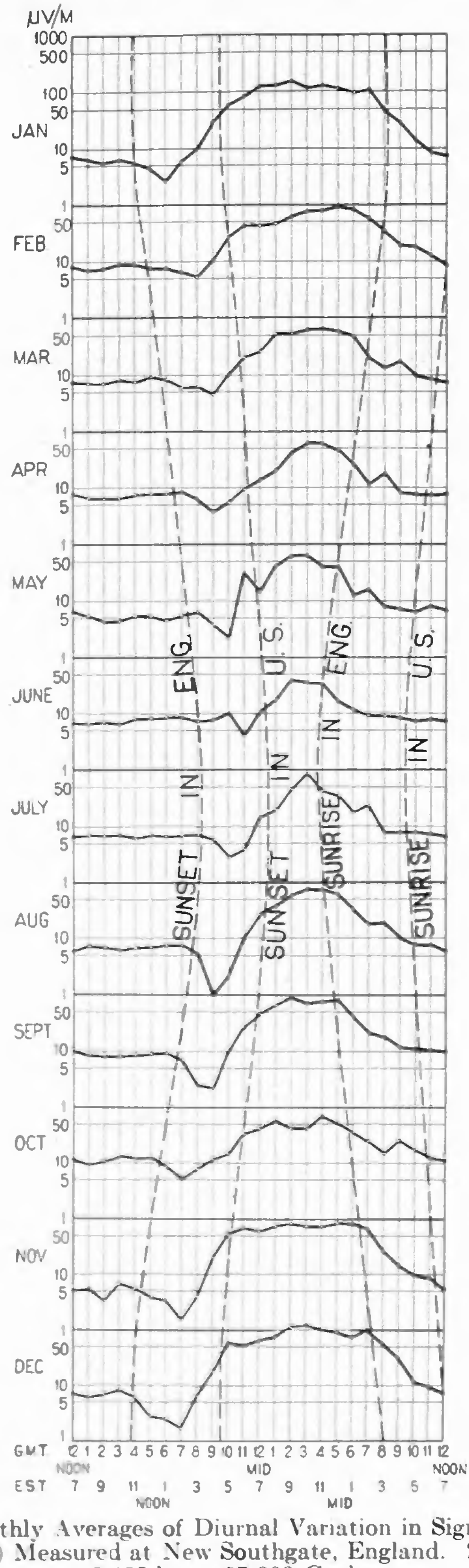


FIGURE 10—Monthly Averages of Diurnal Variation in Signal Field. Rocky Point, L. I. (2XS) Measured at New Southgate, England. 20.8 kw. radiated. 5,480 km. 57,000 Cycles 1923—1924

light effects appear to extend into the period in which the transmission path along the earth's surface is unexposed to direct rays of the sun. The effect of this is that with the advance of the season from winter to summer, the time at which the high night-time value is fully attained, occurs later and later, whereas the time at which it begins to fall off occurs earlier and earlier, until the latter part of April when these two times coincide. At this time, then, the transmission path no sooner comes into the full night-time conditions than it again emerges. As the season further advances into the summer, the day conditions begin to set in while the night-time field strength is still rising. The proximity to the daylight hemisphere, which the trans-Atlantic path reaches at night during this season of the year is illustrated in Figure 9.

As the sunlit hemisphere recedes southward after the summer solstice, a time is reached, about the middle of August, when the full night-time values are again realized. Beyond this time they are sustained for increasing periods of time. It is of interest to note that at these two times of the year, the last of April and the middle of August, direct sunlight exists over the darkened hemisphere some 500 kilometers above the great circle path.

For all of the conditions noted above, namely, sunset, sunrise, and summer approach of the transmission path to the northern boundary of the night hemisphere, the path lies in a region wherein the radiation from the sun grazes the earth's surface at the edge of the sunlit hemisphere. The transmission path also approaches this region during daylight in the winter months, as will be seen by reference to the first position of Figure 7 for the month of January. The results of measurements for the months of November, December, and January for all of the frequencies measured show definite reductions in the daylight field strengths. This reduction is evident in Figure 8 for the 57-kilocycle transmission, but shows up more strikingly in the curves of Figure 11. The effect of each of these conditions, in which the transmission path approaches the region in which the solar emanation is tangential to the earth's surface, will be observed to be that of an increase in the transmission loss. The fact that in one instance this occurs in daylight would seem to suggest, for its explanation, the presence of some factor in addition to sunlight, such as electron emission.

Field Strength Formulas—The two major phases of the diurnal variation of signal field strength which lend themselves to possible predetermination are the daylight values and the

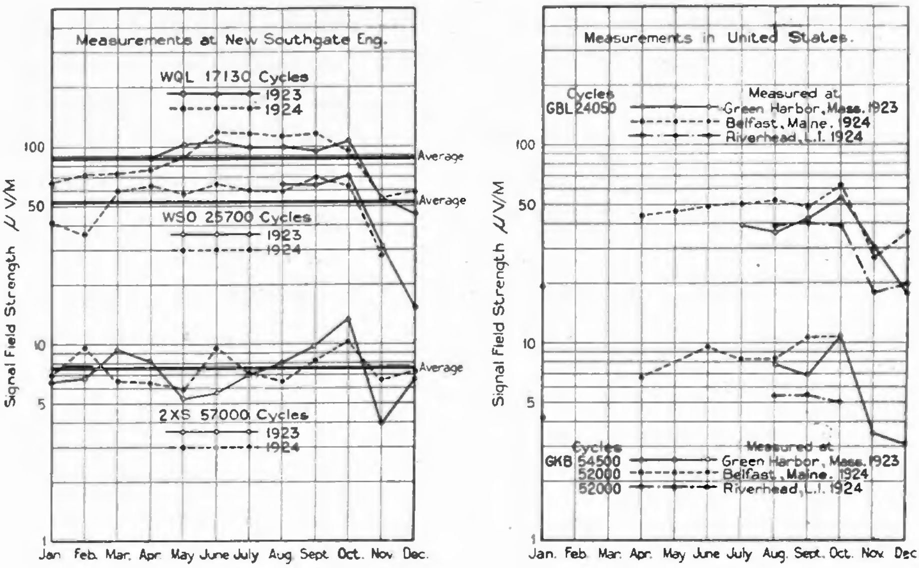


FIGURE 11—Monthly Averages of Daylight Field Strength

established night-time values. As to the night-time values our data show, within the limits of experimental error, that the maximum values do not exceed that defined by the Inverse Distance Law. This fact seems to support the viewpoint[3] that the high night-time values are merely the result of a reduction of the absorption experienced during the day. Figure 11 presents the monthly averages of the daylight field strengths for the various frequencies on which measurements were taken. The chart at the left is for reception in England and that at the right for reception in the United States.

The difficulty in predicting by transmission formulas, values to be expected at any one time will be evident and the best that can be expected is to approximate the average. The formulas of Sommerfeld, Austin-Cohen, and Fuller take the form

$$E(\mu v./m.) = \frac{377\,H\,I}{\lambda\,D}\,\varepsilon^{-\frac{a\,D}{}}$$

where the coefficient $\frac{377\,H\,I}{\lambda\,D}$ represents the simple Hertzian radiation field and the exponential $\varepsilon^{-\frac{aD}{\lambda}}$ the attenuation factor. From theoretical considerations, Sommerfeld (1909) gave $a=0.0019$ and $x=1/3$. In the Austin-Cohen formula a is given as 0.0015 and $x=1/2$. Fuller gives $a=0.0045$ and $x=1.4$. The Austin-Cohen formula was tested out experimentally chiefly

[3] See also "Radio Extension of Telephone System to Ships at Sea," Nichols and Espenschied, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, June, 1923, pages 226-227.

with data obtained from the Brant Rock station (1911) and from the Arlington station by the U. S. S. *Salem* in February and March, 1913. Fuller derived his 0.0045 value of α from 25 selected observations from tests between San Francisco and Honolulu in 1914.

An attempt has been made to determine the constants of a formula of the above form which would approximate averages of some 5,000 observed values of field strength over this particular New York to London path and over the frequency range of 17 kc. to 60 kc. For each transmitting station a series of comparatively local measurements were taken to determine the power radiated. By combining these local measurements with the values obtained on the other side of the Atlantic we found that approximately $\alpha = 0.005$ and $x = 1.25$. The transmission formula then becomes

$$E(\mu v./m.) = \frac{377\, H\, I}{\lambda\, D}\, \varepsilon^{-\frac{0.005\, D}{\lambda^{1.25}}}$$

or in terms of power radiated

$$E = \sqrt{P}\, \frac{298 \times 10^3}{D}\, \varepsilon^{-\frac{0.005\, D}{\lambda^{1.25}}}$$

where

E = Field strength in microvolts per meter
P = Radiated power in kw.
D = Distance in km.
λ = Wave length in km.

Correlation Between Radio Transmission and Earth's Magnetic Field—In analyzing the measurements we were impressed by the occasional occurrence of marked deviations from the apparent normal diurnal characteristic. A series of measurements which includes an example of this condition is represented in the upper curves of Figure 12. The curves of the first four days exhibit the normal diurnal characteristic as did the curves of the preceding measurements. The next test of February 25-26 exhibits a marked contrast with that of two days previous. Such abnormality continues in greater or less degree until partial recovery in the test of April 29-30.

The table following summarizes the data relative to daylight transmission.

TRANSATLANTIC RADIO TELEPHONE MEASUREMENTS

Trans-mitting Terminal	Receiving Terminal	Freq.	Dis-tance Km.	Power* Radiated Kw.	Daylight Field Strengths Observed			Daylight Field Strengths Calculated		
					1923	1924	Av.	Austin-Cohen	Fuller	This Paper
2XS	New Southgate, England	57,000	5482	20.6	7.5	7.65	7.6	6.9	21.2	7.8
WSO	New Southgate, England	25,700	5282	8.95	(Aug.-Dec.) 48.7	(Jan.-Nov.) 54.6	52.7	16.6	78.5	50.2
WQL	New Southgate, England	17,130	5482	12.	(Apr.-Dec.) 86	87.2	86.8	27.7	116.	86.
GBL	Green Harbor, Mass.	24,050	5149	4.06	(July-Jan.) 34.2			13.2	59.	39.
	Belfast, Maine	24,050	4885	4.06		(Apr.-Dec.) 51(?)		15.6	64.7	41.8
	Riverhead, L. I.	24,050	5363	4.06		(Aug.-Dec.) 31.5		11.4	55.2	34.5
GBL	Green Harbor, Mass.	34,130	5149	4.85	(July-Jan.) 16.1			9.5	41.2	22.6
GKB	Green Harbor, Mass.	54,500	5241	7.9	(Aug.-Dec.) 6.1			5.6	18.6	7.1
	Belfast, Maine	52,000	4980	5.4		(Apr.-Oct.) 9.1		6.15	20.	9.05
	Riverhead, L. I.	52,000	5457	5.4		(Aug.-Oct.) 5.3		4.2	15.	5.9

*Computed from local observations using formula of this paper.

NOTE—Measurements of transmission from Rocky Point (2XS) on 57,000 cycles measured at Mexico City, July, 1924, give an average daylight field strength of 39.4 $\mu v./m.$ Calculated value 42.5 $\mu v./m.$

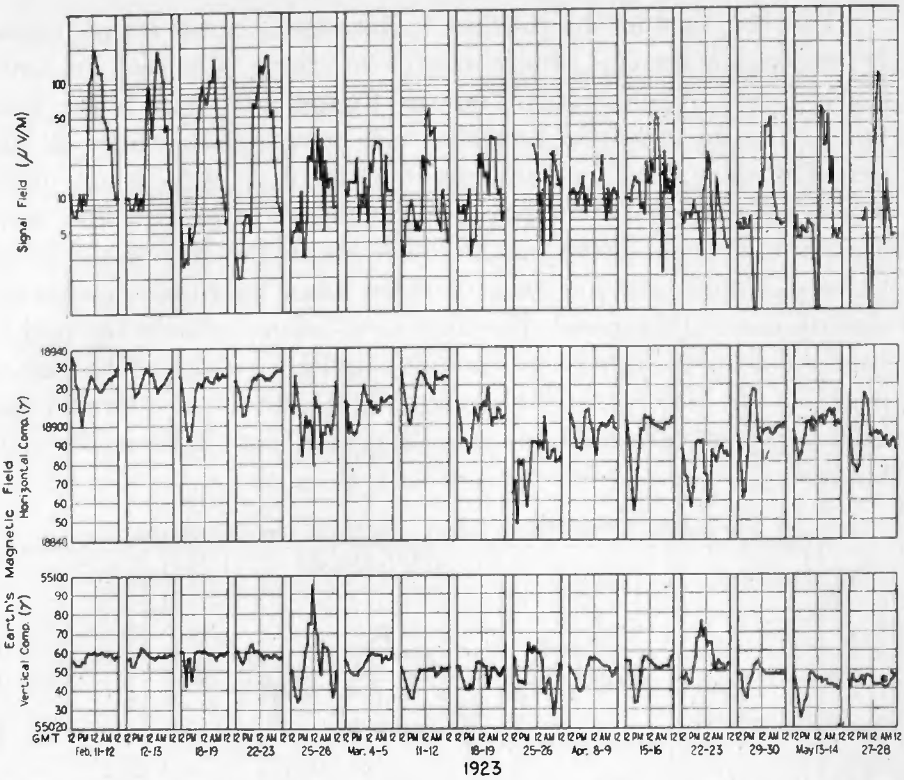


FIGURE 12—Correlation of Radio Transmission and Earth's Magnetic Field. Transmission from Rocky Point, L. I., U. S. A. (57,000 Cycles) to London, England. Earth's Magnetic Field Measured at Cheltenham, Md., U. S. A.

Comparison of these data with those of the earth's magnetic field for corresponding days shows a rather consistent correlation. This will be evident from inspection of the magnetic data plotted below the same figure. Both the horizontal and vertical components of the earth's field are shown. The first decided abnormality occurs February 25-26. The three succeeding periods show a tendency to recover followed by a second abnormality on March 25-26 and again one on April 22-23. It is of interest to note that within limitations of the intervals at which measurements were taken, these periods correspond roughly to the 27-day period of the sun. Coincidences similar to those described above have been found for other periods. Except for this coincidence of abnormal variations in earth's magnetic field and radio transmission, exact correlation of the fluctuations has not been found possible.

The magnetic data have been supplied thru the courtesy of the United States Goedetic Survey. Similar data taken in England were obtained from the Kew observatory and show similar results.

The contrast in the diurnal variations of radio transmission before and after the time a magnetic storm is known to have started, is further brought out in Figure 13. The lower left-hand curve in this figure superimposes curves of February 22-23, and February 25-26 of the previous figure. Additional cases where such marked changes occur are also shown. It will be seen that similar effects exist on the lower frequency of 17 kc. All of these examples are for days of other than maximum magnetic disturbance. In general the effect is to reduce greatly the night-time values and slightly increase the daylight values. The higher peaks in the daylight field strength of Figure 11 are due to the high daylight values which prevail at the time of these disturbances.

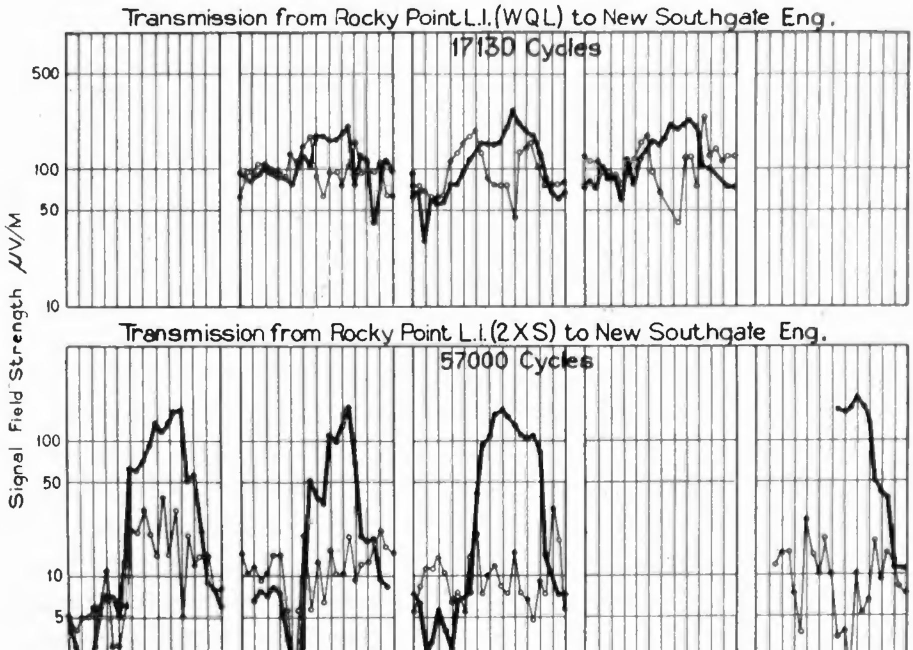


FIGURE 13—Effect of Solar Disturbances on Radio Transmission. Heavy Line Represents More or Less Normal Transmission Week End Before Disturbance Occurred. Light Line Represents Abnormal Transmission on Following Week End After Disturbance Began But Still in Progress

NOISE STRENGTH

Next to field strength the most important factor in determining the communication possibilities of a radio channel is that of the interfering noise. The extent to which noise is subject to diurnal and seasonal vatiations is, therefore, of first order of importance.

Diurnal Variation—An example of the diurnal characteristic of the noise for both ends of the trans-Atlantic path is given in Figure 14. One curve is shown for each of the several frequencies measured. The outstanding points to be observed are:

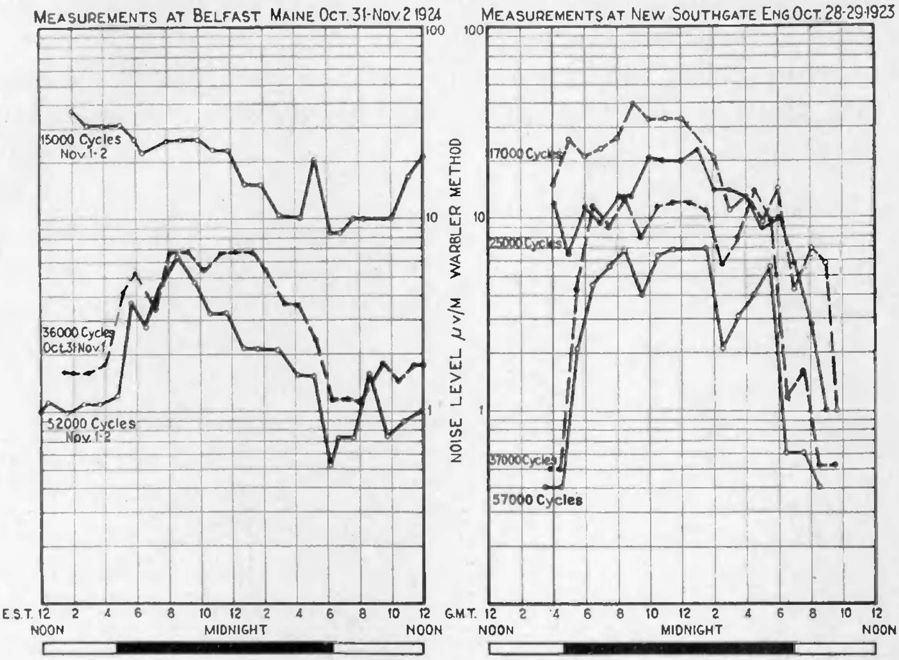


Figure 14—Diurnal Variation in Noise

1. The rise of the static noise about the time of sunset at the receiving station, the high values prevailing at night, and the rather sharp decreases accompanying sunrise. The curve for 15 kc. shows the existence of high values also in the afternoon period. During the summer months high afternoon values are usual for all frequencies in this range. They extend later into the Fall for the lower frequencies, and hence are in evidence on the dates on which these measurements were taken, October-November.

2. In general, the noise is greater the lower the frequency.

Noise as a Function of Frequency and of Receiving Location—The distribution of static noise in the frequency range under consideration is depicted in Figure 15 for the case of reception at New Southgate, England. The set of full-line curves is for daylight reception and the set of dash-line curves for night-time reception. The values obtaining during the transition period between day and night have been excluded. For both conditions three curves are shown, one the average of the summer months, another the average of winter months and the third, the heavy line, the average for the entire year. The curves represent averages for all of the measurements taken during both 1923 and 1924. In considering curves of this type it should be remembered that they represent an average of a wide range of conditions and at any one time the distribution of static may differ widely from that indicated by the curves. Also it should be realized that the extreme difference between winter and summer static is much greater than the difference between the averages.

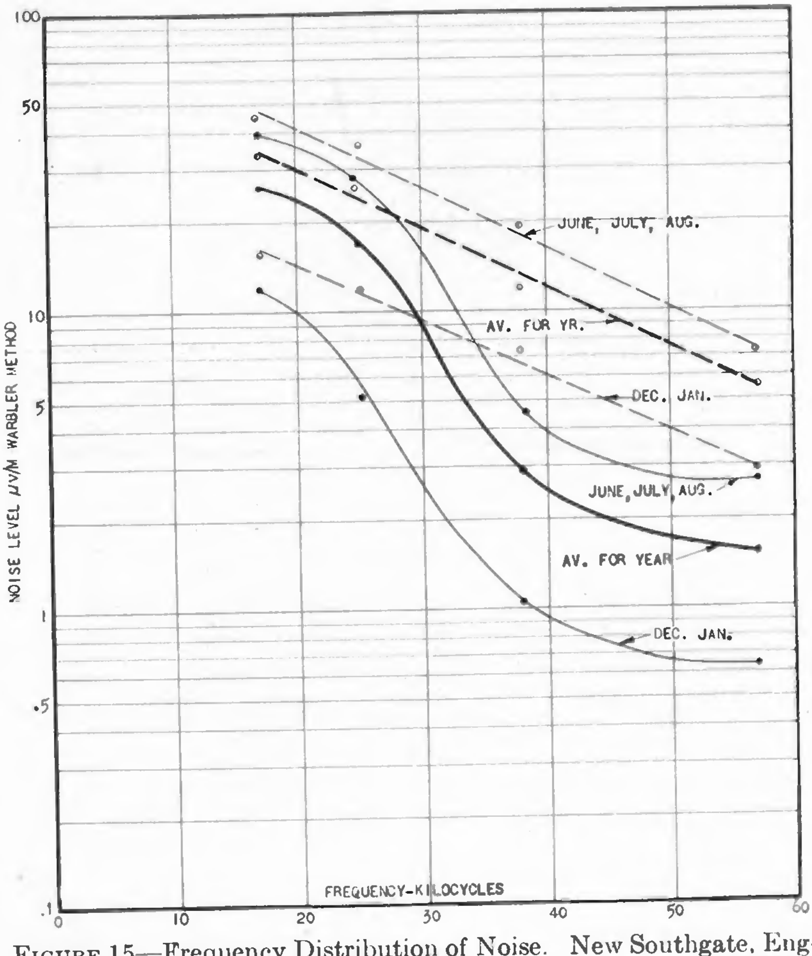


FIGURE 15—Frequency Distribution of Noise. New Southgate, England. Night-time— — — — —. Daytime————————. 1923—1924

A similar study of frequency distribution was made at two locations in the United States, Belfast and Riverhead. The results obtained at these two locations, together with those for New Southgate, England, are presented in Figure 16 for a period during which data were obtained for all three places. The similarity of the three sets of curves shows that there is an underlying cause common to both sides of the Atlantic which may account for the difference between the daytime and night-time static on the longer waves. It will be evident from the curves that for frequencies around 20 kc. there is not very much difference between the day and night static noise, but that at the higher frequencies in the range studied, the daylight values become considerably less than the night-time values. Actually the divergence between the night-time and the daytime noise curves, up to about 40 kc., is an exponential one. This suggests that the lowering of the daylight values may be largely due to the higher absorption which occurs in the transmission medium during the day. There is a further interesting point to be noted concerning both figures, namely, that the night-time values decrease exponentially with increase in frequency. Since these night-time values are but little affected by absorption in the transmitting medium, the distribution of the static energy as received, also roughly represents the distribution of the static power generated.

The curves of Figure 16 show also the substantial difference in the noise levels which exists at the three receiving points. The New Southgate curve indicates, as has been experienced in practice, that England is less subject to interference than northeastern United States. In the United States the superiority of Belfast over Riverhead is also consistent with the better receiving results which in general have been experienced in Maine. There should be noted also the fact that the curves for these three locations lie one above the other in the inverse order of the latitudes. This is in keeping with other evidence which points towards the tropical belt as being a general center of static disturbance on the longer wave lengths. Further evidence on this point is presented below in connection with the seasonal variations of noise.

Seasonal Variation—Curves showing the diurnal variation in noise level for each month of the year as well as the variations of sunset and of sunrise are shown in Figure 17. Each curve is the average of all the measurements taken during that particular month in 1923 and 1924. The diurnal variations are generally similar for the different months in respect to the high night-time values which are limited to the period between the times of sunset and sunrise in England. There is a certain deviation, however, which it is well to point out. During the summer months the rise in night-time static starts several hours before and reaches high values at about sunset in England, whereas in the winter-

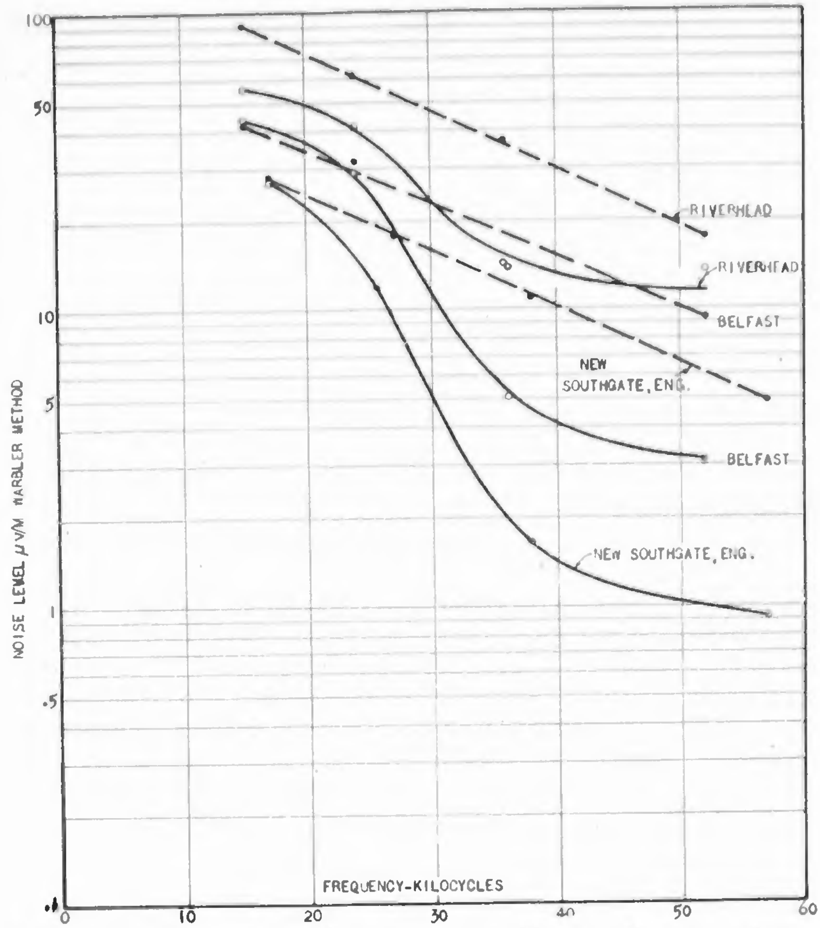


FIGURE 16—Frequency Distribution of Noise. New Southgate, England, Belfast, Maine, Riverhead, L. I. Night-time — — —. Day-time————. August–December, 1924

time, the night-time static begins to rise at about sunset and reaches high values several hours later. A similar effect is observed for the sunrise condition wherein the reduction of static sets in during the summer months about the time of sunrise, reaches low daylight values several hours later, and in the winter the reduction commences several hours before sunrise and reaches low daylight values at sunrise. In other words, the rise to high night-time values occurs earlier with respect to sunset in the summer than in the winter, and conversely the fall from high night-time static to the lower daylight values occurs later with respect to sunrise in the summer than in the winter.

This is more definitely brought out in Figure 18, which combines the data for all frequencies measured. The dash lines associated with the sunset curves delineate the beginning and the attainment of the night-time increases, and those associated with the sunrise curve delineate the beginning and the attainment of

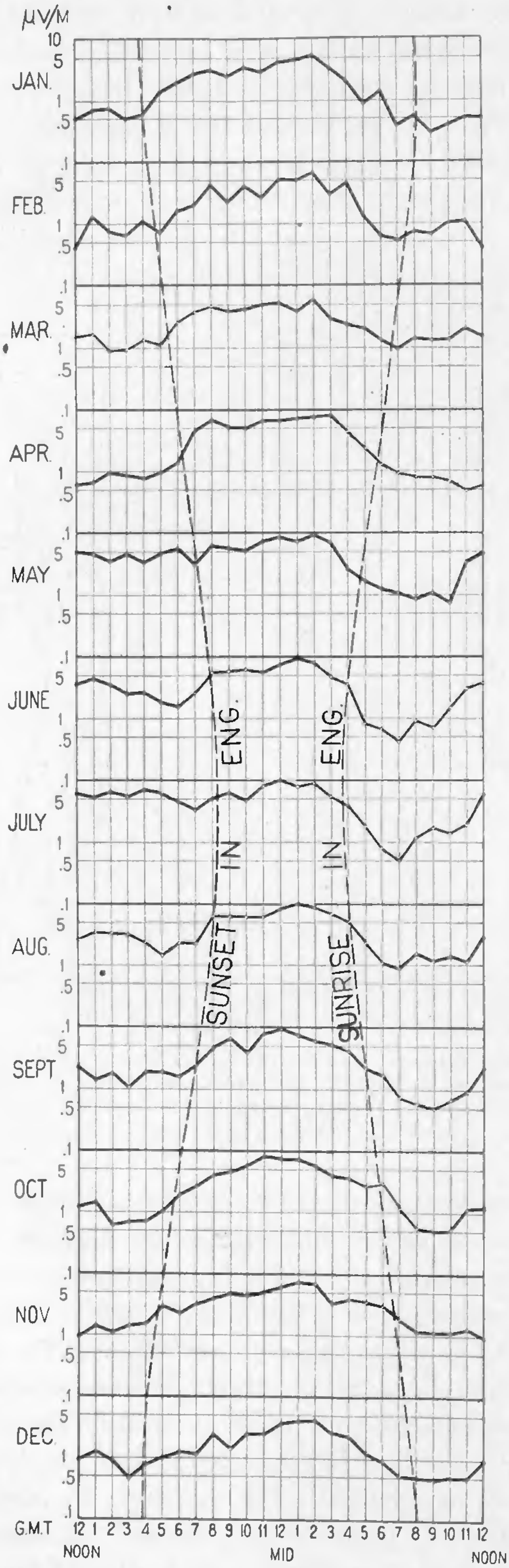


FIGURE 17—Monthly Averages of Diurnal Variation in Noise. 57,000 Cycles.
New Southgate, England
1923—1924

the low daylight values. This discloses the fact that sunset and sunrise at the receiving point does not completely control the rise and fall of the high night-time static. It has been found that the discrepancy can be accounted for if sunrise and sunset are taken with respect to a static transmission path as distinguished from the receiving point alone, and if the assumption is made that the effect of sunlight upon the static transmission path is similar to that on usual radio transmission.

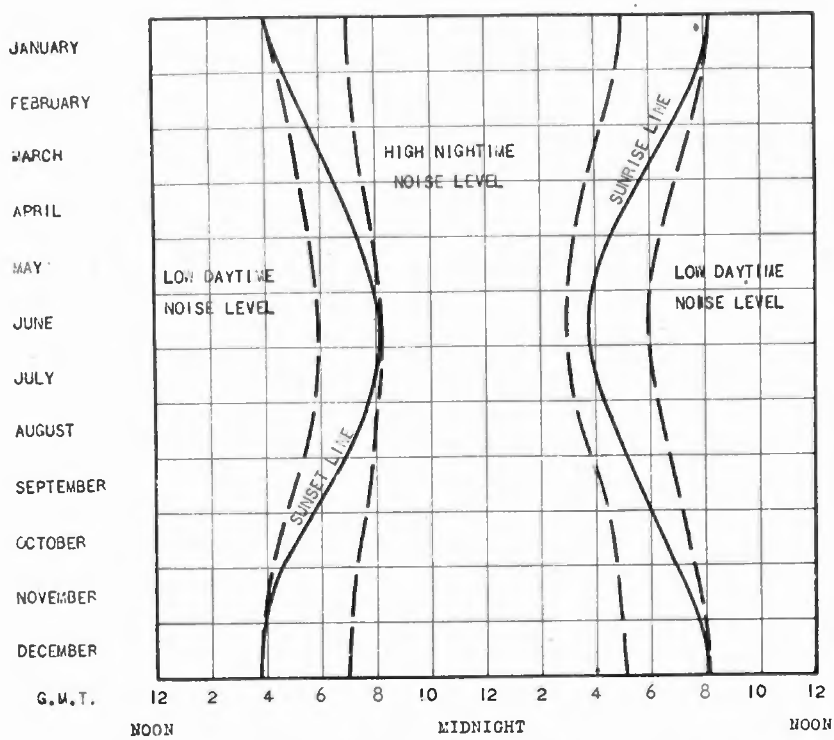


FIGURE 18—Seasonal Variation in Distribution of Daytime and Night-time Noise with Respect to Sunset and Sunrise. New Southgate, England
1923—1924

MAJOR REGIONAL SOURCE OF STATIC NOISE—A broader conception as to the causes underlying the diurnal and seasonal variations is obtained by considering the time of sunset and sunrise over a considerable area of the earth's surface. Figure 19 shows a series of day and night conditions for three representative parts of the January diurnal noise characteristic at England. It will be seen that the rise to high night values does not begin until practically the time of sunset in England with over half of Africa still in daylight. By the time the high night-time values are reached, as indicated in the second phase, darkness has pervaded all of the equatorial belt to the south of England.

Incidentally at this time sunset occurs between the United States and England, resulting in very poor signal transmission. The third phase of this series shows the noise having just reached the low daytime value and, altho the sun is just rising in England, the African equatorial belt is in sunlight, subjecting the static transmission path to high daylight atenuation.

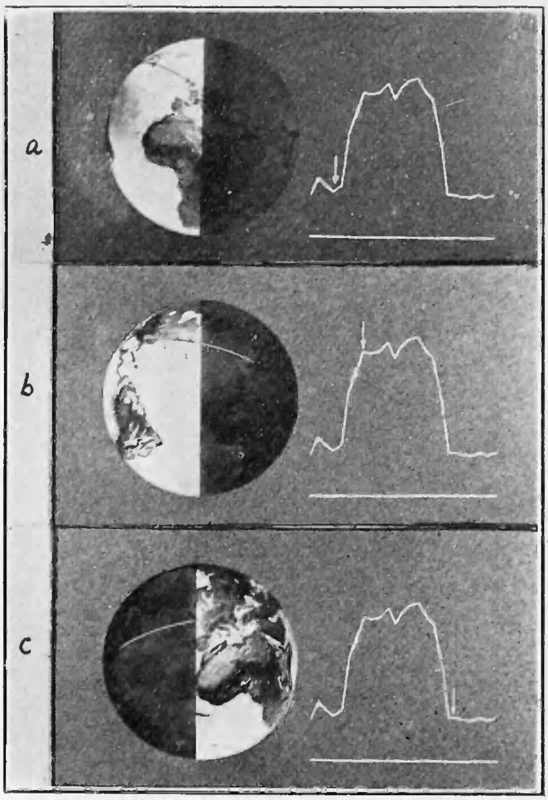


FIGURE 19—January Noise. *a.* Sunset Conditions as Night-time Noise Begins to Increase. *b.* Sunset Conditions When Noise Has Reached High Night-time Values. *c.* Sunrise Conditions When Noise Has Reached Normal Low Values

The sunset conditions which existed for the afternoon and evening of the day upon which the diurnal measurements of Figure 14 were taken are shown in Figure 20. The hourly positions of the sunset line are shown in relation to the evening rise of static in London. The coincidence between the arrival of sunset in London and the start of the high night-time noise on the higher frequencies is evident. By the time the high night-time values are reached, about 7 o'clock G. M. T., the equatorial belt to the south of London is in darkness.

Figure 21 shows the sunrise conditions in relation to the decrease in static from the high night-time values to the lower day-

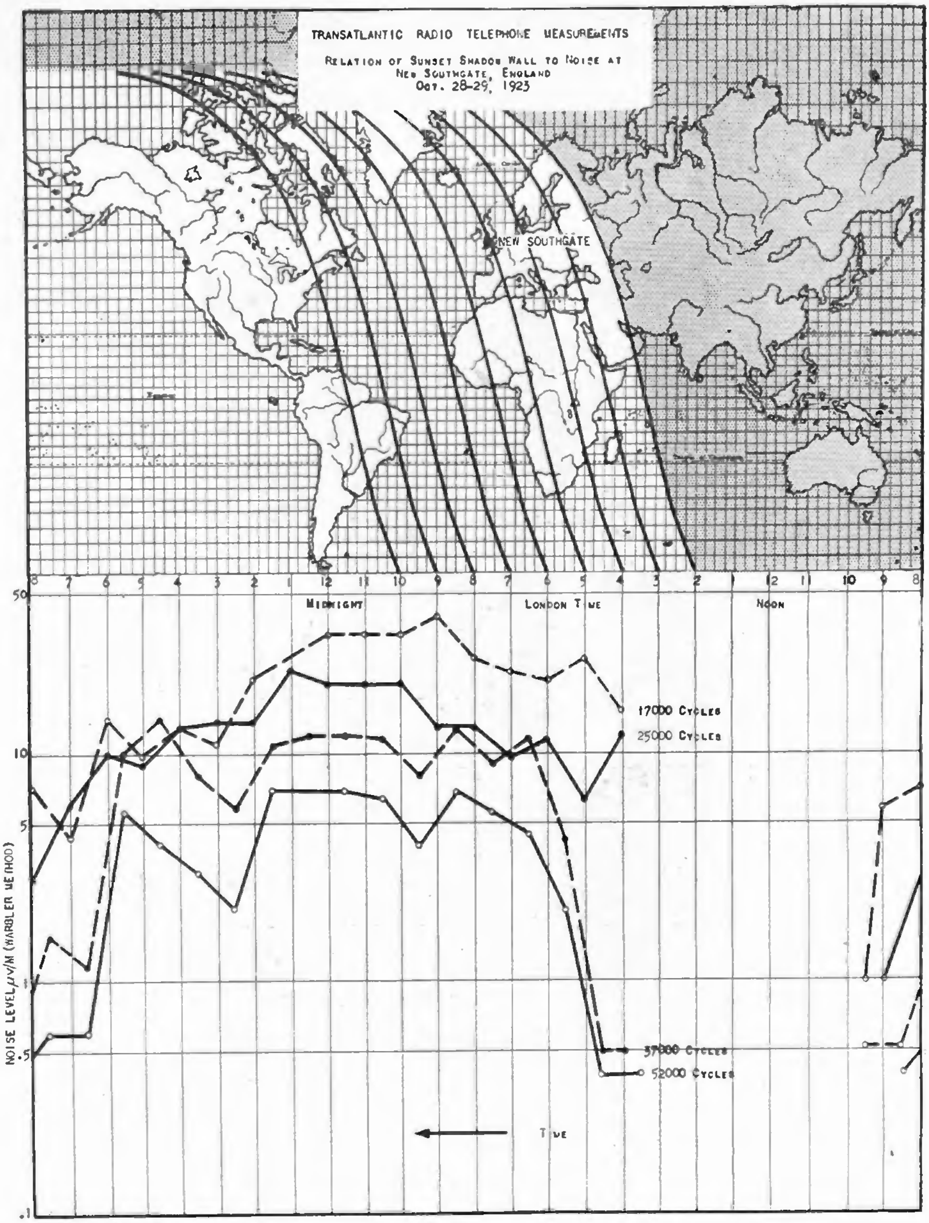


FIGURE 20—Relation of Sunset Shadow Wall to Noise at New Southgate
England
October 28-29, 1923

light values. The decline starts about 5 or 6 o'clock, an hour or two before sunrise, and is not completed until several hours later, at which time daylight has extended over practically the entire tropical belt to the south of England which corresponds in general to equatorial Africa.

Another fact, presented in the previous figures, which appears to be significant in shedding light upon the source of static, is that noise on the lower frequencies rises earlier in the afternoon

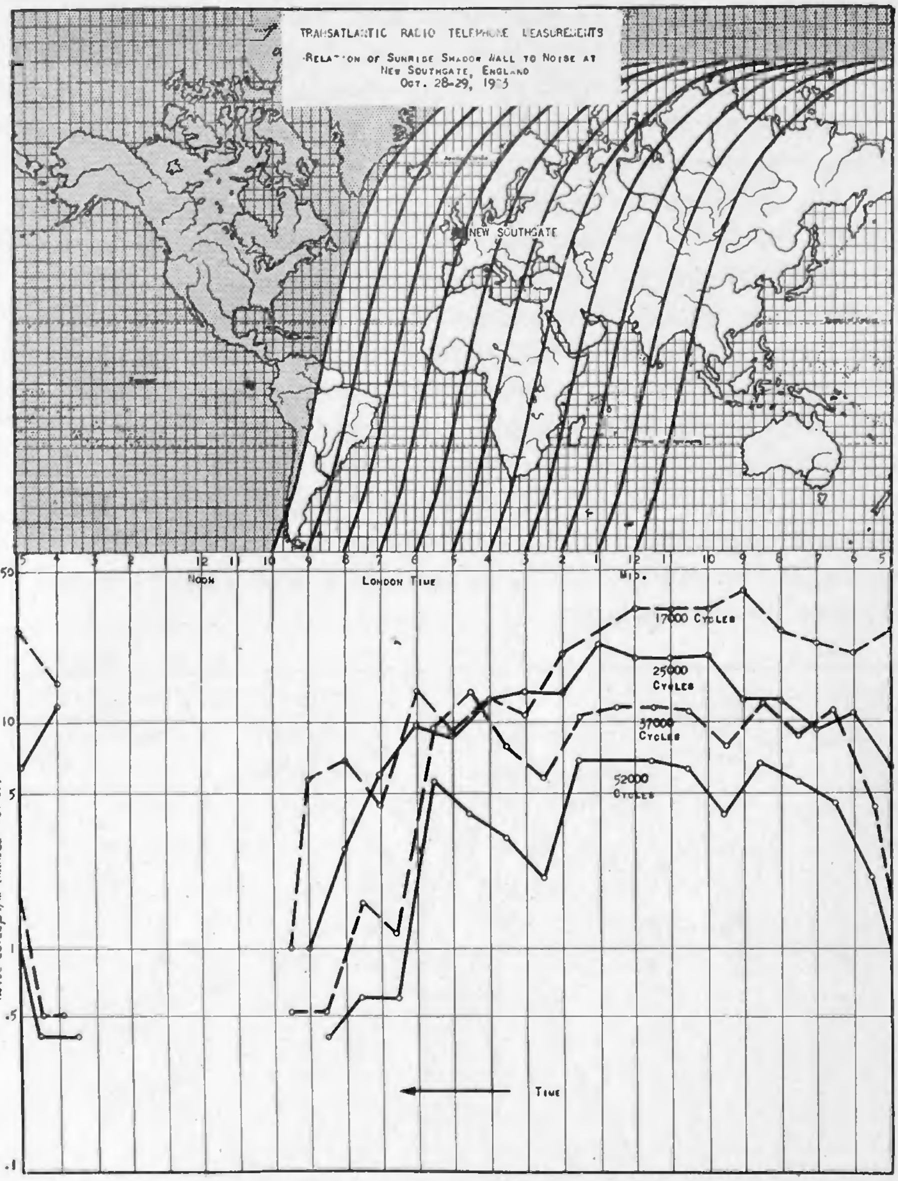


FIGURE 21—Relation of Sunrise Shadow Wall to Noise at New Southgate England October 28-29, 1923

and persists later into the morning than does the noise on the higher frequencies. This could be accounted for on the basis that the limits of the area from which the received longer wave static originates extend farther along the equatorial zone than they do for the higher frequencies.

The inclination of the shadow line on the earth's surface, which is indicated in the previous figure for October 28, shifts to a maximum at the winter solstice, recedes to a vertical position at the equinox and then inclines in the opposite direction. These several positions are illustrated in Figure 22. The set of three full lines to the right shows the position which the sunset shadow line assumes upon the earth's surface for each of three seasons—winter solstice, equinox, and summer solstice. Likewise, the dash-line curves show the position assumed by the sunrise line for the corresponding seasons. The particular time of day for which each of the sunset curves is taken, is that at which the static in London begins to increase to large night values. In winter, this occurs about sunset, at the equinox about one hour earlier, and in summer about two hours earlier, as illustrated in Figure 18. Correspondingly, the time for which each of the sunrise curves is taken, is that at which the high night-time values have reached the lower daylight values. From Figure 18 it will be evident that this occurs during the winter at about sunrise, at the equinox about an hour later, and during the summer some two hours later.

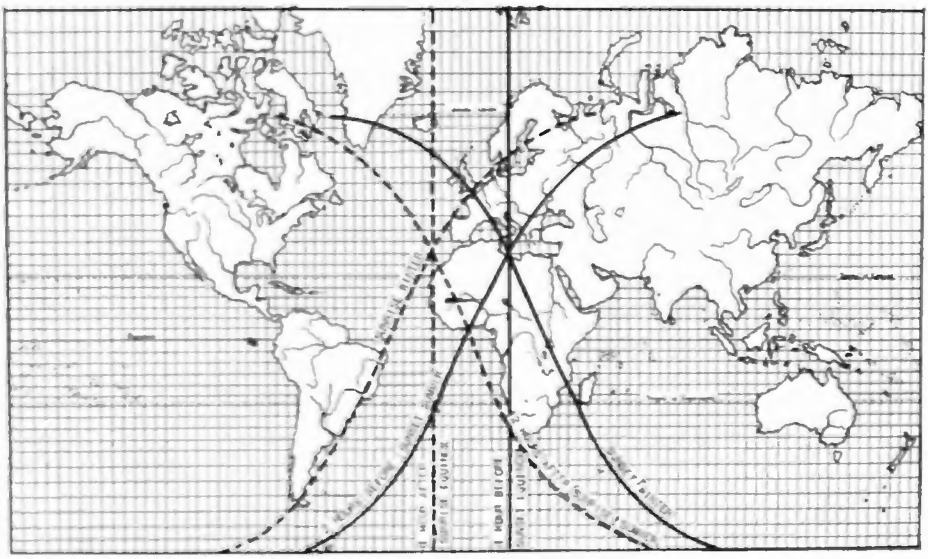


FIGURE 22—Position of Sunset Lines at Sunset Dip and Sunrise Lines at Sunrise Dip in Noise Level in England for Various Seasons

It will be observed that the two sets of curves, one for sunset and the other for sunrise, intersect at approximately the same latitude, the sunset curves southeast and the sunrise curves southwest of England. If it is assumed that the effect of the shadow wall upon the transmission of static is similar to that upon signal transmission across the Atlantic, namely, the high night-time values commence when the shadow wall is approximately half-way between the terminals, the crossing of the lines upon the chart may be taken as having significance in roughly determining the limits of the tropical area from which the major static originates. The crossing of the sunset lines indicates that the eastern limit of the area which contributes most of the static to England is equatorial East Africa. The crossing of the sunrise lines indicates that the corresponding western limit is somewhere in the South Atlantic, between Africa and South America. In other words, from these data the indications are that there is a more or less distinct center of gravity of static, which extends along the tropical belt, and that most of the long-wave static which affects reception in England comes from the equatorial region to the south of England, namely, equatorial Africa. This is exclusive of the high afternoon static prevailing during the Summer months.

The data obtained in the United States indicate that generally similar conditions exist there as to the relation between sunset and sunrise path and the major rise and fall of static. This relationship is shown in Figure 23, which shows in the upper half the course of the night-time belt as it proceeds from Europe to America and the corresponding rise in the static noise. The noise curves are the same as those shown in Figure 14 for reception at Belfast, Maine. The rise commences about one hour before and continues for one hour or so after sundown. This is for the fall season of the year. A similar chart for the sunrise conditions is given in Figure 24. Altho high night-time values started to fall off some five hours before sundown in Belfast, the more rapid drop was within two hours in advance. While these curves are for but a single day, they are fairly representative of the average of a greater amount of data. The change in the inclination of the sunset-sunrise curves with the season of the year effects changes for American reception somewhat similar to those shown for reception in England, except that for the summer months the coincidence is less definite. It may be that this is because of the somewhat lower latitude of the United States terminal and of the reception of a greater proportion of the static from the North American continent.

In general, therefore, the American results accord with those obtained in England in indicating quite definitely that a large proportion of the static received on the longer waves is of tropical origin.

Signal-to-Noise Ratio

It is, of course, the ratio of the signal-to-noise strength which

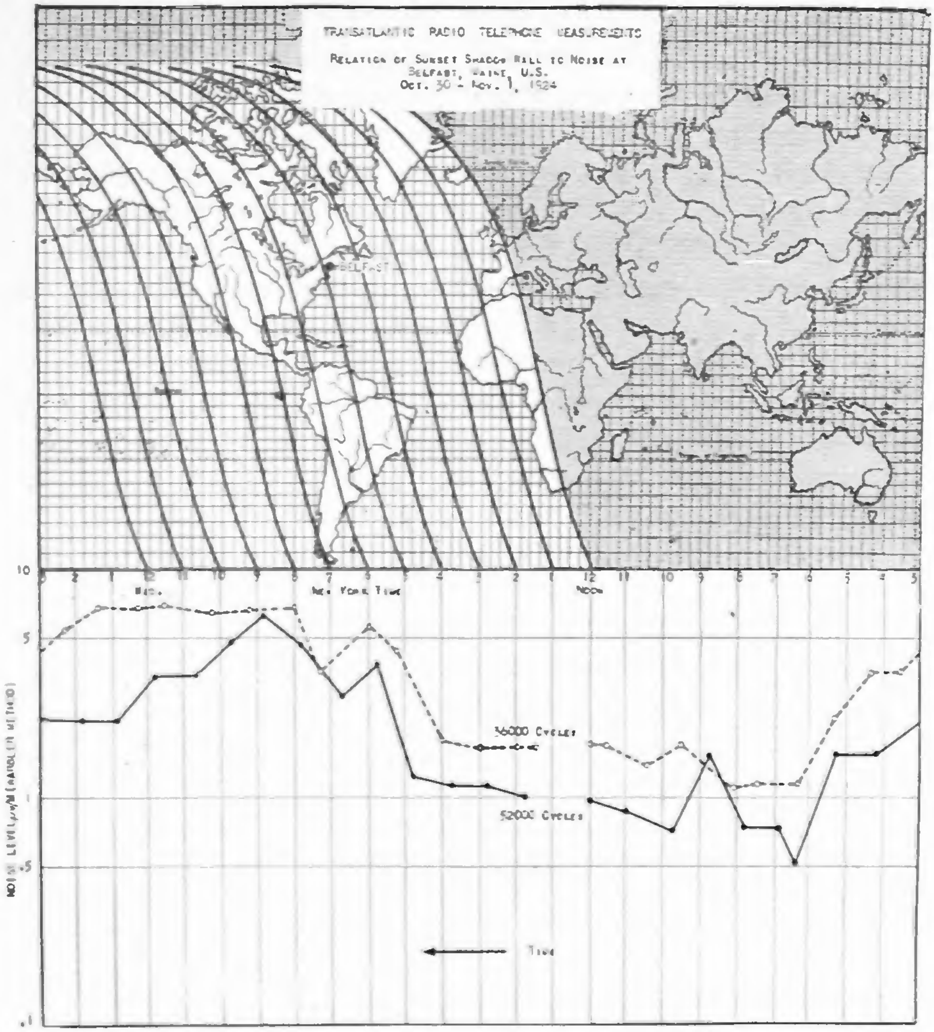


FIGURE 23—Relation of Sunset Shadow Wall to Noise at Belfast, Maine, U. S. October 30–November 1, 1924

determines the communication merit of a radio transmission channel.

VARIATION WITH FREQUENCY—Comparison of the signal-to-noise ratio for the two extreme frequencies measured, for representative summer and winter months, is given in Figure 25. Both of these transmissions were effected from the same station, Rocky Point, and similar antennas were employed. Comparison is made of the over-all transmission by correcting the values of the two curves to the same antenna power input, the power of both channels being scaled down to 68 kilowatts, the power used in the telephone channel during the early parts of the experiment. This chart shows clearly the greater stability in signal-to-noise ratio obtainable on the lower frequency channel. While for certain periods of the day the higher frequency gives a much

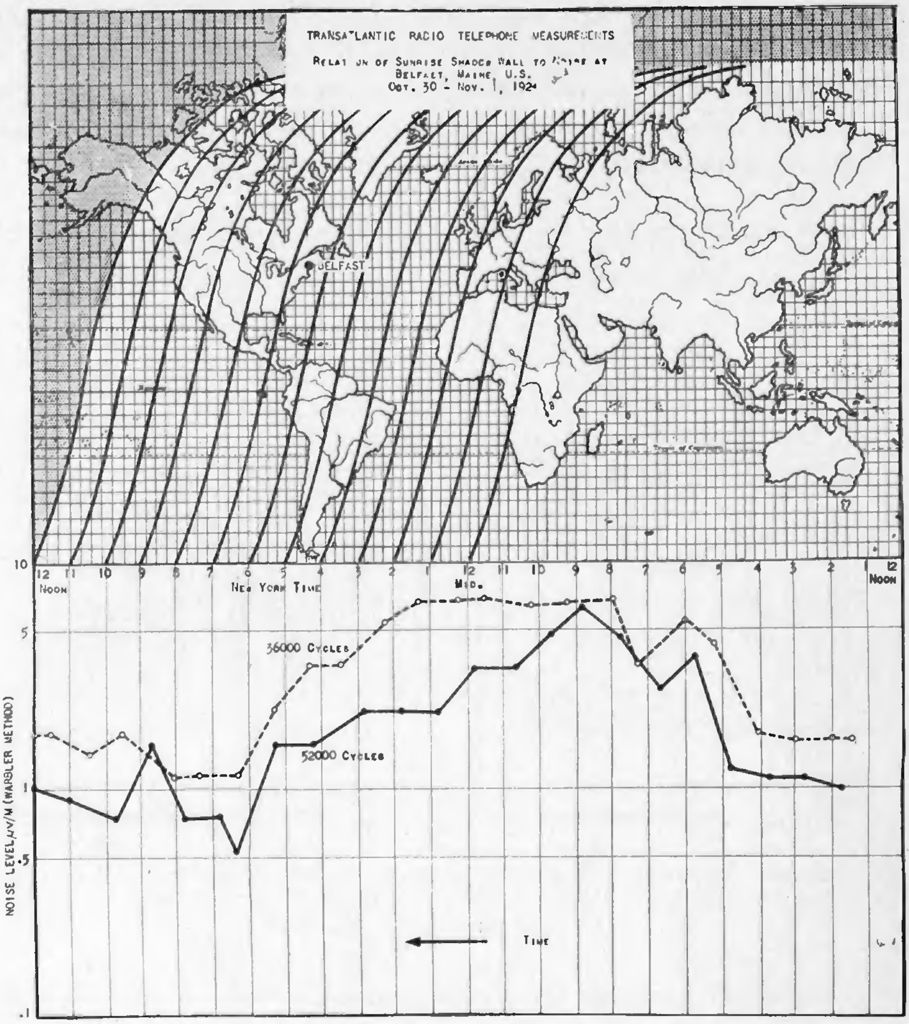


FIGURE 24—Relation of Sunrise Shadow Wall to Noise at Belfast, Maine, U. S. October 30,—November 1, 1924

better ratio, it is subject to a much more severe sunset decline than is the lower frequency. During the summer time, afternoon reception in England is better on the higher frequency channel. This is because of the considerably greater static experienced at this time on the lower frequency. The higher signal-to-noise ratio prevailing during the winter month of January as compared with the summer month of July is evident. This is due primarily to higher summer static.

SEASONAL VARIATION IN ENGLAND AND UNITED STATES—For the 57-kilocycle channel there is shown for each month of the year in Figure 26 signal-to-noise ratios of two years' data. These show a distinct dip corresponding to the sunset dip of the signal field strength. The night-time values are generally high in accordance with the high night-time signal strength, but the maximum values are shifted toward the time of sunrise. This is due to the fact that the noise rises earlier in the afternoon and declines earlier in the morning than do the corresponding variations in signal strength.

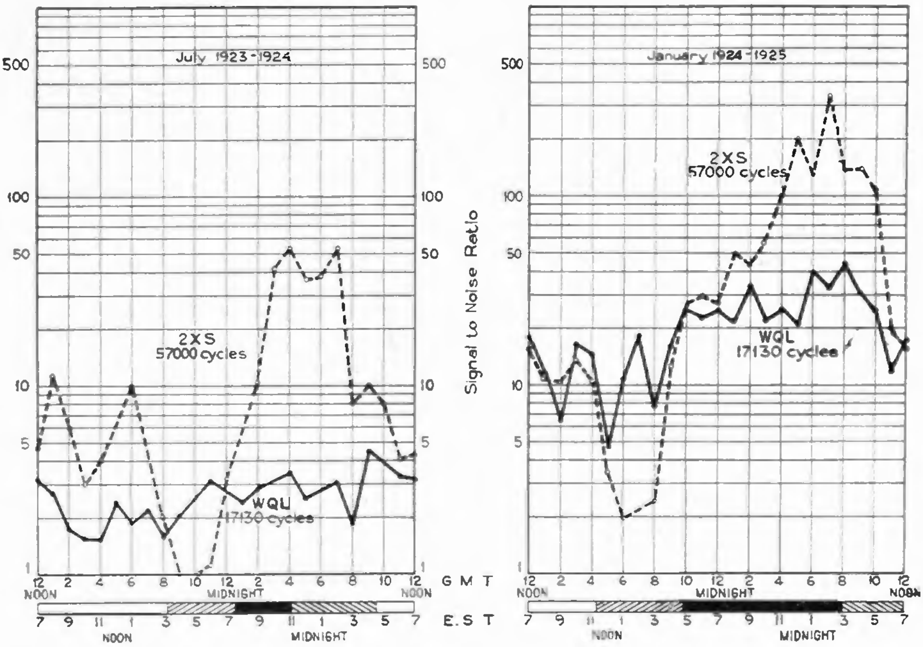


FIGURE 25—Variation of Signal-to-Noise Ratio with Frequency. Corrected to Same Antenna Input Power (68.5 kw.) in Rocky Point Antenna. Reception at New Southgate, England

Figure 27 presents the signal-to-noise ratios for such data as ave thus far been obtained upon transmission from England to the United States on a frequency of 52 kilocycles. The low values obtained about sunset are, of course, due to the evening dip in field strength. In general, the night-time ratios do not reach such high values as do those for England because the early morning signal field strength begins to fall off while the noise level is still high. Comparison of the signal-to-noise ratios obtained at New Southgate and at Belfast show that the Belfast values are somewhat higher for that part of the day which corresponds to forenoon in the United States and afternoon in England. This is because the forenoon static in the United States is lower than the afternoon static in England.

DIRECTIVE RECEIVING ANTENNAS

The picture which has been given of the transmission of static northward from the tropical belt suggests that the signal-to-

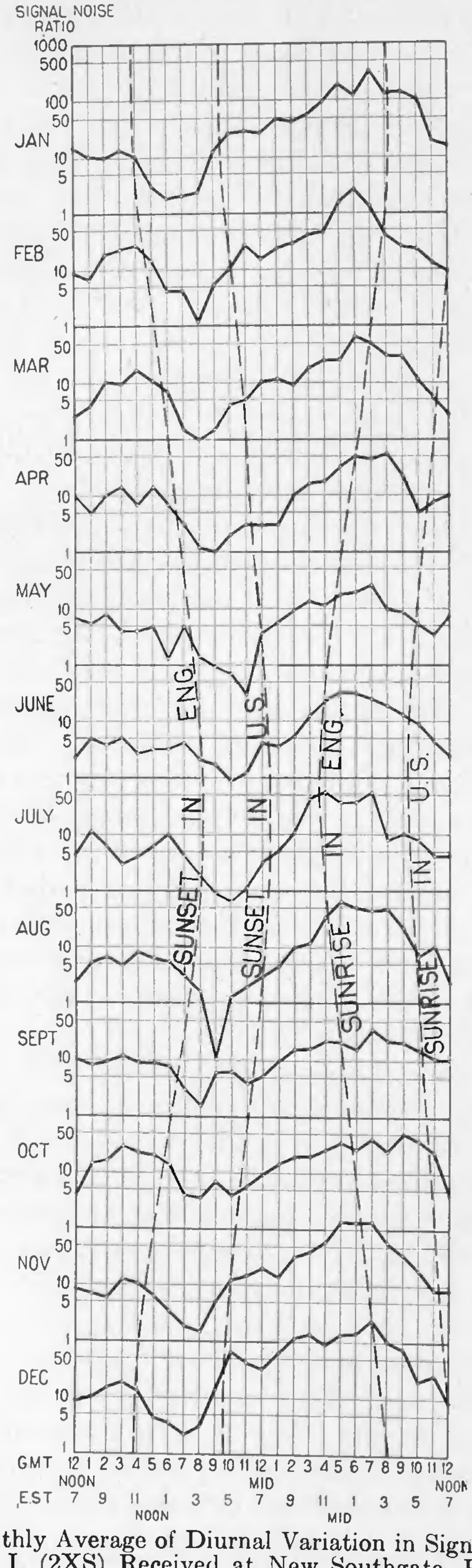


FIGURE 26—Monthly Average of Diurnal Variation in Signal-to-Noise Ratio. Rocky Point, L. I. (2XS) Received at New Southgate, England, 20.8 kw. radiated. 5,480 km. 57,000 Cycles. 1923-1924

noise ratio might be materially improved by the use of directional receiving systems This is, of course, what has actually been found to be the case in commercial trans-Atlantic radio telegraphy wherein the Radio Corporation of America has made such effective use of the wave antenna devised by Beverage. The expectations are confirmed by measurements which have been made in the present experiments using such wave antennas.

A year and a half ago the British Post Office established a wave antenna with which to receive from the Rocky Point radio telephone transmitter. More recently a program of consistent observations in directional reception of east-to-west transmission was also undertaken in which were employed wave antennas built by the Radio Corporation of America for radio telegraph operation upon lower frequencies.

An indication of the improvement which the wave antenna gives in signal-to-noise ratio is had by reference to Figure 28. The set of curves to the right is for reception at Chedzoy, England, and those at the left for reception at Belfast and Riverhead in the United States. The improvement is measured in terms of the signal-to-noise ratio obtained on the wave antenna, divided by the signal-to-noise ratio measured on the loop. For the particular days and frequency indicated, the improvement in England will be seen to vary over a considerable range, averaging about 5. Data for reception in England are for 1924, while those for the United States are for the corresponding period of 1925. The United States results will be seen to be generally similar to those obtained in England. Altho these experiments are still in an early stage, the results do give a measure of the order of improvement which can be expected.

Test of Words Understood—Perhaps the most convincing measure of the efficiency of directional receiving systems for trans-Atlantic transmission is the improvement effected in the reception of intelligible words. Figure 29 shows the improvement which the wave antenna in England has made in the ability to receive certain test words spoken from Rocky Point. For this purpose there was transmitted from Rocky Point a list of disconnected words. A record was made at Chedzoy of the percentage of the words understood for reception on the loop and on the wave antenna. This constitutes a convenient method of rough telephone testing. It will be appreciated, however, that it would be possible to understand a greater proportion of a conversation than is represented by these results. The curves show that it was possible to receive, for example, 80 percent of the

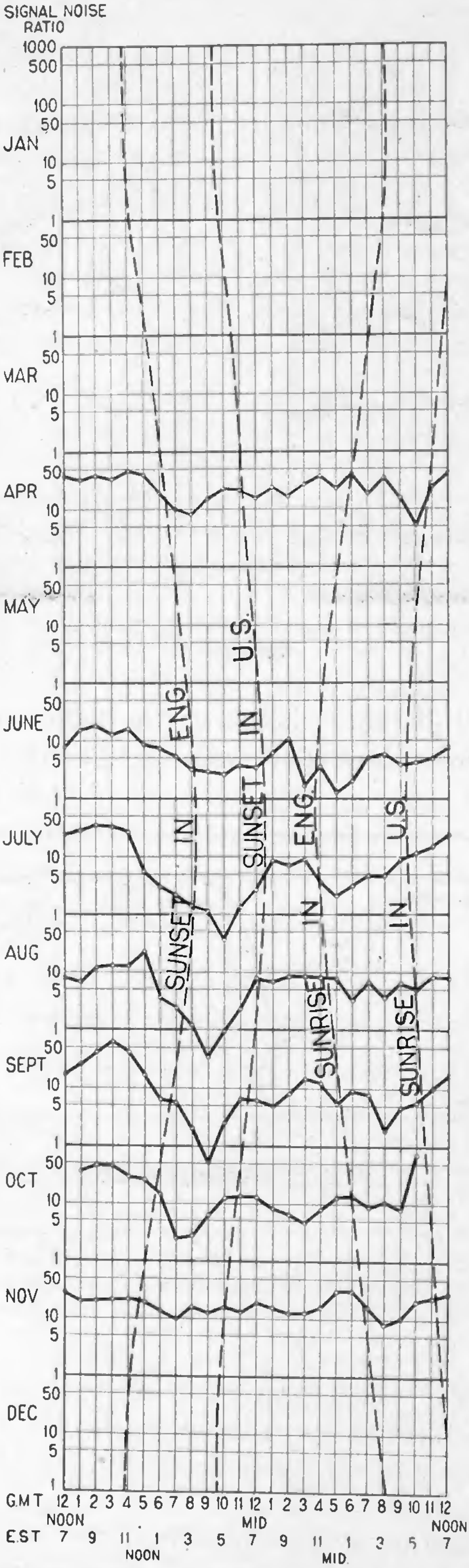


FIGURE 27—Monthly Averages of Diurnal Variation in Signal-to-Noise Ratio. Northolt, England. (GKB) Received at Belfast, Maine. Corrected to 20,8 kw. Radiated. 4,980 km. 52,000 Cycles. 1924

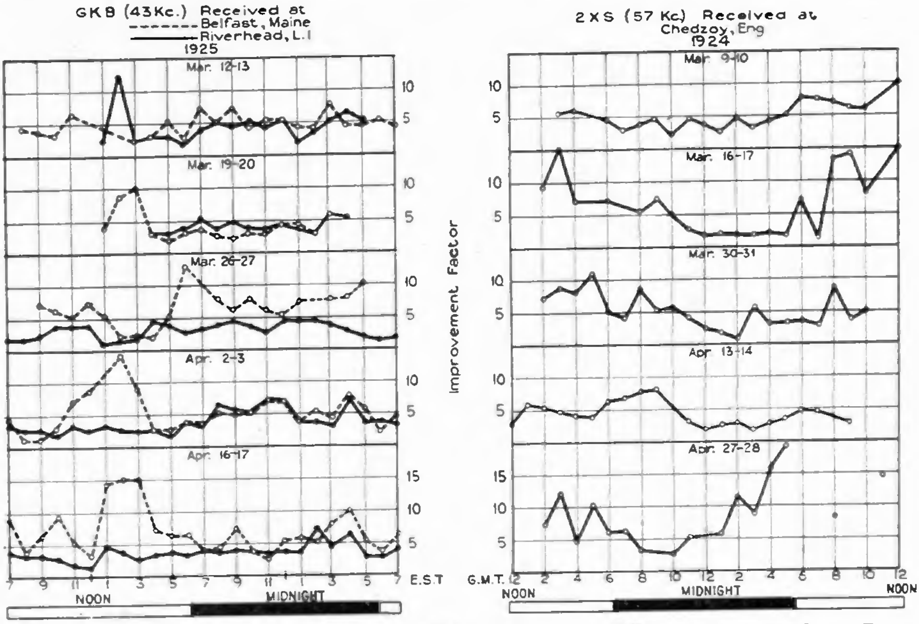


FIGURE 28—Improvement in Signal-Noise Ratio of Wave Antenna Over Loop Reception

words for but 9 of the 24 hours on the loop, whereas with the wave antenna, reception continued for 18 hours.

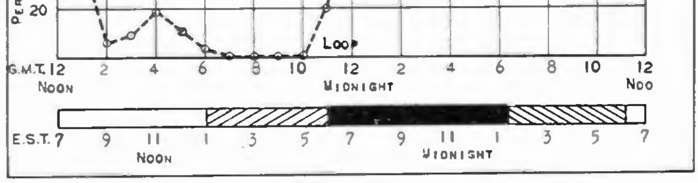


FIGURE 29—Comparison of Reception on Wave Antenna and Loop Percent of Words Understood. Reception of Rocky Point (2XS) at Chedzoy, England, March, 1924

CONCLUSIONS: This paper gives analyses of observations of long-wave transmission across the Atlantic over a period of about two years. The principal conclusions which the data seem to justify are as follows:

1. Solar radiation is the controlling factor in determining the diurnal and seasonal variations in signal field. Transmission

from east to west and west to east exhibit similar characteristics

2. Transmission in the region bordering on the division between the illuminated and the darkened hemispheres is characterized by increased attenuation. This manifests itself in the sunset and sunrise dips, the decrease in the persistence of high night-time values in summer, and the decrease in daylight values during the winter.

3. Definite correlation has been found between abnormal radio transmission and disturbances in the earth's magnetic field. The effect is to decrease greatly the night-time field strength and to increase slightly the daylight values.

4. The limit of the high night-time value of signal field strength for trans-Atlantic distance is essentially that given by the Inverse Distance Law. The normal daylight field strengths obtained in these tests can be approximated by a formula of the same form as those earlier proposed but with somewhat different constants.

5 The major source of long-wave static, as received in both England and the United States, is indicated to be of tropical origin.

6. In general, the static noise is lower at the higher frequencies. At night the decrease with increase in frequency is exponential. In daytime the decrease with increase in frequency is linear in range of 15 to 40 kilocycles. The difference between day and night static is, therefore, apparently due largely to daylight attenuation.

7. The effect of the static noise in interfering with signal transmission, as shown by the diurnal variations in the signal-to-noise ratio, is found to be generally similar on both sides of the Atlantic.

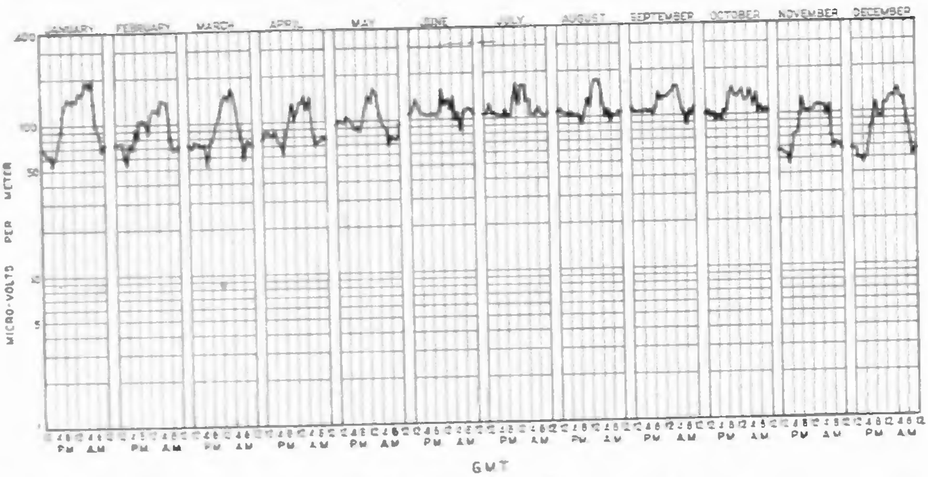
8. Experiments in both the United States and England with directional receiving antennas of the wave antenna type show an average improvement in the signal-to-static ratio of about 5 as compared with loop reception.

SUMMARY: The paper reports upon measurements of trans-Atlantic radio transmission which had been made during the past two years in a study of the possibilities of trans-Atlantic radio telephony. These measurements cover several different frequencies in the range below 60 kilocycles in both directions across the Atlantic and represent probably the most comprehensive study yet made of any transmission path. An earlier paper described the special high-power radio telephone system and the measurement methods employed in the tests, and gave certain preliminary measurement results.

The relation which exists between the diurnal and seasonal variations of signal field and the exposure of the transmission path to sunlight is shown. The conformity of the measured results to the values determined by formulas is indicated. Interesting correlation is shown between abnormal radio transmission and magnetic storms.

The diurnal and seasonal characteristics of noise are shown to be generally similar to those of signal strength and indicate the noise to be of tropical origin. The average frequency distribution of static is shown for various receiving stations.

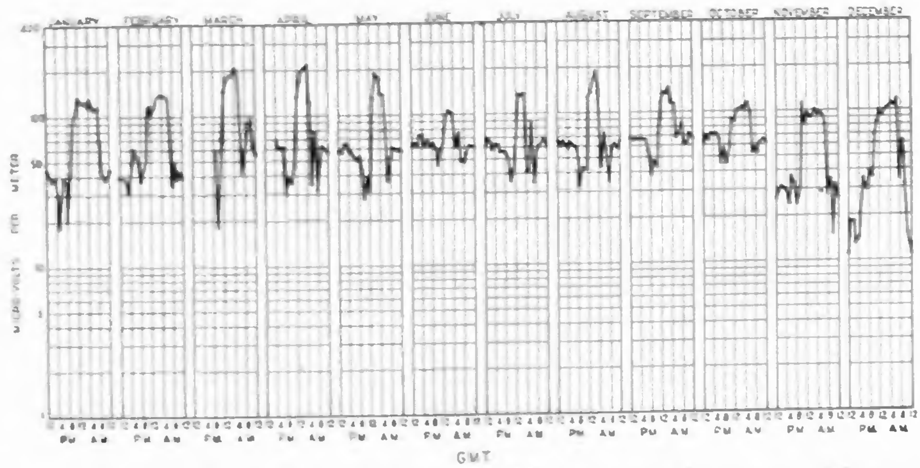
Signal-to-noise ratios are shown for both England and United States for transmission on 50 odd kilocycles, together with the improvement afforded by a directional receiving system of the wave-antenna type.



Monthly Averages of Diurnal Variation of Signal Field Strength. Rocky Point, L. I., U. S. A. (WQL) Measured at New Southgate, England. Corrected to 600 Amperes Antenna Current

5,480 Km. 17,130 Cycles

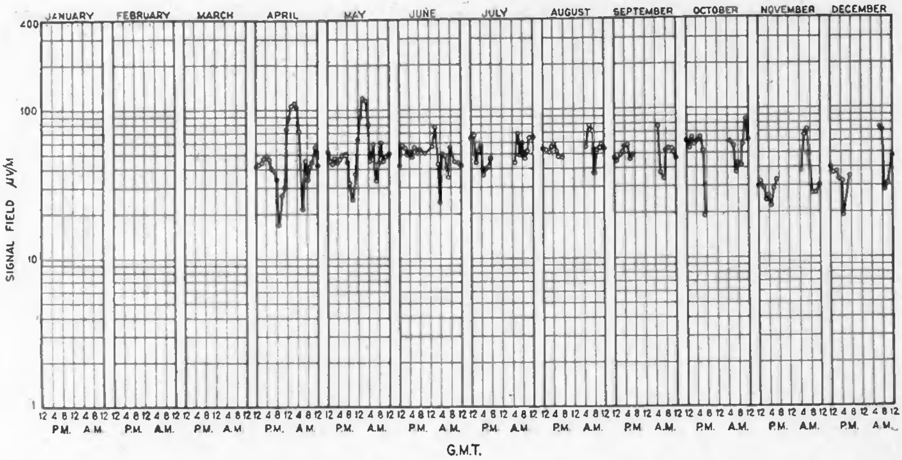
April, 1923—February, 1925



Monthly Averages of Diurnal Variation of Signal Field Strength. Marion, Mass., U. S. A. (WSO) Measured at New Southgate, England. Corrected to 600 Amperes Antenna Current

5,280 Km. 25,700 Cycles

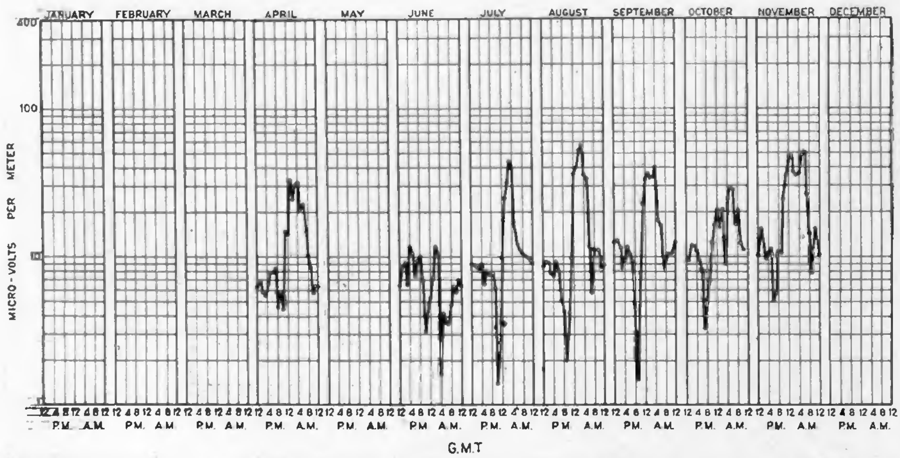
August, 1923—February, 1925



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield England. (GBL) Measured at Belfast, Maine. Corrected to 300 Amperes Antenna Current

4,980 Km. 24,050 Cycles

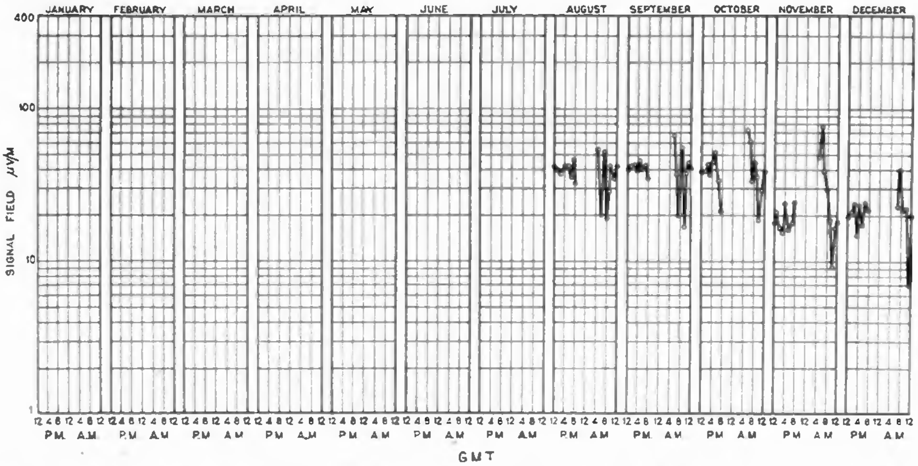
1924



Monthly Averages of Diurnal Variations of Signal Field Strength. Northolt, England. (GKB) Measured at Belfast, Maine. Corrected to 100 Amperes Antenna Current

4,885 Km. 52,000 Cycles

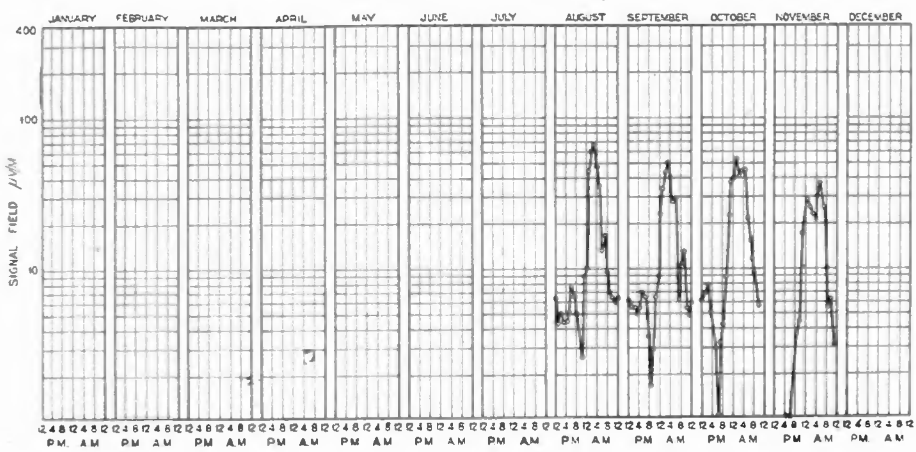
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield, England (GBL) Measured at Riverhead, L. I. Corrected to 300 Amperes Antenna Current.

5,360 Km. 24,050 Cycles

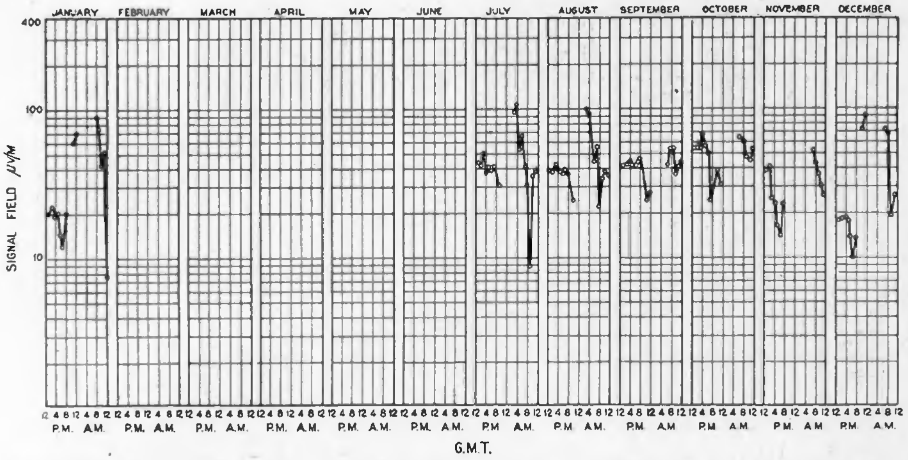
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Northolt, England. (GKB) Measured at Riverhead, L. I., Corrected to 100 Amperes Antenna Current

5,460 Km. 52,000 Cycles

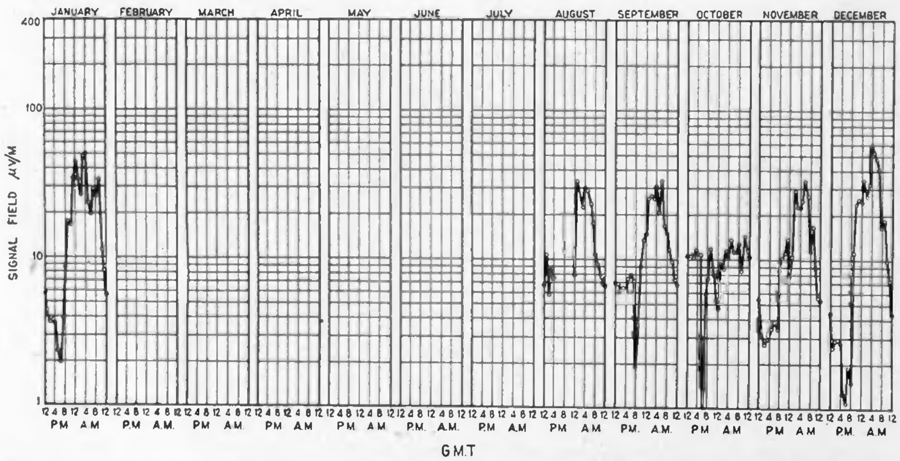
1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Leafield, England. (GBL) Measured at Green Harbor, Mass. Corrected to 300 Amperes Antenna Current

5,150 Km. 24,050 Cycles

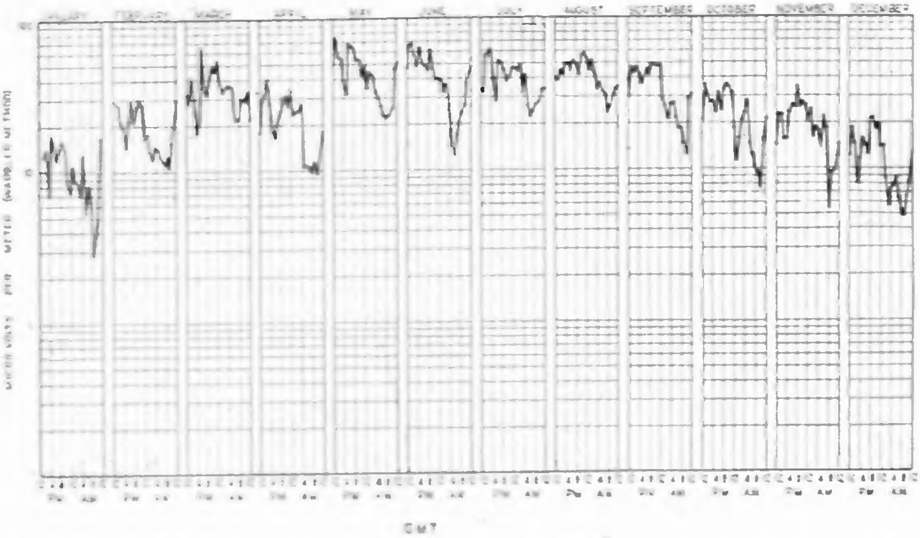
July, 1923—January, 1924



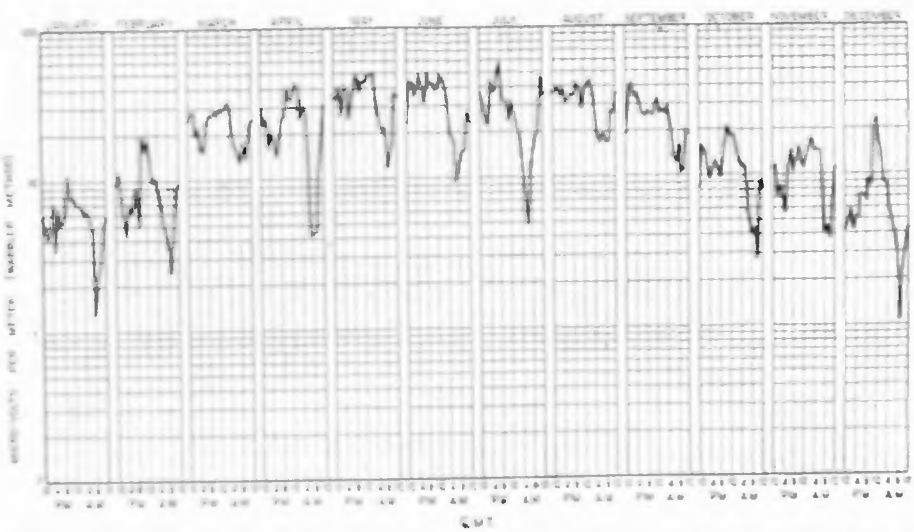
Monthly Averages of Diurnal Variation of Signal Field Strength. Northolt, England. (GKB) Measured at Green Harbor, Mass. Corrected to 100 Amperes Antenna Current

5,240 Km. 54,500 Cycles

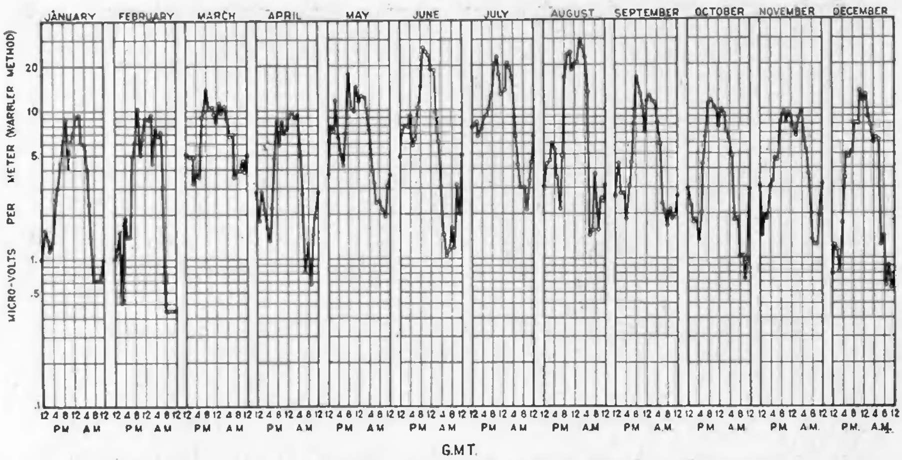
August, 1923—January, 1924



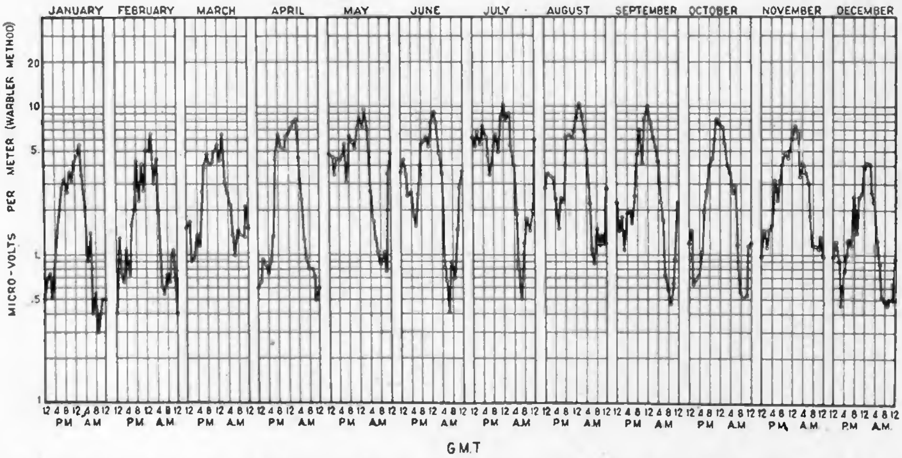
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
17,000 Cycles
April, 1923—February, 1925



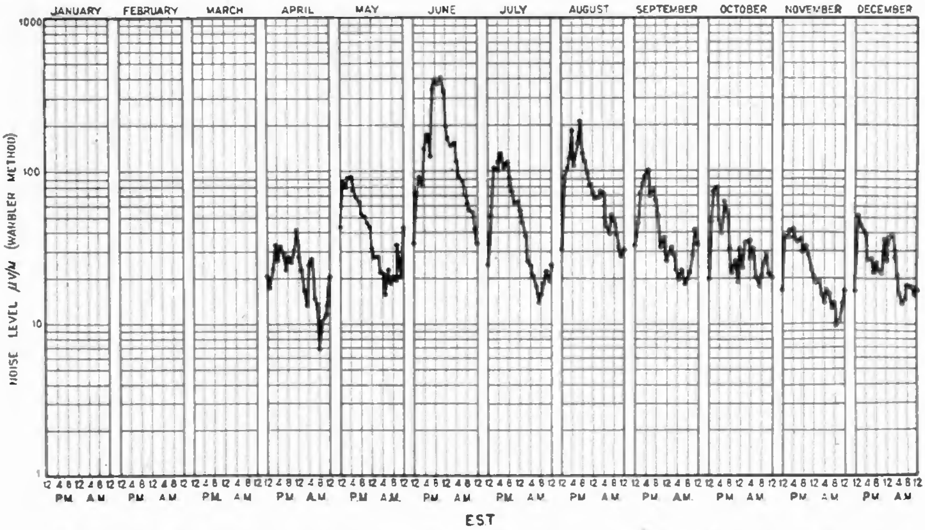
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
25,000 Cycles
August, 1923—February, 1925



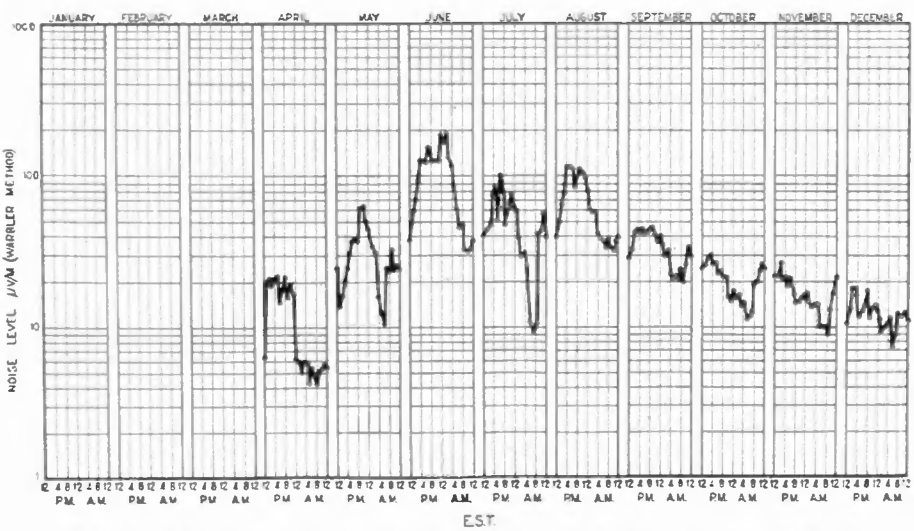
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
37,000 Cycles
October, 1923—February, 1925



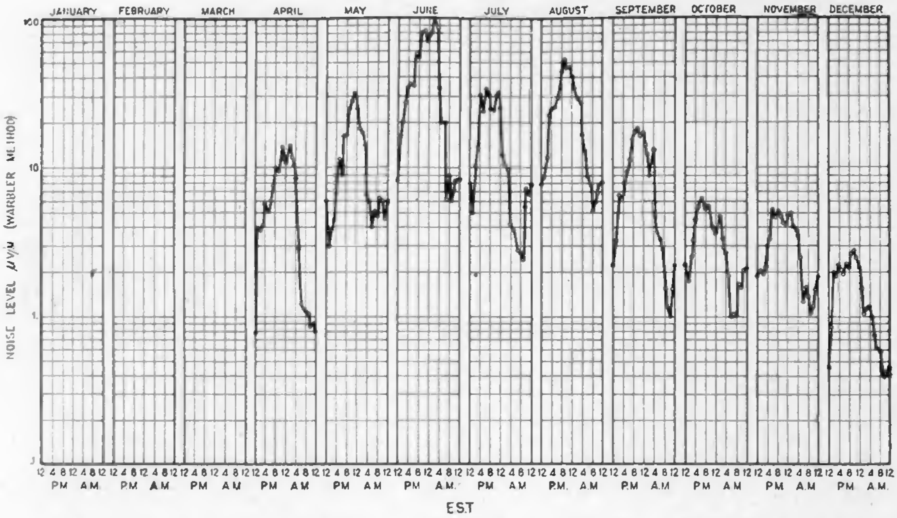
Monthly Averages of Diurnal Variation of Noise. New Southgate, England
57,000 Cycles
1923—1924



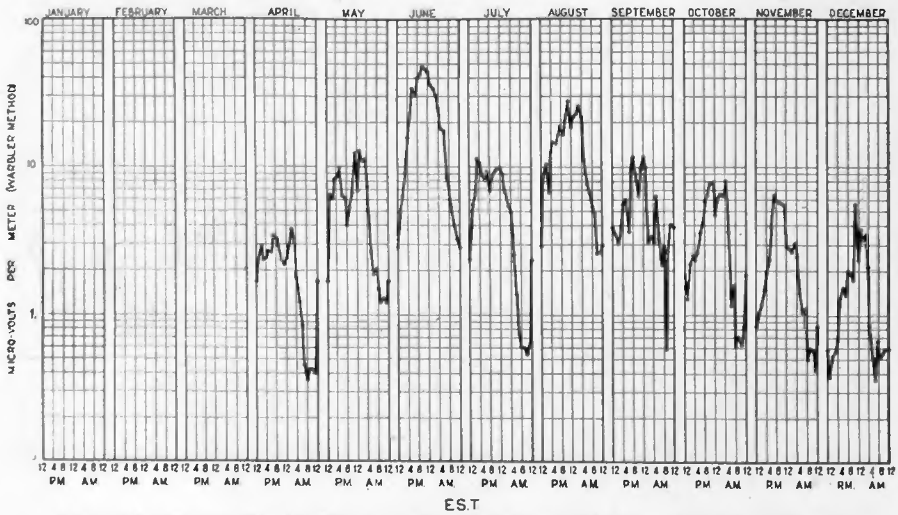
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
15,000 Cycles
1924



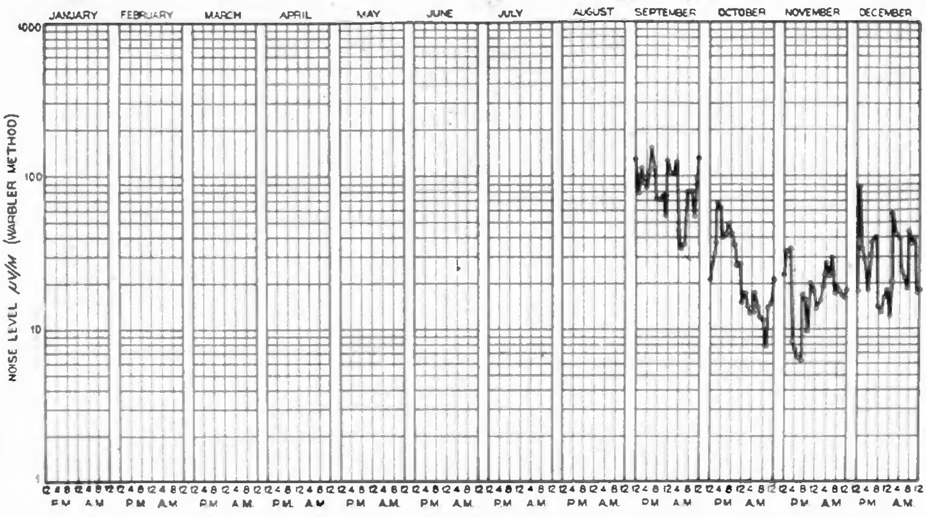
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
24,000 Cycles
1924



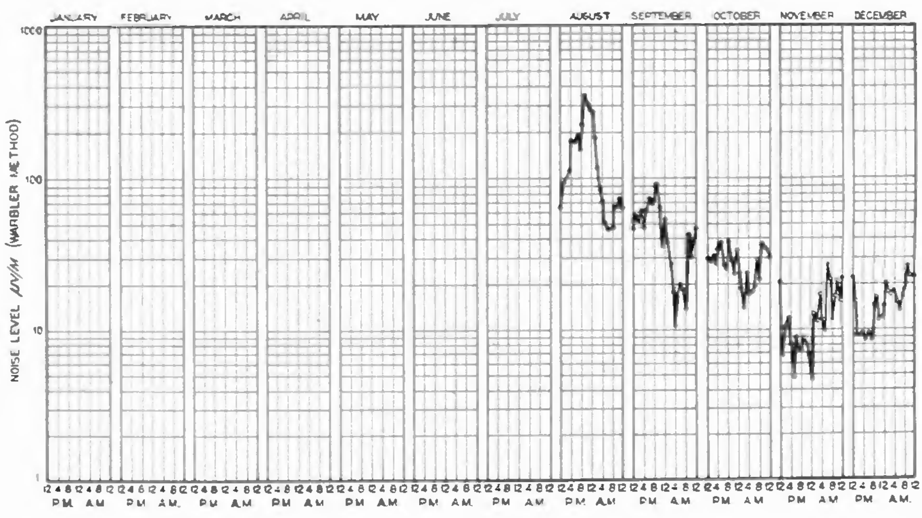
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
36,000 Cycles
1924



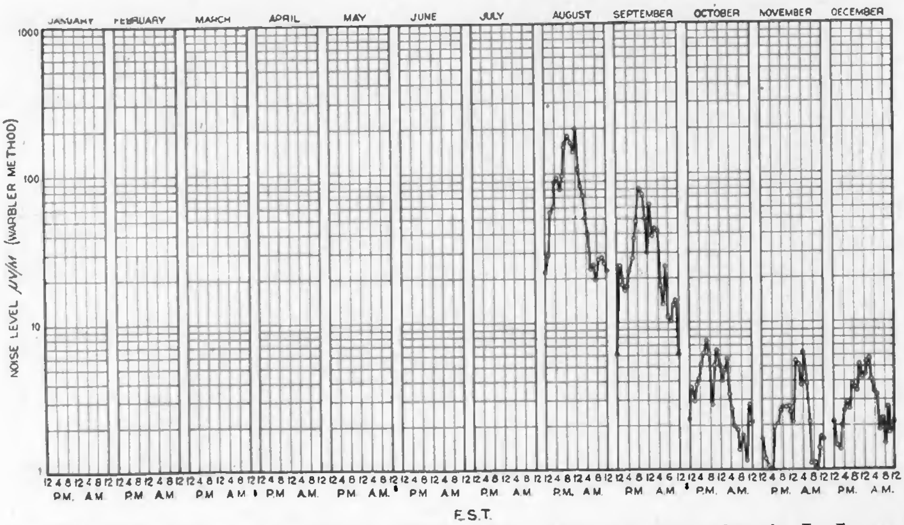
Monthly Averages of Diurnal Variation of Noise. Belfast, Maine
52,000 Cycles
1924



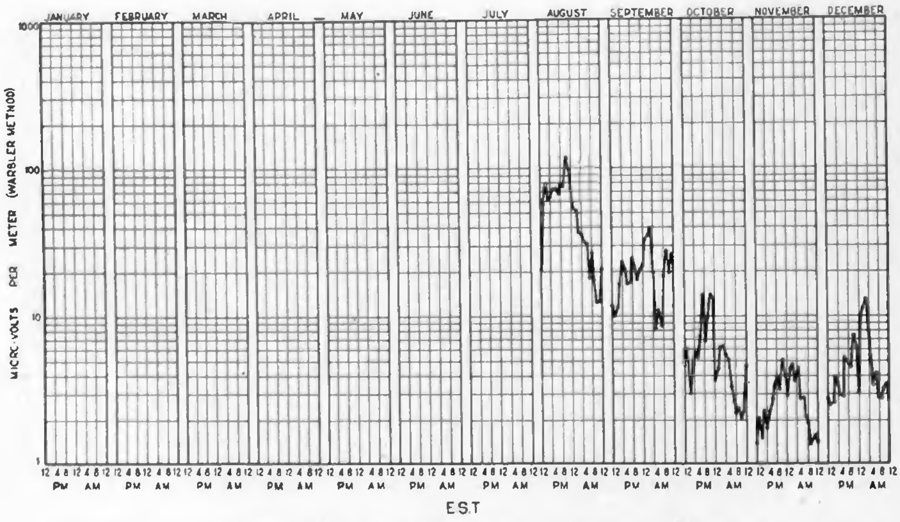
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
15,000 Cycles
1924



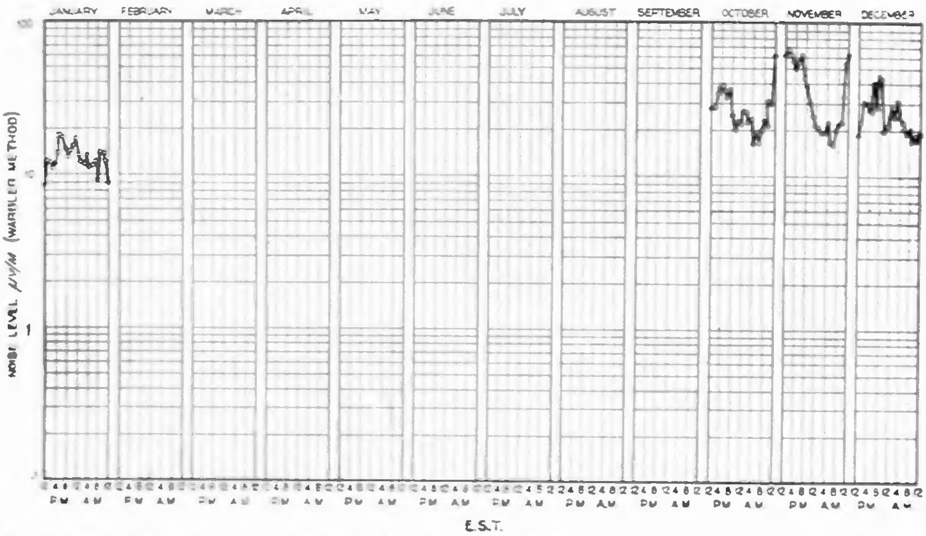
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
24,000 Cycles
1924



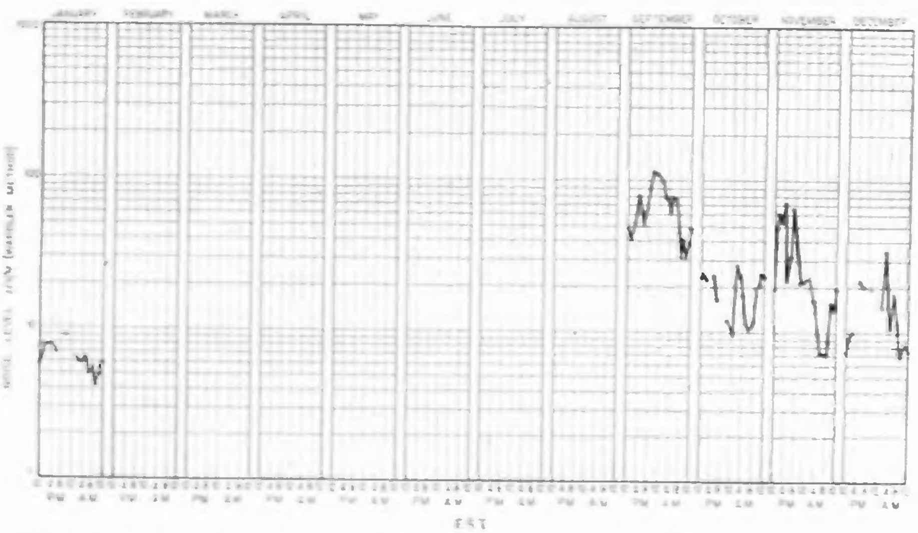
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
36,000 Cycles
1924



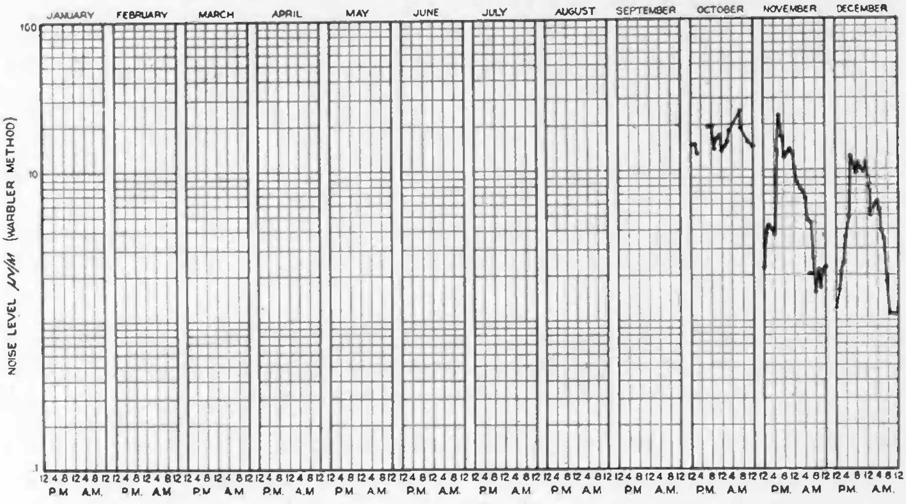
Monthly Averages of Diurnal Variation of Noise. Riverhead, L. I.
52,000 Cycles
1924



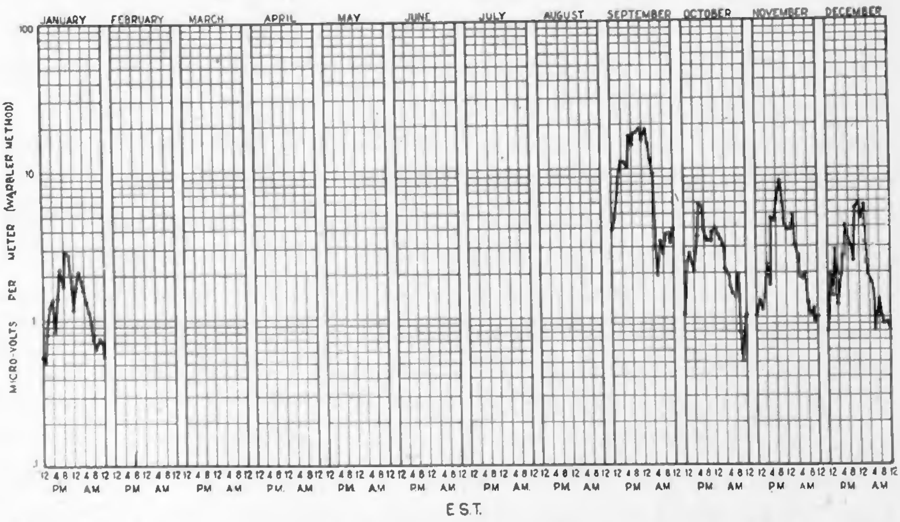
Monthly Averages of Diurnal Variation of Nouse. Green Harbor, Mass.
15,000 Cycles
October, 1923—January, 1924



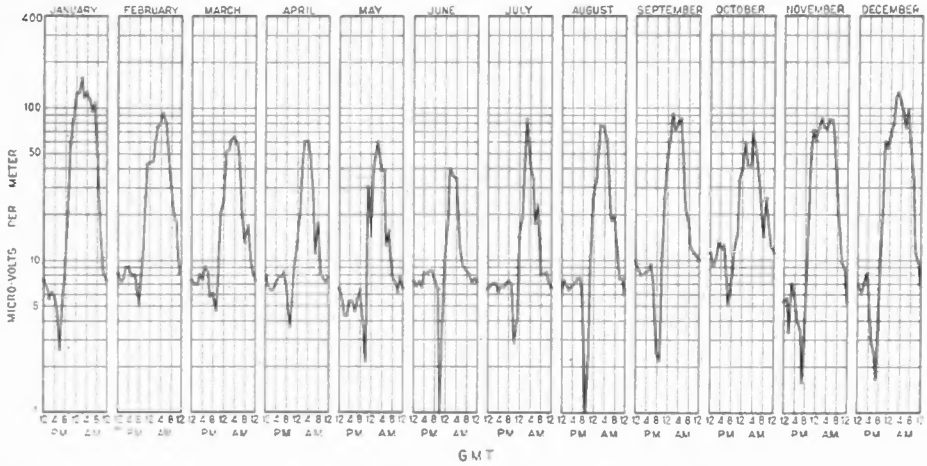
Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
24,000 Cycles
September, 1923—January, 1924



Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
34,000 Cycles
1923



Monthly Averages of Diurnal Variation of Noise. Green Harbor, Mass.
55,000 Cycles
September, 1923—January, 1924



Monthly Averages of Diurnal Variation of Signal Field Strength. Rocky Point, L. I., U. S. A. (2XS) Measured at New Southgate, England. Corrected to 300 Amperes Antenna Current

5,480 Km. 57,000 Cycles

January, 1923—December, 1924

SOME STUDIES IN RADIO BROADCAST TRANSMISSION

By

Ralph Bown, DeLoss K. Martin and Ralph K. Potter

Department of Development and Research, American Telephone and Telegraph Company

One of the things which must be given increasing attention, if the technique of radio telephone broadcasting is to consolidate and continue its remarkable progress, is the mechanism of the transmission of radio signals through space. In many receiving situations the largest apparent defects present in the reproduced signal are those suffered not in the terminal apparatus but in transit through space, and in these cases better methods of utilizing the transmitting medium must precede any major betterment in overall results. In the present paper we are reporting some investigations in this field of radio transmission which have uncovered a number of interesting facts and have led to at least one conclusion which is of practical utility.

Nighttime transmission, which is the usual case in broadcasting, is in many places commonly marred by fading and sometimes by actual distortion of signals. Often these occur in certain areas not more distant from the transmitting station than other areas which enjoy freedom from such annoyance. Selecting a particular instance of these difficulties in an area near New York City which, in so far as can be judged at present, is probably a typical instance, we have subjected it to an intensive experimental study to determine what is the inherent nature of the troubles and if possible how thay may be alleviated. In doing this it has been necessary to employ novel forms of tests especially fitted to bring out in a concrete way the phenomena being investigated.

To provide a suitable background for the subject we have started our discussion below with a brief recital of some of the things which a transmission medium is called upon to do. Following this we have described our tests, pointing out in what ways the existing media seem to fall short of doing these things and offering certain speculations as to the reasons for the shortcomings. In conclusion, we have analyzed some practical problems in the light of this work.

Fundamental Considerations

As the radio art has progressed from spark telegraphy into continuous wave telegraphy and into high quality radio telephone broadcasting, increasing demands have been made on the transmission medium to deliver at the receiving point a true sample of what was put into it at the transmitting station. The requirements have grown in rigor because in telegraphy the end has been to develop increased reliability of communication at longer ranges and in telephony the medium is called upon to transmit a highly complex form of intelligence.

Of the requirements placed on the transmission medium by modern uses, those imposed by telephony are far more exacting than those for telegraphy. In telegraphy a single frequency, or at most a narrow band of frequencies sent out intermittently in accordance with a dot and dash code must reach the receiving station in such shape that it may be converted into audible sound for aural interpretation or into current pulses for the operation of relays or recording instruments. Leaving aside noise, the principal requirement is a sufficient freedom from fading so that signals can be interpreted or recorded without interruption. In radio telephony, as at present practiced in broadcasting, there is transmitted a modulated high-frequency wave comprising a relatively wide band of frequencies, usually at least 10 kilocycles. Such a modulated high-frequency wave drawn out in the familiar graphical representation is a comparatively simple-looking thing, but analyzed into its elements and studied in detail it is revealed as being an intricate fabric of elemental waves so interwoven with each other that no one of them can be disturbed without changing in some degree the complexion of the whole. For perfect results the whole band must arrive at the receiver with an amplitude continuously proportional to that leaving the transmitter, or the inflections or expression of the speech or music will not be correctly reproduced. All the component frequencies within the band must be unchanged in their relative amplitudes lest the character of the sounds be altered. Even the relative phase relations of the various frequencies must be preserved or, as will be shown later, the interaction of the two side bands in the receiving detector will result in the partial loss of some of the frequency components.

It is not long since the time when radio was supposed to be the perfect medium for voice transmission, it being presumed that since the ether of space (if there be such a thing) was substantially perfect in its electrical characteristics it must transmit frequency bands carrying telephone channels without distortion of any kind. This may be true theoretically of a pure ether, but in fact, the ether used for radio communication is filled with a number of things ranging from gaseous ions down to the solid bed rock of the earth. It is rather to be expected that these will affect the progress of electromagnetic waves, and we know from experience that they do. Diurnal variations of attenuation, fading, directional changes, dead spots and the like are already well-known phenomena, resulting from the complexity of our transmission media, although no entirely adequate explanations of their causes have been certainly established. One of the most recent manifestations of the effects of irregularities in transmission through space is in the distortion of the quality of telephone signals. This was perhaps first noticed in the use of short waves for broadcasting, it being found that frequently the transmission was so distorted that after detection the signals such as speech and music were in severe cases almost unrecognizable.

Preliminary Investigations

For some time after quality distortion was recognized as a characteristic of existing short wave transmissions, it was thought that for the lower broadcasting frequencies, at least, it was present only at night and at relatively very great distances from the transmitter. However, careful observations demonstrated that there were points relatively near New York City where quality distortion from several broadcasting stations in the city was marked at night, and in at least one case was detectable even in daytime. When the station 2XB, the Bell Telephone Laboratories' experimental station at 463 West Street, New York City, was used to transmit test signals, it was found that quality distortion could be observed in northern Westchester county and in southern Connecticut at distances of about 30 to 50 miles from the transmitter. Fading was also pronounced, and it was noted as a significant fact that distortion was always accompanied by some fading although the reverse was not consistently true. In the course of these trials it was noticed that at a particular point near New Canaan, Connecticut, signals from 2XB were much weaker and more distorted than signals from 2XY, the experimental station of the American Telephone and Telegraph Company at 24 Walker Street, New York, even though the transmitter at 2XB was about ten times more powerful. Daylight field strength measurements at this point showed that the field strength of 2XB was only one-third that of 2XY. This led to the rather startling conclusion that there is a ratio of 100 to 1 in the power efficiency of transmission to that particular receiving point from these two transmitting stations in New York which are only about one mile apart.

In order to throw some light on this state of affairs, a field strength survey was made by G. D. Gillett which resulted in the field strength contour map[1] here reproduced in Figure 1. The

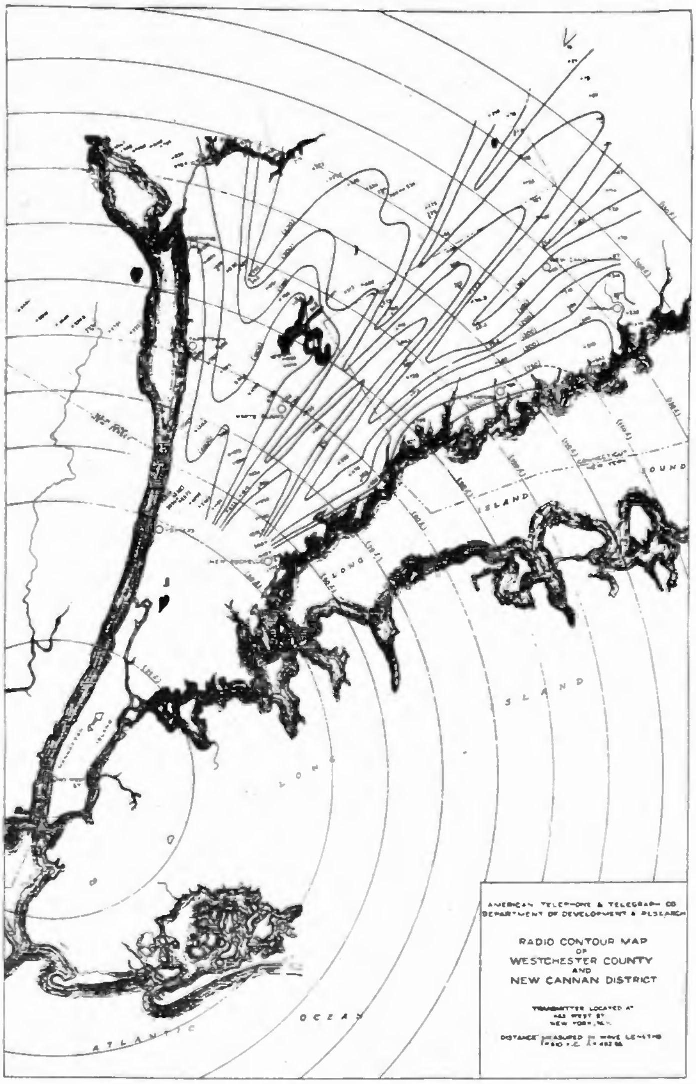


FIGURE 1—Radio Contour Map Showing Wave Interference Pattern

[1] This map was prepared by Mr. Gillett using the methods discussed in a aper "Distribution of Radio Waves from Broadcasting Stations Over City Districts," by Ralph Bown and G. D. Gillett, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 12, number 4, page 395, August, 1924.

contours on this map show that there is a series of long nearly parallel hills and valleys of field strength which, extrapolated, would converge in lower Manhattan and which extend out to the northeast as far as it was thought worth while to follow them. There has occurred to us no better explanation of this hitherto unchartered form of field strength distribution than that it is a gigantic wave interference pattern. A detailed discussion of this theory is given in another section of this paper.

The fixed pattern shown by Figure 1 is definitely present only in the daytime, but that it is fixed is attested by the fact that a second survey made about a year later checks with the original one quite closely. At night fading is pronounced in the area covered by the pattern and it is apparent that some other factors must enter. As a result of an endeavor to check up the pattern at night it was discovered that quality distortion was, in general, most evident at places which were, by day, in the valleys of the field strength diagram, and a point in one of these valleys near Stamford, Connecticut, was selected for the establishment of a temporary field test station. The interior of this station, which was in the empty hay-mow of a barn, is illustrated by the photograph, Figure 2. At this place apparatus was set up to enable a study of the nature of the distortion in signals from 2XB. Many of the records discussed in succeeding paragraphs were taken at this Stamford field station. Others were taken near Riverhead, Long Island, which was also found to be well located for such work. Figure 3 is an outline map showing the relative positions of these field receiving stations and the transmitting station.

The reason for settling down at a fixed point in this way was to attack the problem from a new angle. The field strength, survey and aural observations had yielded much interesting information, but did not appear at that time to shed a gread deal of light on the quality distortion, so it was decided to attempt, by an oscillographic study of received signals sent out under rigorously controlled conditions, to determine just what alterations these signals suffered in their journey through space.

In finding such distortions the ear is, of course, the primary testing instrument or indicator of trouble, for, if the trained ear is unable to detect anything wrong with a received signal in comparison with its original counterpart it is safe to say that nothing detrimental of importance has happened to it. But the ear is a poor quantitative indicator and furnishes no permanent or easily analyzed record of its observations. It is evident that if we are to study quantitatively the characteristics of radio transmission which give rise to quality distortion, we must devise tests which will disclose changes, of whatever kind, in the relations between the various component frequencies of the transmitted band and furnish interpretable permanent records. In fact, in the studies described herein, a considerable portion of the job was to devise or perfect suitable methods of attack.

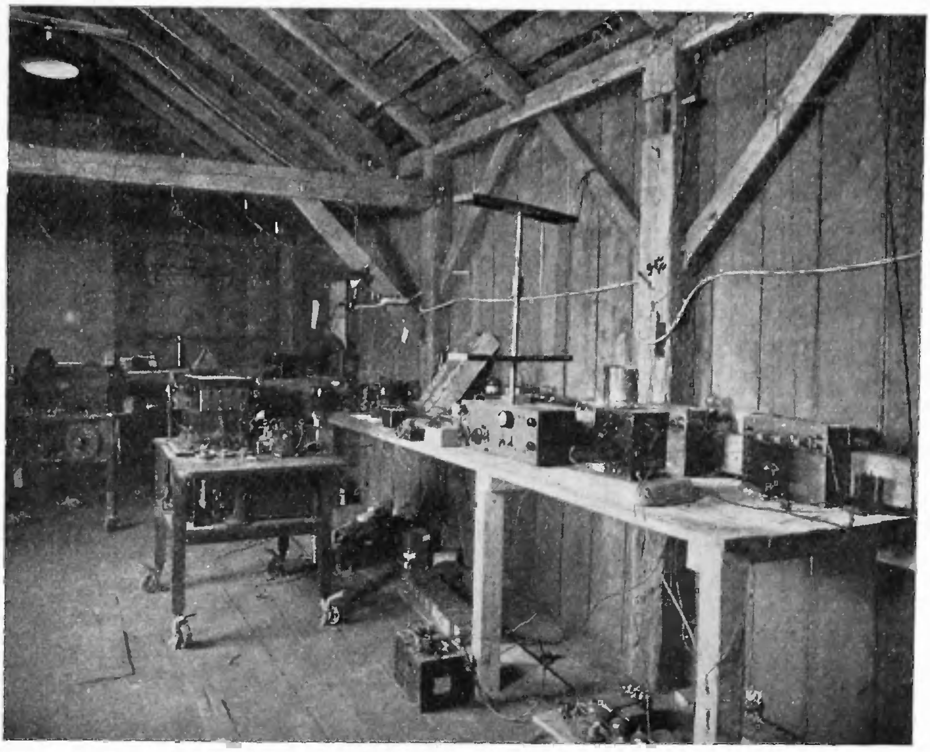


Figure 2—Interior View of Test Station Near Stamford, Conn.

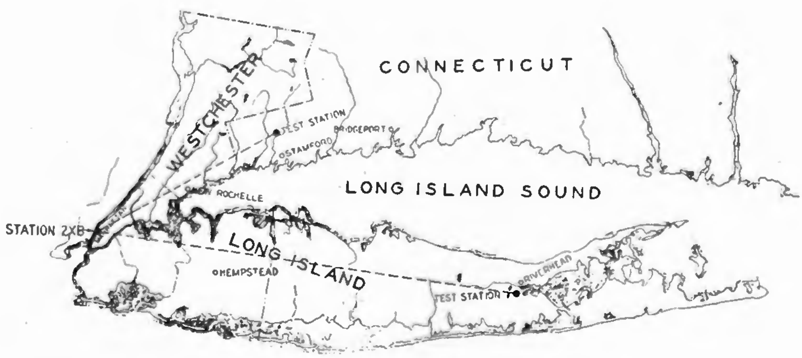


Figure 3—Outline Map Showing Locations of Transmitting Station and Receiving Test Stations

Single, Double, and Triple Frequency Tests

The variable factors in radio transmission which may be directly controlled are located at the transmitter and receiver. We have as yet no tangible means of controlling the transmitting medium, but it can be studied indirectly through the characteristics of the received signals. Obviously, it is desirable in the interest of simplicity to stabilize the apparatus variables to the extent that they may be idealized in considering observed results. Furthermore, at both the transmitter and receiver, it is desirable to make the antenna arrangements of the simplest form. For our work the normal antenna arrangement at station 2XB was used perforce, since any important changes would have constituted a major operation. It is far from a simple arrangement, as shown in Figure 4, which is an outline elevation and plan of the antenna and building at 463 West Street, New York City. Fortunately there are no buildings considerably higher than the antenna within a distance of several wave lengths.

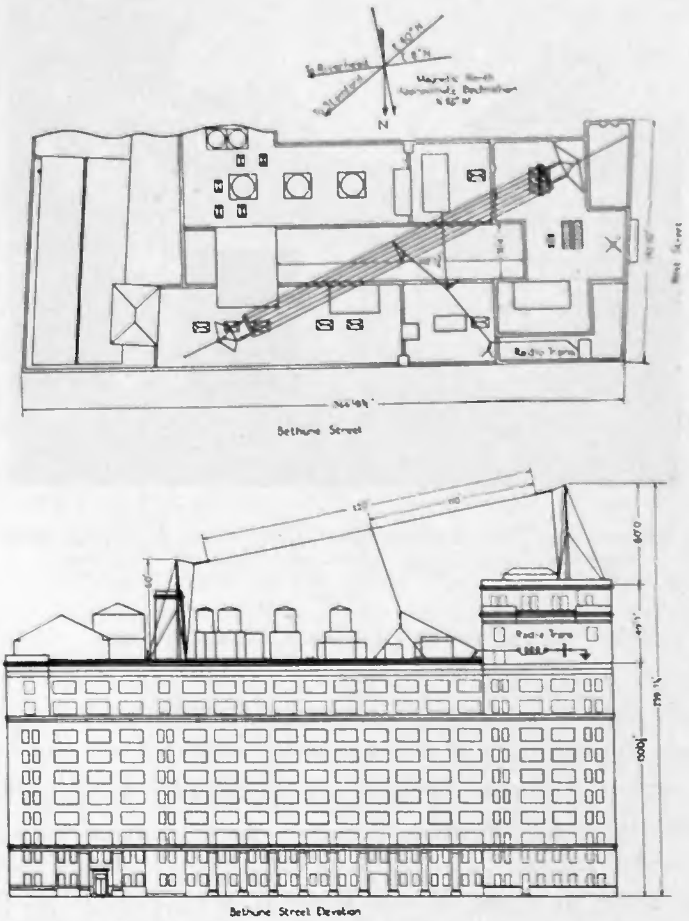


Figure 4—Plan—Elevation of the Transmitting Antenna

At the receiving test stations both loop and vertical antenna were used; but in most of the experiments a simple vertical antenna was employed. It was constructed of brass tubing, 30 feet long, and guyed in a vertical position. A galvanized iron pipe 12 feet long was driven in the earth for a ground connection. The vertical receiving antenna projected through the roof of the test station building at Riverhead, L. I., as shown in Figure 5. The receiving antenna was not tuned, but was connected to the radio receiver through fixed inductive coupling.

FIGURE 5—Receiving Test Station Near Riverhead, L. I., Showing Vertical Antenna Projecting Through Roof of Building

The carrier power in the transmitting antenna normally remains fairly constant, except for minor variations in voltage of the supply mains, and with a little care on the part of operating personnel, the antenna current can be kept within the limits of a 1 per cent. variation, which is small compared with the signal fading usually experienced.

The stabilization of the frequency was of the greatest importance since in some of the tests it was desired to beat or heterodyne the signals down to audio frequencies and pass them through narrow band filters. To provide this stability engineers of the Bell Telephone Laboratories arranged the 5-kw. transmitter at station 2XB to obtain its carrier frequency by amplification of the output of a 610-kc. piezo-electric crystal oscillator.

When desired, some of the antenna current from the output of the transmitter was rectified and the resulting current was sent over a telephone line to the receiving station so that the frequency and wave form of the modulating signal could be seen and photographed at that point, thus guarding against any possible distortion in the transmitter and enabling a direct "before and after" comparison to be made. The telephone circuit was also used for communication between engineers at the two terminal stations.

At the receiving station double detection receivers and audio frequency amplifiers were employed. These did not have entirely "flat" transmission characteristics over the audio frequency band, but in most of the tests this was of no importance. In cases where it affected the results, the making of necessary corrections was a simple matter. In tests involving beating the received signals down to audio frequencies through the agency of a local heterodyning frequency, this was supplied from a shielded vacuum tube oscillator which on comparison with a standardized piezo-electric oscillator was found to possess the required stability. The double detection type receivers were used for no other reasons than their availability and their convenience for quantitative work. The beating down oscillator within the sets and the intermediate frequency step passed through in the sets by received signals do not figure in the following discussion of test methods, but, of course, in each case the necessary set tuning adjustments were made. To avoid confusion it is well to think of these receivers as being replaced by high-frequency amplifiers and simple detectors since the local beating oscillator referred to in later pages is the separate shielded oscillator described above which is used to beat the signals down to audio frequencies.

In this work the moving coil type oscillograph was used throughout for the purpose of making photographic signal records. As indicated in Figure 6, two oscillographs with elements connected in series were employed; one for the purpose of making a continuous record of the variation in the amplitude of the signal using a slow moving photographic paper tape and the other to obtain the wave shape of the signal by means of the usual high speed photographic film drum. An element of one oscillograph was also used at times to record on the film drum the wave shape of signals rectified at the transmitting antenna and sent over the telephone lines.

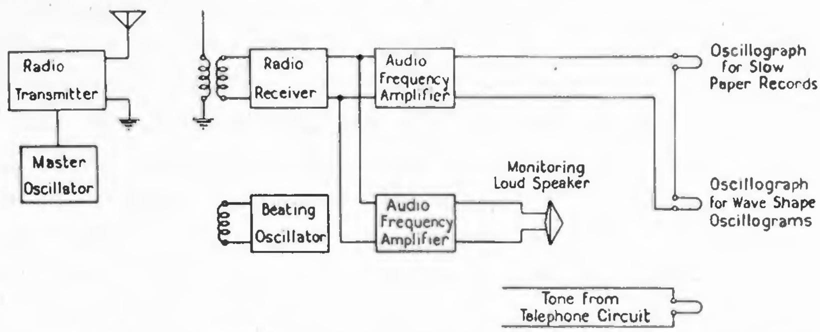


FIGURE 6—Diagram of System Used for Single Frequency Tests

Figure 7 is the interior view of the test station at Riverhead showing the general arrangement of the oscillographs and accessory apparatus. This oscillograph equipment formed about the

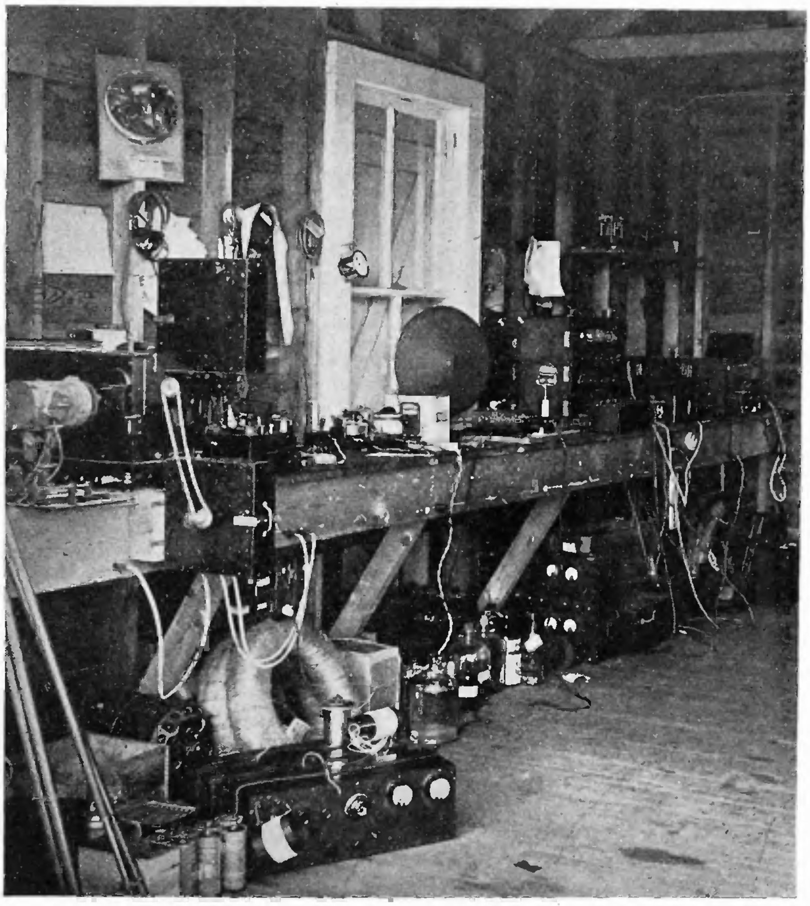


FIGURE 7—Interior View of Riverhead Testing Station Showing Recording Apparatus

only fixed portion of the apparatus, other portions being changed from time to time for different tests. These arrangements will be described later in connection with the records which they were used to obtain.

In considering these various records perhaps we had best look first at the simpler ones and then proceed in a more or less orderly fashion to the more involved ones. The simplest records are fading records of the unmodulated carrier frequency of 610 kc. At the receiver the carrier was heterodyned with a local oscillator to produce a beat tone of about 250 cycles, which was fed through amplifiers to the oscillograph elements.

A representative sample of the form of signal records made in the manner described above which show the variation in the amplitude of the received carrier signal with time, is given in Figure 8. It shows a typical fading record made at Stamford, Connecticut, May 16, 1925. The timing interval on strip 6 is 2.6 seconds.

The feed of the photographic paper tape through the oscillograph was varied somewhat during the course of the experiments, but was generally in the range of 6 to 12 inches a minute. At this rate the record of an audible frequency signal is a shadow band of varying width corresponding to twice the amplitude of the signal, as both the positive and negative half-cycles are recorded. It will be observed that the outer limits of the band corresponding to the peaks of the sine wave are darker than the center portion of the record. This is due to the fact that the rate of change of the movement of the light spot on the record is a minimum at the peak of the signal; hence, a greater quantity of light affects these portions of the record. This shading effect was very useful in the way it brought out changes in the distortion of the received signal. This is discussed fully in another section of the paper. The fuzzy irregular outline on portions of the records is caused by static and radio noise. The timing marks on the record allow a measurement of the time interval between points of minimum signal. Figure 9 is a sample oscillogram of the wave shape of a beat note signal recorded by the method described above.

Marked changes in the fading cycle or time interval between points of minimum signal may occur within a period of a few minutes, and from day to day there is often evidenced a modification of the general character and the recurrence of these changes. An example of this change in a short period of time is well illustrated by the oscillograms in Figure 10. Strips 1, 2 and 3 form a continuous record starting at 1.52 A. M.; strips 4, 5 and 6 start at 2.16 A. M.; and strips 7, 8 and 9 start at 2.37 A. M. These are three sections of a continuous record selected for the purpose of showing the decrease in the fading period, in a 45-minute interval. The timing interval on strip 10 which applies to these records is 5 seconds. In this particular record only half of the

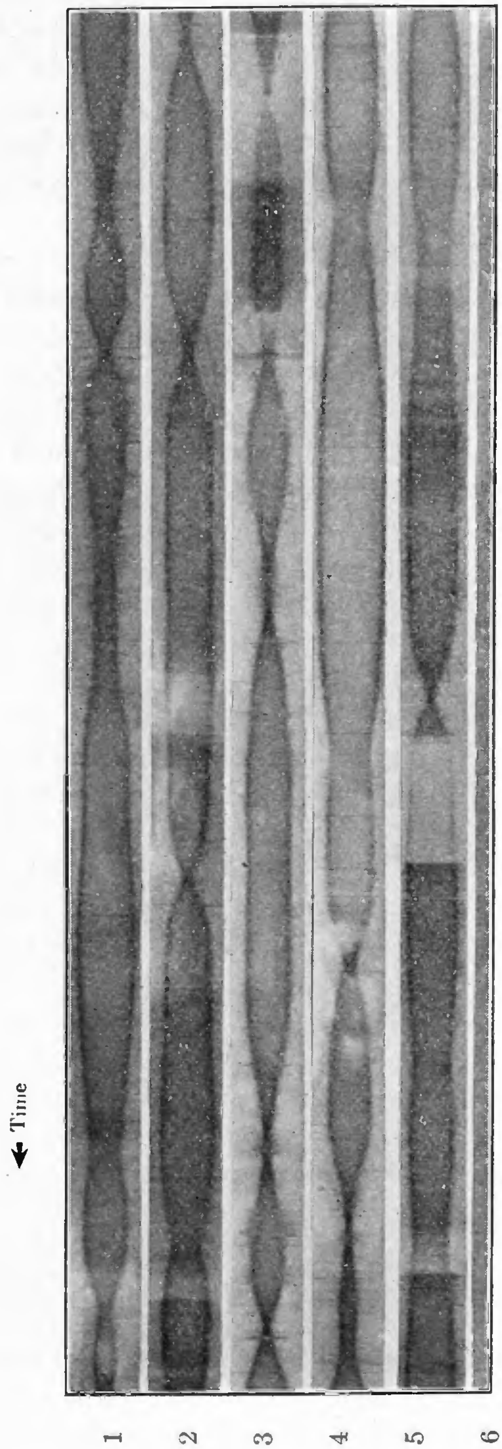


FIGURE 8—Single-Frequency Fading Record. Made at Stamford, Conn., May 16, 1924, 1.54 A. M. Timing Marks, on Strip 6, 2.5 Seconds Apart

audio signal was recorded, the edge of the strip being the zero line.

These single frequency fading records do not offer very much to work on. There is, however, just enough suggestion of regularity about them to annoy one with the thought that perhaps thay may follow some definite combination of periodicities, and with this in mind we have taken sections of two different records and subjected them to a harmonic analysis.

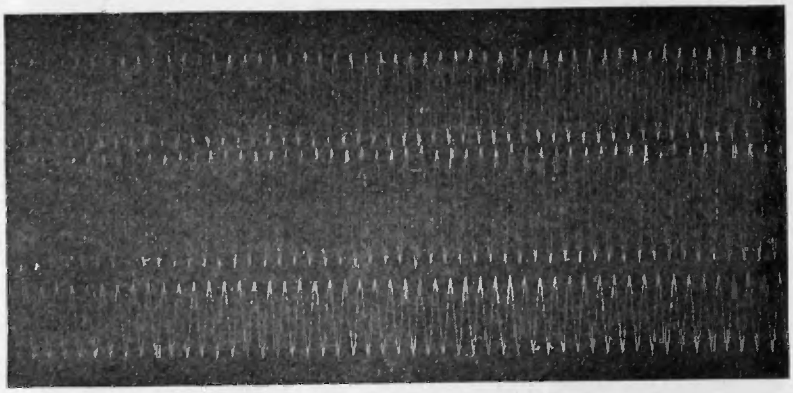


FIGURE 9—Wave Form of Beat Note Signal for Single-Frequency Test. Center Trace Signal from Vertical Antenna, Upper and Lower Traces Signals from Loop Antenna Receivers

So far we have been able to draw no more useful conclusions from such harmonic analyses than that the heterogeneous scattering of harmonic values is about what one would expect from the looks of the curves.

One significant thing about these oscillographic single frequency fading records is that they show no high speed fading of important magnitudes. Occasionally one cycle of the beat tone will be somewhat upset by a sudden change in the amplitude, but in general no changes which consistently distort the wave form were observed.

The slow fading may be considered as a modulation, and on this basis the received signal is seen to be composed of the original constant carrier frequency accompanied by very narrow side bands occupying at best perhaps a fraction of a cycle.

The next progressive step in the radio transmission studies is naturally from a single frequency to two or more frequencies transmitted simultaneously. By the use of two crystal oscillators at the transmitter, two separate and distinct radio frequency signals were transmitted simultaneously. These crystals were ground by the Bell Telephone Laboratories to oscillate at 610,000 cycles and 609,750 cycles. The amplitudes of these signals at the transmitter were controllable so that it was possible to make them equal, or one larger than the other, equivalent to the relative magnitudes usually found for the carrier and single side-band

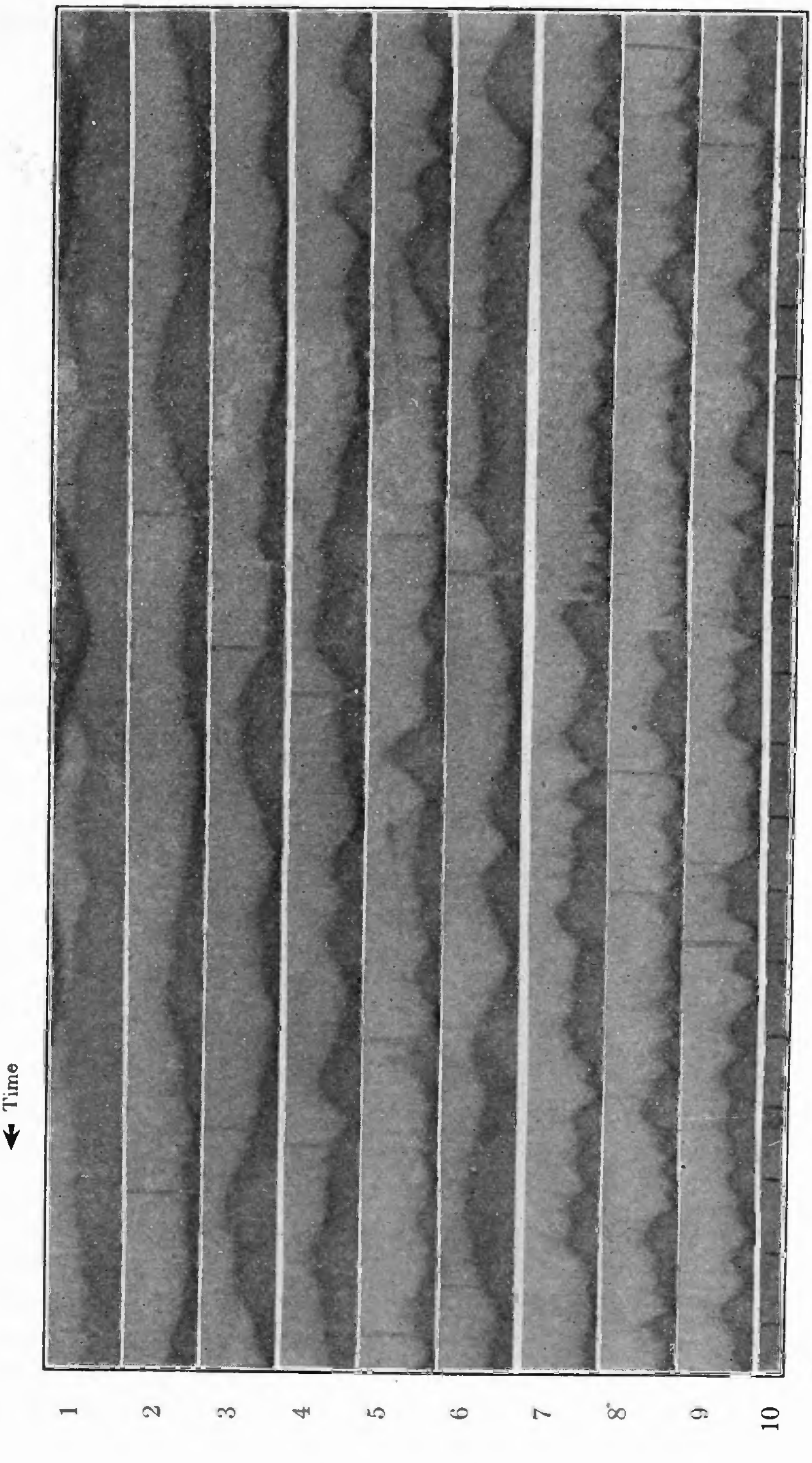


FIGURE 10—Single Frequency Fading Record, Showing Variation in Rapidity of Fading, Made at Riverhead, L. I., July, 16, 1925, 1.52 A. M. Timing Marks, on Strip 10, 5 Seconds Apart

transmission case. Records were obtained of the variation of these radio signals, but none is reproduced here since the information shown by them can be just as easily obtained from the triple frequency records shown below.

Radio transmission on three frequencies is readily obtained by modulating the carrier with an audio frequency tone, and observing the three frequencies separately at the receiver.

If the modulating tone is

$$\sin (v t+\phi)$$

and the carrier signal

$$A \sin p t,$$

the transmitted signals are

$$+\frac{A a}{2} \cos [(p+v) t+\phi] \qquad \text{(upper side band)}$$

$$+A \sin pt \qquad \text{(carrier)}$$

and

$$-\frac{A a}{2} \cos [(p-v) t-\phi] \qquad \text{(lower side band)}$$

where a is a constant proportional to the percentage modulation.

These three frequencies are not merely a mathematical fiction, but are physically existent as three separate waves bound together only at their point of origin.

To adequately record them separately by means of the oscillograph, advantage was taken of the fact that a group of frequencies beaten with a single frequency differing from them by a small amount and detected may thereby be reduced to audible frequencies without having their interrelations of phase, amplitude or difference frequency composition, changed in any respect. For instance, if the frequencies expressed above are beaten with a local constant frequency,

$$B \cos (qt+\psi)$$

the resultant lower or difference frequencies will be

$$+\frac{k B A a}{2} \cos [(p+v-q) t+\phi-\psi]$$

$$+k B A \sin [(p-q)t-\psi]$$

$$-\frac{k B A a}{2} \cos [(p-v-q)t-\phi-\psi]$$

Each one of the three components has been changed in amplitude by the same factor kB representing the efficiency of detection. Each one has been reduced in frequency by exactly the same amount $\frac{q}{2\pi}$ and each has had its instantaneous phase shifted by an angle $-\psi$. Relative to each other they remain unchanged.

In our actual case the carrier frequency $\frac{p}{2\pi}$ was 610 kc. The modulating frequency $\frac{v}{2\pi}$ was 250 cycles and the beating frequency $\frac{q}{2\pi}$ was 608,375 kc., so that the resulting three audio frequencies were 1,875 cycles, 1,625 cycles and 1,375 cycles.

As indicated in Figure 11, in order to make a record of these signals they are separated at the receiver by means of band filters. These filters and others similar in type for other modulating frequencies were designed and made by the Bell Telephone Laboratories especially for this work. The band filters used for the purpose of selecting the carrier and side-band frequencies had a cutoff of 40 Transmission Units 250 cycles from the mid-band frequency.

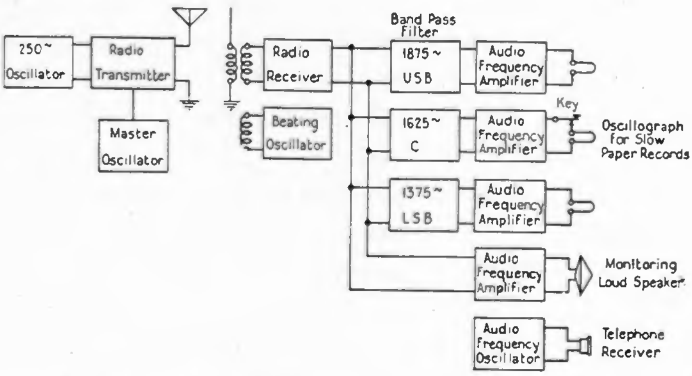


FIGURE 11—Diagram of System Used for Three-Frequency Tests

These cutoffs, together with the position in the frequency range of the pass bands of the filters, preclude any troubles from cross modulation of the radio carrier and side bands during the beating down process. The products of such cross modulation would be frequencies which are multiples of 250 cycles, and these cannot pass the filters. On the other hand, the beaten down frequencies will pass practically intact, since, as has been shown by the previously described single frequency tests, each of the three frequencies received, although subjected to amplitude modulation, by fading, represents only a very narrow band of frequencies for which the filter pass bands were of adequate width.

As the modulating tone was carefully calibrated to 250 cycles and the filters adjusted to transmit the frequencies specified, it was only necessary to transmit the carrier while adjusting the receiving beating oscillator. The following procedure for this adjustment was found to be very successful. A local audio frequency oscillator was set to the reduced carrier frequency of 1,625 cycles, and its output connected to a telephone receiver. The audio beat note from the radio signal and local beating oscillator was reproduced by a loud speaker and its frequency adjusted to zero beat the 1,625-cycle tone from the telephone receiver.

When this adjustment had been completed the carrier was modulated with the 250-cycle tone, and the side-band signals automatically passed through their respective filters.

The signals from the outputs of the filters were amplified, and recorded separately by the three oscillograph elements. The sample records shown in Figure 12 are representative.

Strips 1, 2 and 3 are taken from a long record obtained May 7, 1925, 3.22 A. M. The upper trace is a record of the upper side-band signal, the center trace the carrier, and the lower trace the lower side band. Strips 4, 5 and 6 are from a section of a similar type of record made May 23, 1925, 1.06 A. M., where the carrier was modulated with a 500-cycle tone and different filters were used. In this record the upper trace is the lower side band and the lower trace the upper side band.

It will be noticed that the timing interruption appears only in the side-band signals, as the tone was interrupted before modulation took place, and that the amplitude of the carrier signal is not affected by the interruption of the modulating tone. This makes it very easy to identify the side-band signals. These records give an excellent graphic picture of ordinary radio telephone transmission, bringing out the fact that three truly individual frequencies are transmitted to reproduce one.

In Figure 12, strips 1, 2 and 3, the relative amplitude of the three signals are very nearly in proportion to the relative amplitudes of the signals as they existed in the ether at the receiving point. Before this record was made a transmission characteristic of the complete receiving circuit, including the oscillograph elements, was obtained, using a local transmitter with modulated carrier for the purpose of making the measurement. The gain of the audio amplifiers at the outputs of the filters was adjusted to give substantially uniform transmission on each of the three frequencies corresponding to the carrier and side bands of the radio frequency signal.

As shown in Figure 11, a telegraph key is placed in the circuit of the center oscillograph element, for the purpose of placing identifying signals on the records. An example of these identifying signals is shown in Figure 12, strip 4, which gives the date and

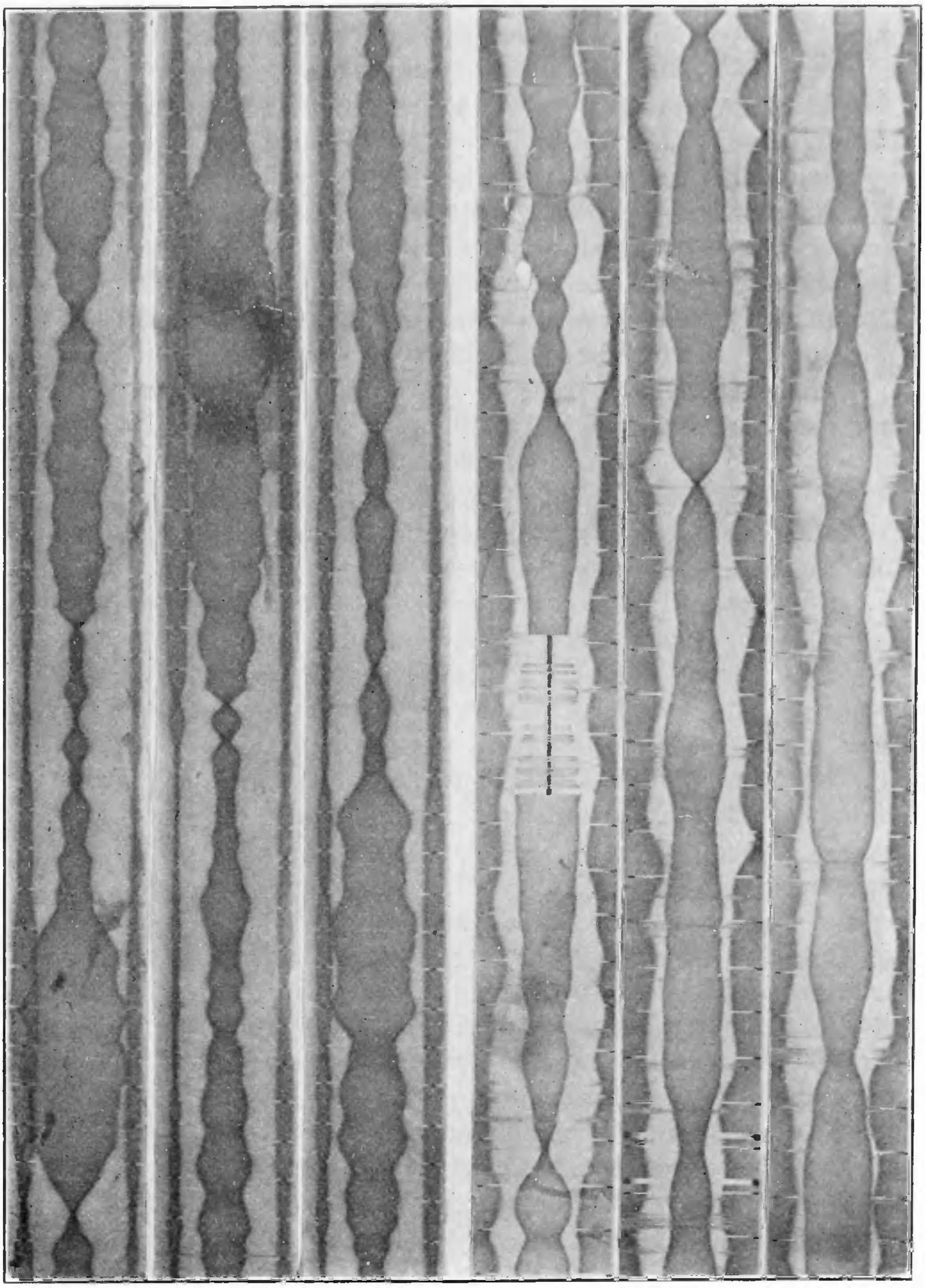


FIGURE 12—Fading Record Showing Individually the Fading of Carrier and Side-Band Frequencies. Made at Riverhead, L. I. Timing Interruptions in Side-Band Signals, 5 Seconds Apart

time the record was started, July 23, 1925, 2.06 A. M. (Eastern daylight saving time).

The record in Figure 13 is of the carrier and side-band signals with 500-cycle modulation made at Riverhead, L. I., May 25,

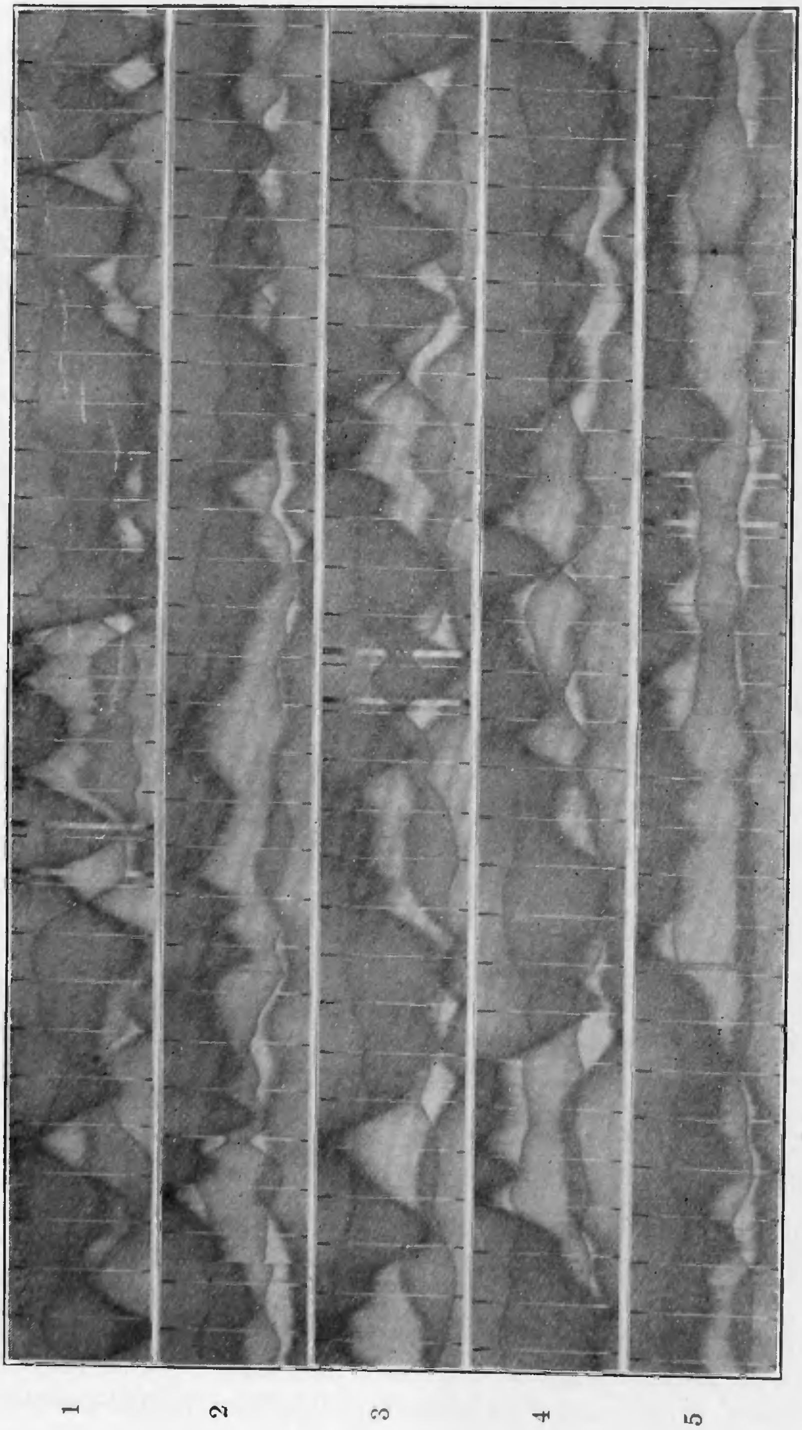


FIGURE 13—Fading Record of Carrier and Side-Band Signals, Made at Riverhead, L. I. Timing Interruptions in Side-Band Signals, 5 Seconds Apart

1925, 1.25 A. M. More gain was used in the side-band amplifiers for this record in order that the effects of fading could be brought out more prominently. In this record only half of the side-band signals were recorded, the zero reference line being at the edge of the strip. The upper trace is the upper side band, the center the carrier, and lower trace the lower side band. Where the traces of the signals overlap, a darker record is obtained. This record may be confusing at first, but if strip 5 is examined where the amplitudes of the signals are not so large, a better picture of the form of the record will be obtained.

It is obvious from these records that the carrier and side-band signals do not fade together as a unit. The carrier may pass through a zero value with still considerable amplitude in the side-band signals, as in strips 1 and 3. In the first case, strip 1, the three frequencies successively fade through points of minimum signal in the order lower side-band, carrier and upper side-band; and in the second case, strip 3, the three frequencies fade through points of minimum signal in the reverse order. This is a definite indication of *selective fading*; that is, *fading is a function of frequency as well as time.*

An endeavor to form an explanation of the cause of this selective action in fading must be largely in the nature of speculation. Furthermore, since our data consist in the results of things which have happened rather than in any first-hand information on the processes of the happening, the building of an explanation is a synthetic process. In general, for any given set of facts it is possible to synthesize a number of explanations. Bearing this philosophy in mind we have considered various theories in connection with our observations and have concluded that simple wave interference as a major cause of the signal variations is at present the most likely explanation. While wave interference may be called a major cause it should perhaps also be called a secondary cause, since the assumption of wave interference presupposes for its origin, primary causation by some physical state or configuration of the transmission medium. Speculation as to the nature of this primary cause is one stage further removed from the data contained in our oscillographic records than is the assumption of wave interference.

Since it is desirable in the remainder of this discussion to point out the evidences of wave interference, let us consider briefly the nature of this phenomenon.

To avoid any possible confusion of terms, let it be said that by "wave interference" we mean a particular physical phenomenon in wave transmission and have no reference whatever to static, signals from other stations, or any other of the forms of radio noise which are commonly designated by the word "interference" when they hinder the reception of desired signals.

When two single frequency plane polarized wave trains start out at the same time from a common source and travel by different routes to meet again at a distant point, the nature of disturbance at that point is determined by the relative space phases of the planes of polarization and time phases of the amplitude of the two arriving waves.

If we let E represent the vertical resultant of the electric field, which would be the only part affecting a simple vertical antenna, such as we have used in most of our tests, then

$$E = e_1 \sin 2\pi (F t + d_1) + e_2 \sin 2\pi (F t + d_2) \qquad (1)$$

where F is the frequency and d_1 and d_2 are the distances along the respective paths measured in wave lengths and e_1 and e_2 are the vertical components of the two waves. These two sine terms may be thought of as two vectors differing in phase.

The condition that these add giving a field

$$E = (e_1 + e_2) \sin 2\pi F t$$

$$\text{is that, } d_1 - d_2 = (\text{a whole number}) \qquad (2)$$

that is, the difference in length of the two paths must be an exact whole number of wave lengths. The condition that the two waves cancel each other giving a field

$$E = (e_1 - e_2) \sin 2\pi F t$$

$$\text{is that, } d_1 - d_2 = (\text{a whole number}) + \tfrac{1}{2} \qquad (3)$$

that is, the difference in length of path must be an exact odd number of half wave lengths.

Thus if the two components e_1 and e_2 are equal, the resultant vertical field E will go through values ranging from $(e_1 + e_2)$ down to zero as the path lengths change relative to each other. If the two waves do not have exactly the same amplitude, the minimum value of E will be something more than zero.

Differences in attenuation of the two waves and differences in their direction of arrival will modify the relative amplitudes of e_1 and e_2, but will not modify the time relations required for minima of the resultant field E unless we assume that at the time of a minimum neither wave has an appreciable vertical component. Since the consequences of such an assumption do not accord with our experimental data, we have considered that it may be left out of account in the present discussion.

This is obviously a picture which fits in very well with the simple single frequency fading records. The major maxima and minima occur when the conditions of equations (2) and (3) are met and e_1 and e_2 are nearly equal. On the other hand, it seems doubtful that the picture can be so simple. If we suppose two wave paths, why not three or more? Additional paths would add irregularities to the fading and it would not be necessary to assume as great a degree of irregularity in the changes in any one path. But with an increasing number of paths the various arriving waves would tend to average to a more or less constant mean value, and large departures from this mean would become rare. The fact that the fading signal continually covers a large range of amplitude, with the maximum many times the minimum, definitely points toward there being but a very small number of major paths, probably not more than two.

Considering now the question of selective fading in relation to wave interference, we refer back to equation (2).

If we assume the distances to be measured in any desired units and call them d_1' and d_2' our equation will still hold provided we divide each distance by the wave length measured in the same units, thus

$$\frac{d_1'-d_2'}{\lambda} = \text{a whole number} = x;$$

rearranging this and writing $\frac{V}{F}$ for λ where V equals the velocity of the waves, we have

$$F = x\left(\frac{V}{d_1'-d_2'}\right). \qquad (4)$$

If now we assume $(d_1'-d_2')$ to be fixed, we find that F can have a series of values which are integral multiples of $\frac{V}{d_1'-d_2'}$, which we may call the frequency spacing interval. That is, with changing frequency E will go through maximum values with frequency at a series of frequencies beginning theoretically with zero and extending upward in regular spacing to infinity.

The spacing interval is obviously that number of cycles which corresponds to the lowest finite frequency in the series, namely, the frequency for which the distance $(d_1'-d_2')$ is just one wave length since when $x=$ unity, equation (4) becomes

$$F_1 = \frac{V}{d_1'-d_2'} = \text{the spacing interval.} \qquad (5)$$

By using the same process on equation (3) we find that E has minimum or zero values at another series of frequencies having the same spacing interval but lying midway between the frequencies at which maxima occur.

Thus it is apparent that with fixed path length difference the amplitude of the field E will be different for different frequencies, ranging from maxima of (e_1+e_2) down to minima of zero if the polarization planes and amplitudes of the two vertical components are equal.

Furthermore, still thinking of equation (1) as representing two vectors, it is evident that the phase of the resultant field is different for different frequencies even though these different frequencies had exactly the same starting phase at the source.

If the paths are changing with time, the field at a given point, as has already been pointed out, will go through time fluctuations. Another way to look at this is that there is a space pattern of maxima and minima, and as the paths change, the plane section of the pattern taken by the surface of the earth wanders so that at any one point the field is continually fading in and out as the maxima and minima glide by it. Each frequency has its own pattern differing from those of its neighboring frequencies in such a way that at any given point the relation between amplitude and frequency is that just discussed above. Thus as the paths change and the patterns shift, the different frequencies fade not simultaneously but progressively.

In the above analysis of wave interference it has been assumed that all frequencies traveled from transmitter to receiver over a given path in the same elapsed time. This does not mean that they necessarily follow exactly the same route on this path, since they might follow somewhat different routes of equal length or if their transmission velocities were different, they might follow different routes of unequal length and still come within the definition of a "path." It seems reasonable to assume that over the width of an ordinary transmitted band the various frequencies are treated alike by the medium, and the simple assumption that they follow the same route with the same velocity is justified. If none of these assumptions is correct, but the departure is not large, the effect will be merely to introduce slight irregularities into the spacing interval and the general nature of the result will not be changed.

Let us now examine more closely the record, a part of which is shown in Figure 13. A portion of this has been condensed into the curves of Figure 14. One unit along the time axes of these curves represents a 25-second interval.

To obtain these curves the amplitude of the signal has been scaled off and plotted, ignoring all the minor irregularities. From this record the relative fading characteristics of these single frequency signals 500 cycles apart are more easily seen, and it is possible to contrast the time of occurrence of points of minimum signal for any pair of them.

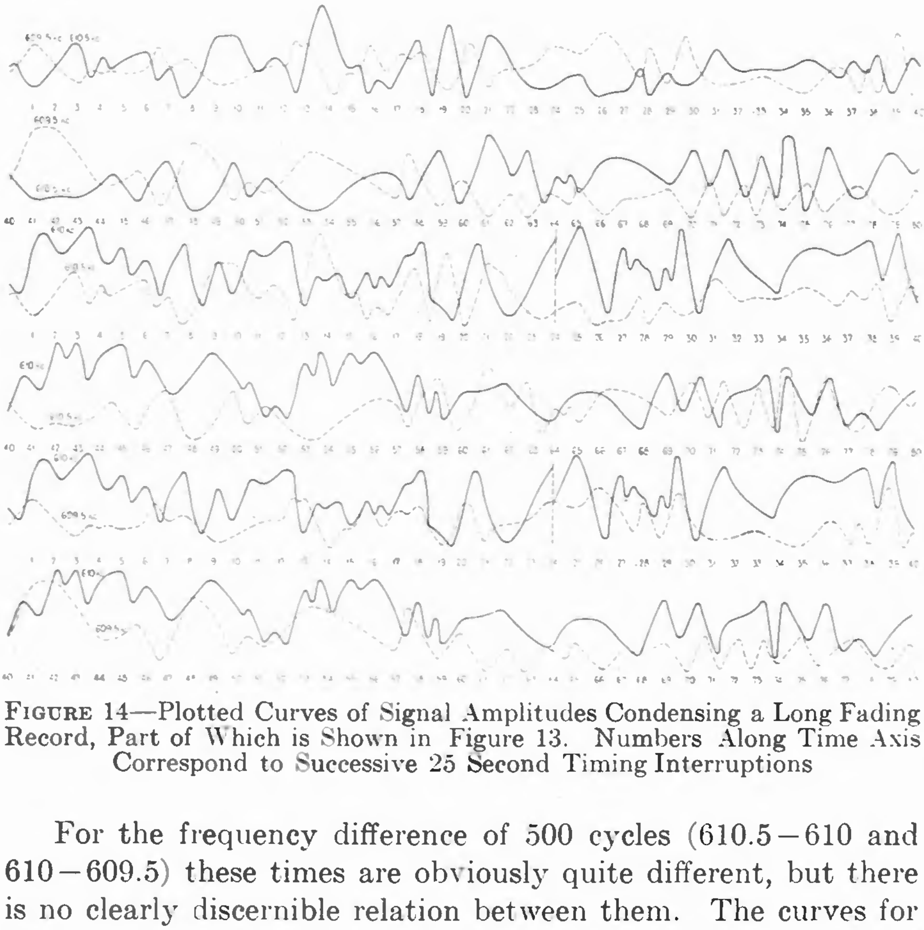


FIGURE 14—Plotted Curves of Signal Amplitudes Condensing a Long Fading Record, Part of Which is Shown in Figure 13. Numbers Along Time Axis Correspond to Successive 25 Second Timing Interruptions

For the frequency difference of 500 cycles $(610.5-610$ and $610-609.5)$ these times are obviously quite different, but there is no clearly discernible relation between them. The curves for 1000-cycle difference $(609.5-610.5)$, however, show a striking relation in that the maxima and minima of the two are opposed fairly regularly over the entire 33-minute interval covered by the plot. This means that when one frequency has a minimum amplitude the other has a maximum, and vice versa. Certainly this suggests a wave interference involving only two major paths whose difference in length is such that the spacing interval is 2,000 cycles. The path difference appears to be changing somewhat irregularly but at an average rate of the order of one wave length (or approximately 500 meters) per minute.

Before speculating further on the numerical values which may be derived from this part of the data, we had perhaps best consider some other records of a somewhat different kind which are better adapted to provide such values. But first let us reiterate that these are *night-time* effects.

During the day signals substantially uniform in amplitude are received. An example of the type of transmission obtained in the daytime is given in Figure 15, which is a record of the carrier and side-band signals received with substantially the same terminal conditions with the exception of the time as that existed when the records shown in Figure 12 were made.

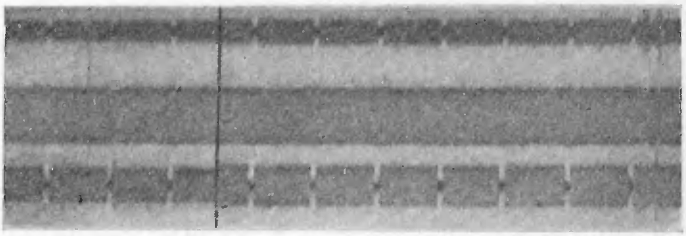


FIGURE 15—Daytime Record of Carrier and Side-Band Signals

The abrupt change in the amplitude of the side-band signals was due to an intentional change at the transmitter in the input level of the tone modulating the carrier, and accordingly the amplitude of the carrier did not change. The timing interval is 5 seconds.

BAND FADING RECORDS

The familiar fading record is limited to two axes, amplitude and time. So far we have extended this cramped perspective somewhat by observing as many as three separate fading records spaced at audio frequency intervals along the frequency axis. Even these three narrow lookouts upon the wide range of ether transmission have indicated amplitude relations along the frequency axis which promise to open a new line of attack upon the problem of night-time fading. But the desirability of knowing what takes place in the interval unrevealed by these cracks in the fence becomes obvious. We should like to know the relative amplitude of frequencies over a wide band, and the change in this relation with time.

Since it is not a simple matter to record simultaneously the amplitude of a large number of waves of frequencies separated by say one hundred cycles in the radio frequency range, a single frequency in combination with a frequency stepping device at the transmitter has been adopted. The circuit arrangement is shown diagrammatically in Figure 16. The rotary contactor

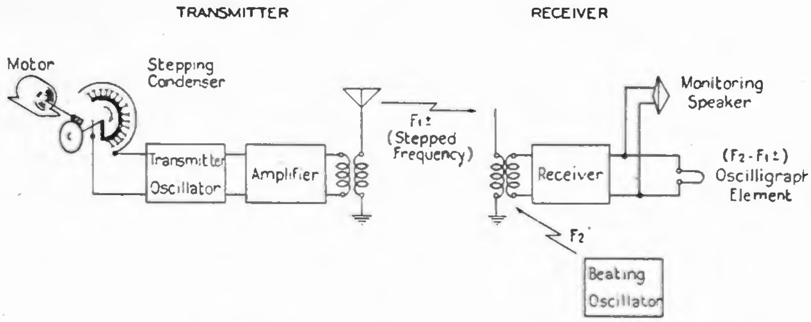


FIGURE 16—Diagram of System Used to Obtain Records of Selective Fading or "Band Fading" Records

bringing into the circuit successively a total of fifteen small condensers across the main condenser of the transmitter oscillator shifts the frequency in steps over an adjustable range. The contactor is rotated at the rate of nine revolutions a minute, which is sufficiently slow to show definite steps in the oscillograph record. At the receiving end a local oscillator supplies a radio frequency wave for beating the incoming frequencies down to values within the audible range.

A long oscillograph record of this stepped frequency gives a sort of moving picture of the fading for the entire band covered.

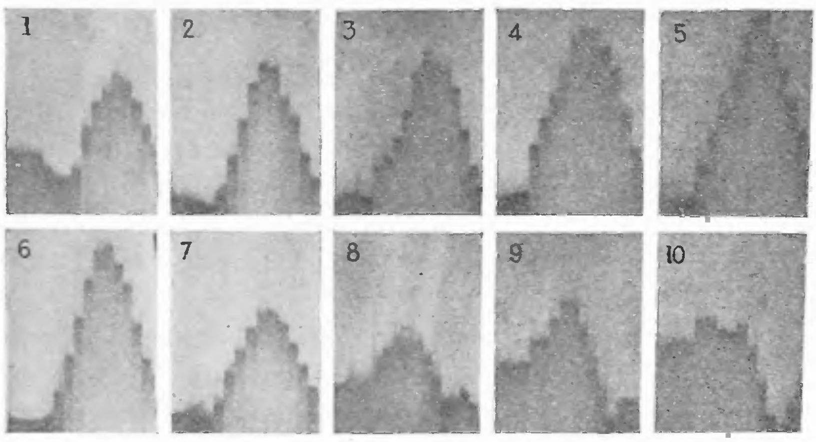


FIGURE 17—Sample Band Fading Record

A sample of such a record is shown in Figure 17 with alternate pictures in the series removed to simplify the relations, since by reason of the two-way traversal of the frequency band successive pictures are reversed. If a series of such built-up pictures as these could be taken rapidly on moving picture film, and projected successively upon a screen we should have before us an animated view of band fading. And according to the results of experimental investigation the subject offers a lively theme for such a presentation. The peaks and depressions glide nervously back and forth across the setting. The successive pictures of Figure 17 (which, by the way, were selected for their half-tone reproduction possibilities rather than as first-class examples of the records taken) illustrate a rather leisurely movement of this sort. These ten built-up photographs cover a period of slightly more than one minute. In the first seven pictures a depression appears at the left, while in the last three this depression seems to have made an exit followed by the simultaneous entrance of another from the opposite wing of the stage. Evidence of such organized spacing of the minima is present in all these night-time band fading records. As has already been suggested, such evidence has an important significance, but before going into this phase of the subject again let us examine a little more in detail the structure of these band fading records.

The steps in any one picture of Figure 17 are, as we have said, snapshots of the wave amplitude for successively different radio frequencies taken about a quarter of a second apart. The fact that the fifteen snapshots used to build up a single picture are not taken simultaneously causes a skewing of the outlines when movement of the depressions as shown in Figure 17 occurs. If, for example, we were to take fifteen separate and successive snapshots of a mountain through fifteen long vertical slits side by side, it would be possible to combine the narrow sections so as to form a true picture of the peak. Now, if by some prodigious act of nature, the mountain were shifted suddenly to one side and back again during the time we were taking the fifteen successive snapshots through the vertical slits, the combination of them would form a profile quite different from that obtained when it was stationary. Or if it were simply moved steadily across the field of vision during the time the snapshots were being taken, one slope would be made to appear precipitous while the other would be leveled to a gentle grade in the finally built-up picture. The character of this skewing, then, and its magnitude depend upon the rate at which the object being photographed in vertical sections moves, and the direction of the movement.

In Figure 18 is shown an imaginary night-time band-fading record in the "assembled" form. Since such a record contains frequency as a third dimension, in addition to amplitude and time as shown in the ordinary fading record, our simple fading curve has assumed the broader aspect of a surface, the selective fading making more or less parallel "valleys" running across it. The stepped-frequency system of recording the points amounts to photographing sections of this solid. The important point to be kept in mind is that these sections are *not perpendicular to the time axis.* If they were, the skewing previously described would not be present. By setting these sections up in their true relation to the time axis, however, and filling in to produce a continuous surface such as is shown in Figure 18, the

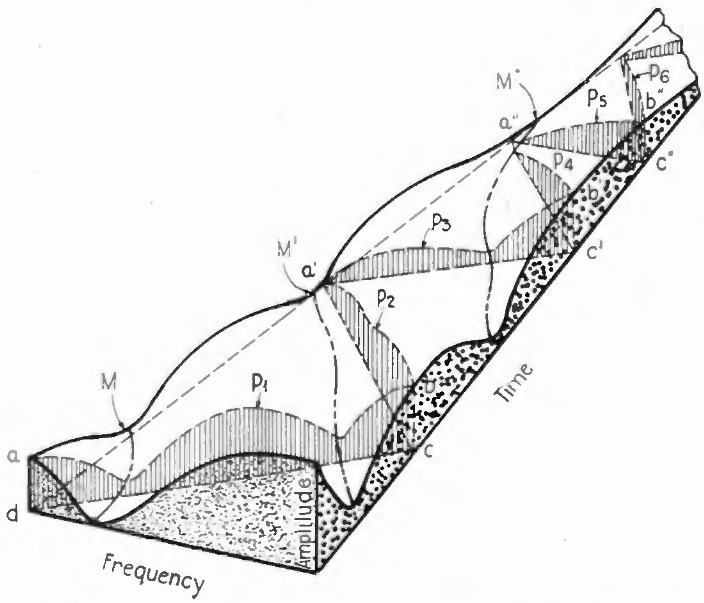


FIGURE 18—Three Dimensional Diagram, Showing the Method of Interpreting Band Fading Records

result is correctly represented. In order to make a detailed and accurate study of the band fading records, therefore, it is desirable to construct from the oscillograph sections the complete surface by the method suggested.

In Figure 18 the trace of minima crossing the band is shown by M, M' and M''. Picture sections obtained as our recording apparatus literally moves back and forth across this frequency band are shown as $(a–b–c–d)$, $(b–c–a')$, $(a'–b'–c')$, etc. It will be evident that the section P_1, for example, will, in case a minimum is crossing rapidly, appear entirely unrelated to section P_2. When the minima run nearly parallel to the time axis (slow changes in transmission conditions), the successive pictures P_1, P_2, P_3, etc., will reveal their relation by direct comparison.

Actually to obtain frequency-amplitude sections perpendicular to the time axis in Figure 18 would require the simultaneous transmission and reception of a large number of frequencies spaced at short intervals along the frequency axis. A more practical thought is to speed up the process and though this

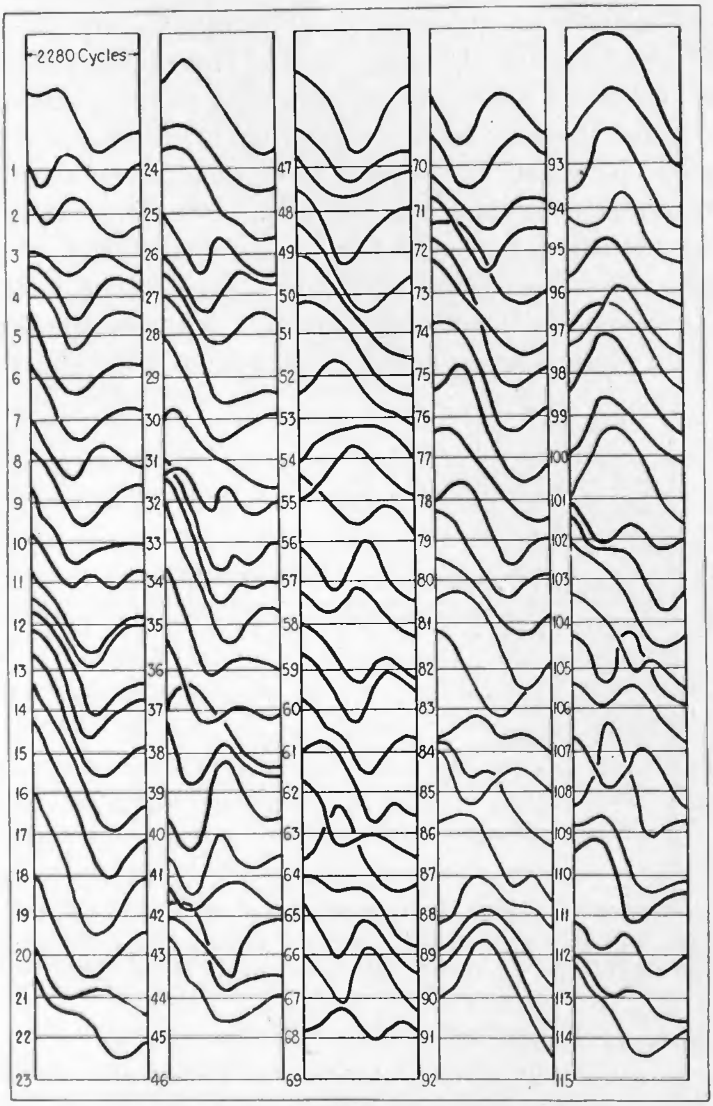


Figure 19—Plotted Curves, Condensing a Long Band Fading Record so as to Bring Out the Effect of Selective Fading

seems very simple at first consideration, it will be shown later to involve a particular kind of distortion which cannot be separated out as easily as the skewing encountered by the more deliberated method.

Now that we are familiar with the data, Figure 19 showing, partially superimposed in vertical strips, the outlines of successive built-up pictures of the frequency traverse will be of greater significance. During the steady periods there appears within the 2,280-cycle band covered by these data approximately one complete cycle of selective fading. The lack of flatness in the audio frequency transmission characteristic of terminal apparatus has caused the suppression of amplitudes toward the right side of these sections. Keeping in mind also the skewing inherent to this system of presentation during transient periods, we are able to trace the movement of minima, as illustrated previously in Figure 17 which was taken from a different record. The relative position of these minima gives us an interesting insight into the nature of the night-time transmission path.

From records covering frequency ranges up to 4,500 cycles in width, the positions of major minima along the frequency axis have been plotted against time as in Figure 20. The widths of

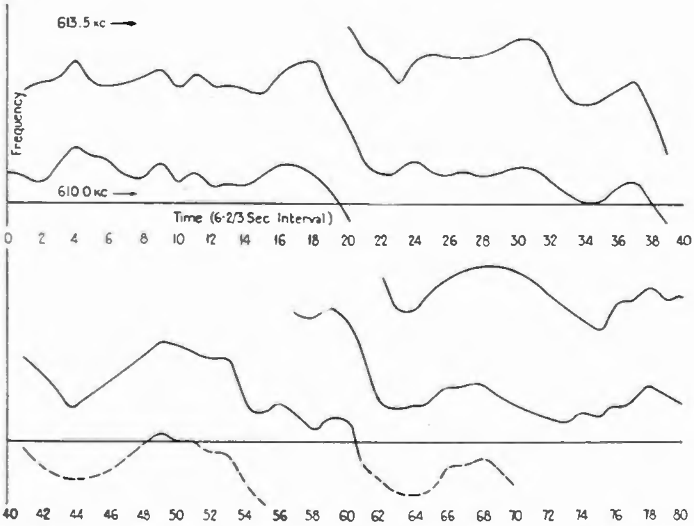


FIGURE 20—Plotted Curves which Condense a Long Band Fading Record so as to Bring Out the Frequency Spacing Interval of the Selective Fading

the frequency bands covered in this case are indicated. This picture is essentially a bird's-eye view of band fading records such as are illustrated in idealized form by Figure 18, the amplitude axis being perpendicular to the page. It reveals the presence of minima spaced at more or less definite frequency intervals, and suggests the presence of other depressions in regular spacing beyond the scope of our pictures, for when one minimum slides out of sight another appears to take its place from the opposite side of the band. The minima traces shown in broken line were outside the record but were located by extrapolating the sections.

Other depressions of small amplitude appear to be superimposed upon the major changes, but the present data appear inadequate to give reliable information concerning them. These minor depressions seem most evident during periods of rapid change.

The presence of these major minima in regular array bears a marked similarity to the familiar wave interference case in light and fits in very nicely with the theory detailed in previous paragraphs. Assume for a moment the simple case of two transmission paths producing such an effect and account for the difference in their lengths by presuming that one path follows more or less closely along the surface of the earth while the other seeks higher altitudes and in some fashion gets back to earth at the receiving station.

The mean frequency difference or spacing interval between successive minima for the records given in Figure 20 is approximately 2,200 cycles. Therefore, the mean wave length difference in length of path from equation (5) is 277 wave lengths, or 136.5 kilometers.

It is evident that the errant waves following the second path must have been led a devious route. While this is about all the information which can be deduced directly from these data it is interesting to speculate further with the information along the lines of some of the theories which have been proposed to account for such wave deflections. For instance, there is the Heaviside layer theory in which there is supposed to be a more or less well defined reflecting layer in the upper atmosphere. For this we would visualize our high altitude waves as proceeding in a straight line up to the layer, being reflected, and striking back to earth at the receiving station.

Since the distance from transmitter to receiver was 110 kilometers the length of the secondary path was 110+136.5 or 246.5 kilometers. By triangulation the height of the assumed reflecting layer may be determined as very nearly 110 kilometers or equal to the distance from transmitter to receiver, and the angle of incidence is 26.5 degrees.

As yet no positive information has been acquired concerning the variation of difference in length of two major night-time transmission paths with direct distance from the transmitter. If the path difference is due to reflection from an overhead layer, the expected relation by triangulation becomes quite simple.

$$\Delta d = \sqrt{\frac{y^2}{4} + h^2} - y.$$

When Δd is the difference in length of path, y is the direct distance and h is the vertical height of the layer.

An investigation of this relation would probably do much to prove or disprove the reflection theory.

At this point it is well to recall the results of earlier tests in which it was observed that single frequency waves separated by 1,000 cycles faded in approximately an inverse relation also indicating a spacing interval of about 2,000 cycles. The agreement of these earlier records is particularly noteworthy since about three weeks elapsed before the more detailed band fading records were made.

Figure 20 shows a time variation in the frequency position of the minima which is explained as due to a variation in the difference of path length. If we indulge in further speculation along the line of layer phenomena we conclude that the reflecting layer is rising and falling. It is improbable that the whole layer would rise and fall together, so we conclude that undulations occur along its surface. These undulations in themselves would cause the length of path of the wave reflected toward the receiver to undergo a continual change. They would also introduce minor reflections from surfaces more distant than that responsible for the major effect which may be responsible for the more rapid, low amplitude fading which is usually superimposed upon the slow changes. Obviously, the character of the fading would in the event that it is caused by undulations along the reflecting layer, be determined by the amplitude and direction of movement over the surface.

If, on the other hand, we examine the possibilities of theories such as those proposed by Nichols and Schelleng, Larmor and others in which the action of free electrons in the atmosphere is invoked, we might visualize the waves on the second path as following a curved trajectory. Or we might have the two sets of waves start off together, become split by double refraction and eventually come together again. Perhaps their planes of polarization will have been rotated. In fact, it is possible to build what appears, we must confess, to be a highly imaginary explanation in which the wave interference is accounted for not on the basis of any great difference in path length but by the assumption that the amount of rotation is such a function of frequency that a change of about 2,000 cycles adds or subtracts a complete rotation, and the further assumption that one set of waves has had its plane of polarization rotated through several more complete rotations than has the other. The synthetic possibilities are almost endless and we must wait upon further data more varied in character before the facts can be established. In the present investigation we have not attempted to determine the mechanism of the transmission medium except insofar as it could be inferred from the results of our tests which were aimed at finding out just how radio signals look after they have been subjected to a trip through this mechanism.

Returning to the solid band fading record illustrated in Figure 18, let us form some conception of the appearance of this figure were it extended toward the much higher and lower frequencies using as a basis of this conception the supposition that the existing record is systematically distorted by wave interference. For a given rate of change in the physical difference in length of path, such as would be encountered in the simple reflection case, the rate of movement of the minima across the band fading pictures would vary directly with the frequency. Therefore, we can extend the narrow section shown in Figure 18 to form a wide band fading record such as is shown in Figure 21, wherein we are looking down upon the distorted surface, the minima being traced by the light lines. Toward the short wave end of the band it is

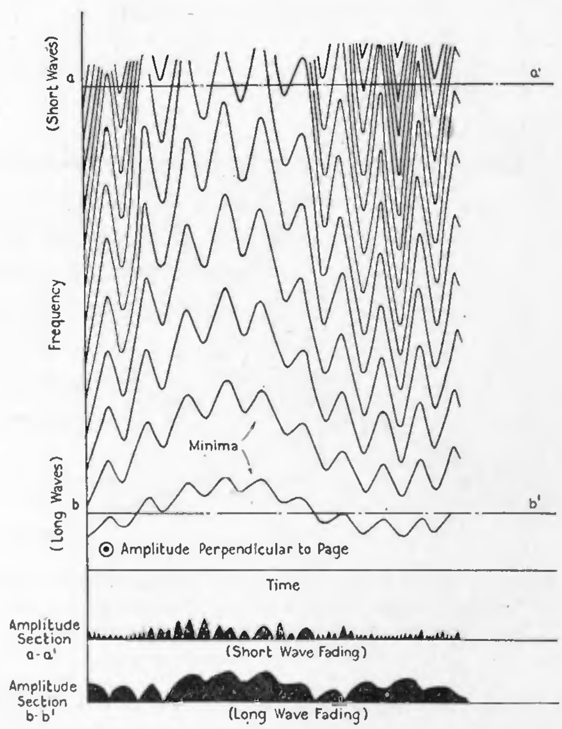


Figure 21—Theoretical Diagram Obtained by Extrapolating Band Fading Records to Show How the Rapidity of Fading Might be Expected to Change with the Wave Length

evident that a fading record for a single frequency represented, for example, by a section parallel to the time axis and perpendicular to the page, $a-a'$, would show rapid fading, while a similar record at the long wave end of the range as $b-b'$ would give slow amplitude changes. Such sections representing theoretical single frequency fading records are shown at the bottom of Figure 21. The relative fading rates for long and short wave lengths as indicated by these idealized characteristics, are in accord with general experience.

In describing the stepped-frequency method of obtaining band fading records, allusion was made to distortion which might result from speeding up the process. Suppose that we were to use a very small rotating condenser in parallel with the main condenser of the transmitter oscillator for changing the frequency, and that this condenser were capable of changing the frequency sinusoidally about a mean value. Then we could represent the variation in frequency with time as is shown by the curve C_1 in (a) of Figure 22. Now if the energy transfer from transmitter to receiver takes place over two paths of different lengths, one wave will constantly lag behind the other.

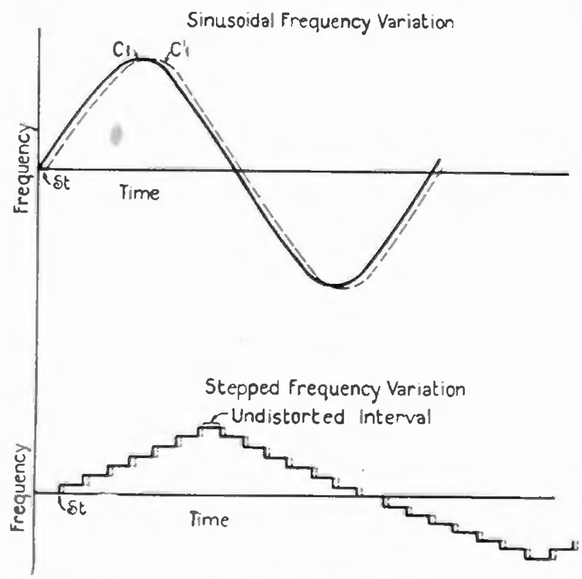


FIGURE 22—Curves Showing the Relative Effect of Transmission Time Lag in Sinusoidal and Step-by-step Methods of Frequency Variations

This lag may be measured as a time interval. In Figure 23 are shown two waves, (a) and (b) of constant amplitude but with frequency modulation. The wave (b) representing the indirect wave, it will be noticed, lags behind the direct wave represented by (a). The amount of this lag is determined by the difference in length of path and the transmission velocity. If we were to receive only one wave, as we should in the daytime, for example, we would find it to be a constant amplitude field (providing the high-frequency characteristic of the receiver is flat over the range of frequency variation). But when two or more distinct paths exist, the combination at the receiver becomes complex. This is evident in curve (c) shown in Figure 23 which is a direct summation of (a) and (b), and in (d) which is the envelope of (c). The amplitude is subjected to variations which did not exist at all in the original wave.

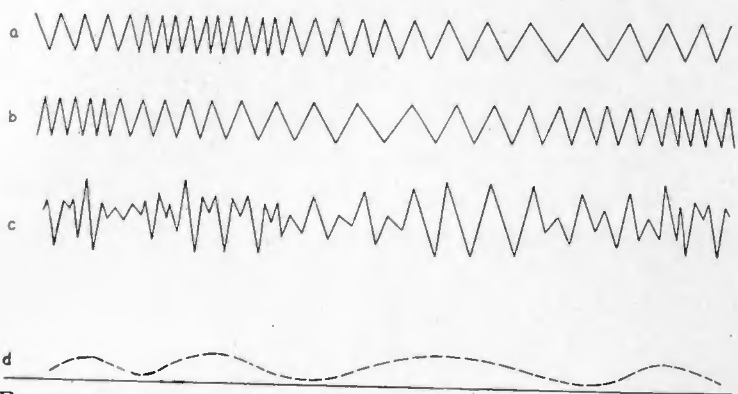


FIGURE 23—Diagram Showing the Effect of Frequency Modulation

We might set up an *equivalent* effect right at the receiver by constructing two small local oscillators having the same characteristics as the transmitter oscillator. The two small rotating condensers would be driven by the same motor, but the rotor of one would be shifted backward in phase relation to the other so as to simulate the case of transmission lag over the longer path. The relative frequency characteristics of the two may then be represented by curves C_1 and C_1' in (a) of Figure 22.

The frequency of the signal arriving over devious paths at the receiver may be put in the form of an equation as,

$$F_1 = F_o + f \sin\left[r\,(t - d_1/V)\right], \qquad (6a)$$

$$F_2 = F_o + f \sin\left[r\,(t - d_2/V)\right], \qquad (6b)$$

wherein,

F_o = the mean frequency
f = one-half the total variation
$r = 2\pi$ times the frequency of rotation of the condenser
d = length of path
V = velocity of waves.

For a difference in length of path equal to 300 wave lengths at a frequency of 600,000 cycles per second, for example, the time lag of one wave behind the other will be equal to 300/600,000 second or 1/2000 second. The lag of one of the condensers behind the other in the "equivalent" case described above would be then for 30 cycles per second rotation of the condensers, 30/2000 times 360 degrees or 5.4 degrees. The lag of 5.4 degrees represents the lag of the condenser rotor, so that the frequency lag will depend entirely upon the rate of change of frequency by the rotating condensers at any given instant.

Now to determine the resultant wave at the receiver we must know both amplitude and relative phase of the components arriving over the different paths. The amplitude will be constant, and we shall assume known, although it may actually follow slow changes with attenuation or variations in length of path. The relative phase must be determined from equations (6a) and (6b). Knowing the frequency variation with time we may, by integrating the following equation, determine the phase relation at any time (t).

$$\theta_1 = \int_o^t 2\pi F_1 \, dt, \tag{7}$$

$$\theta_2 = \int_o^t 2\pi F_2 \, dt. \tag{8}$$

Substituting the general relation for F_1 and F_2 from equations (6a) and (6b) we have,

$$\theta_1 = \int_o^t F_o + f \sin r\,(t - d/V), \tag{9}$$

$$\theta_2 = \int_o^t F_o + f \sin r\,(t - d'/V). \tag{10}$$

Evidently the relative phase ($\Delta\theta$) will be the difference between these two giving:

$$\Delta\theta = \theta_1 - \theta_2 = 2\pi \int_o^t F_o \, dt + 2\pi \int_o^t f \sin r\,(t - d/V)\, dt \tag{11}$$

$$-2\pi \int_o^t F_o \, dt - 2\pi \int_o^t f \sin r\,(t - d'/V) \tag{12}$$

which integrated reduces to the form,

$$\Delta\theta = \frac{2\pi f}{p} (\cos r\,t - 1)\,(\cos r\,d'/V - \cos r\,d)\,V + \sin rt\,(\sin rd'/V - \sin rd/V). \tag{13}$$

The equation is not in itself very illuminating, but what it tells us generally is that if we represent two frequency modulated waves traveling over paths of different lengths to a distant receiver by rotating vectors, these vectors are constantly shifting their relative position. The magnitude of the shift at any instant is given by the varying angle $\Delta\theta$. Due to a change in the angle included by the two vectors, their resultant will undergo an amplitude change, the seriousness of which we will consider later.

Thus far in the discussion of frequency modulation by means of a rotating condenser we have assumed sinusoidal changes in frequency. The ordinary condenser departs considerably from such a performance. By considering the application of the integral equation for $\Delta\theta$ to such a case it will be recognized that the relative space positions of the vectors representing the direct and indirect waves will be subjected to changes at every point where the slope of the frequency-time curve departs from a simple sine relation. The degree of distortion due to the presence of such irregularities may be considerable.

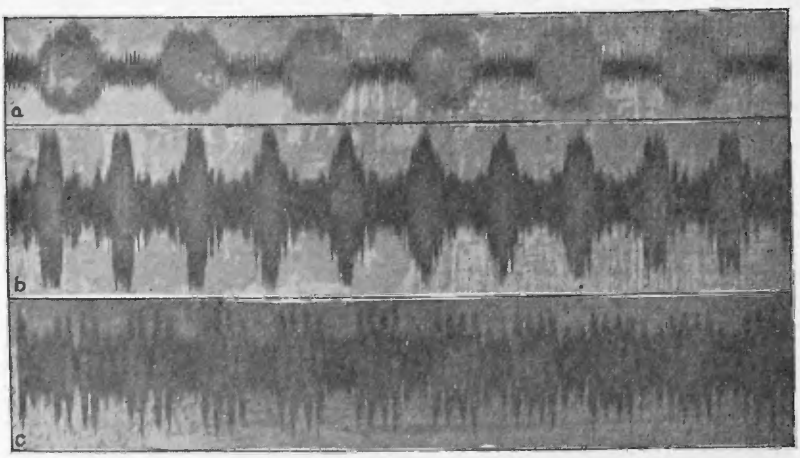


FIGURE 24—Sample Fast Records Showing Distortion Produced by Intentional Frequency Modulation. *a* Day Record, *b* and *c* Night Records

In Figure 24 are shown some samples of "wobbled" carrier frequency records obtained at Stamford, Connecticut. For these records the carrier was wobbled at the rate of about 10 cycles per second. There is some uncertainty as to the range of frequency variation for these records, although it was probably in the order of a few thousand cycles. By means of a constant frequency local oscillator the radio frequency wave was stepped down in frequency to audio values which could be amplified and recorded.

The record (a) of Figure 24 represents stable daytime reception. The record shows amplitude modulation due to the receiver characteristic alone. If the receiver were, as is desirable, capable of amplifying all the frequencies present in the received wave in the same ratio, this record would be of constant width. In the subsequent examination of night records we must keep in mind the fact that the terminal apparatus is responsible for a certain part of the amplitude modulation. Its influence is readily recognizable.

The night-time records shown in (b) and (c) reveal a distinct distortion of the envelope aside from that present in the daytime record. Peaks appear and disappear within time intervals sometimes as short as a fraction of a second.

The record in Figure 25 represents a slow picture of the changes shown in (b) and (c) of Figure 24. If these wobbled frequency waves are studied carefully it will be noted that where a single peak stands at one moment there gradually comes in view another as if it were sliding from behind the first. The cycle length being about 1/10 second we may get some idea from this series of the rate at which the changes take place. The presence of so many peaks in these records is attributed in part to the fact that the rotating condenser used gave a frequency change which was far from a simple sinusoidal relation.

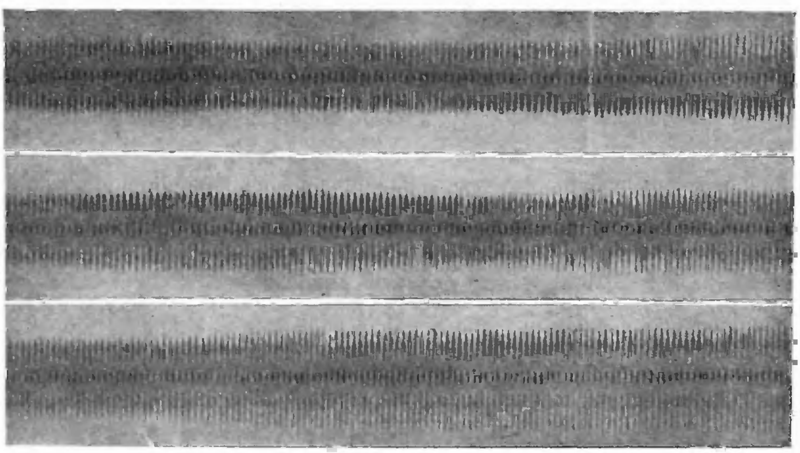


FIGURE 25—Sample Slow Record Showing Distortion Produced by Intentional Frequency Modulation. Night Record

Let us now return to the stepped-frequency method of obtaining the band fading pictures and ascertain why it has certain advantages. In (b) of Figure 22 is shown the "equivalent" characteristic for the stepped condenser. During 1/2000 of a second (for the conditions so far assumed) in each step distortion may occur, due to transit conditions, but during the remainder of the quarter second assigned to each step (for the records so far taken) a steady state is reached. Thus, theoretically, distortion occurs only during about 1/500 of the step interval. In (b) of Figure 22 the lag is greatly exaggerated for purposes of illustration. This means simply that we have maintained constant frequency for a sufficient length of time to establish, before taking our picture, a fixed interference condition over the region including transmitter and receiver at least.

Daytime Field Strength Distribution

Thus far we have been dealing with the unstable phenomena of night-time transmission. Our interest has been directed almost entirely toward variations with time. While the presence of wave interference has been detected, and the movement of this interference effect across the frequency band has been recorded, little effort has been made to form a picture of such interference in its space relation. A discussion of similar stable, daytime phenomena is, therefore, not out of place, and particularly so in view of an evident relation of the fickle nocturnal interference phenomena to the steady states which follow the appearance of daylight.

In a previously published map of field strength distribution in New York City,* it was indicated that the congestion of high buildings just below Central Park cast a heavy shadow. More recently it has been determined from observations on a portable transmitter, set up at various points, that this building center is a consistent performer. The position of this obstruction is determined in Figure 26, wherein only partial contours from maps for the indicated sites are given to prevent confusion. The intersection of these lines from transmitter to shadow, falls at approximately 38th Street in the vicinity of Sixth Avenue.

The dissipation of wave energy at such a point is probably the composite effect of many adjacent structures. Figure 27 gives an elementary idea of how this can occur. The structures filling in each block are, of course, very well connected electrically by means of pipes, cables, etc., with those of adjacent blocks. Between each oscillating circuit (which is pictured as consisting of two buildings with earth connections), there exists a coupling which binds the whole system together more or less flexibly. Thus the obstacle offered by a group of buildings might be of a

*See footnote 1.

selective nature, and evidently its frequency characteristic may vary with direction.

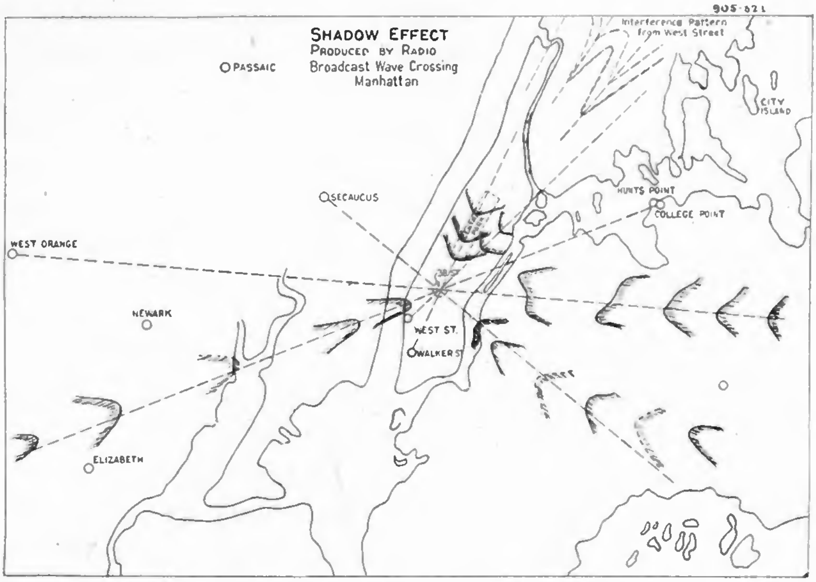


FIGURE 26—Map Showing Location of Radio Obstruction on Manhattan Island as Determined by the Intersection of Lines Between Various Transmitting Points and Their Corresponding Shadows

Such an aggregate would, in addition to absorbing wave energy, produce a change in velocity or a refraction of the wave front. Some indication of such an effect will be discussed later. Before leaving the subject of shadows, however, let us get a physical picture of their significance.

From the transmitter a wave front expanding outward and

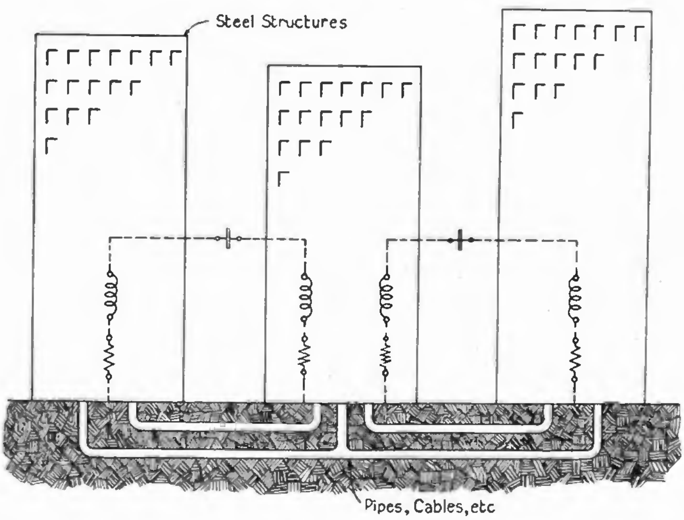
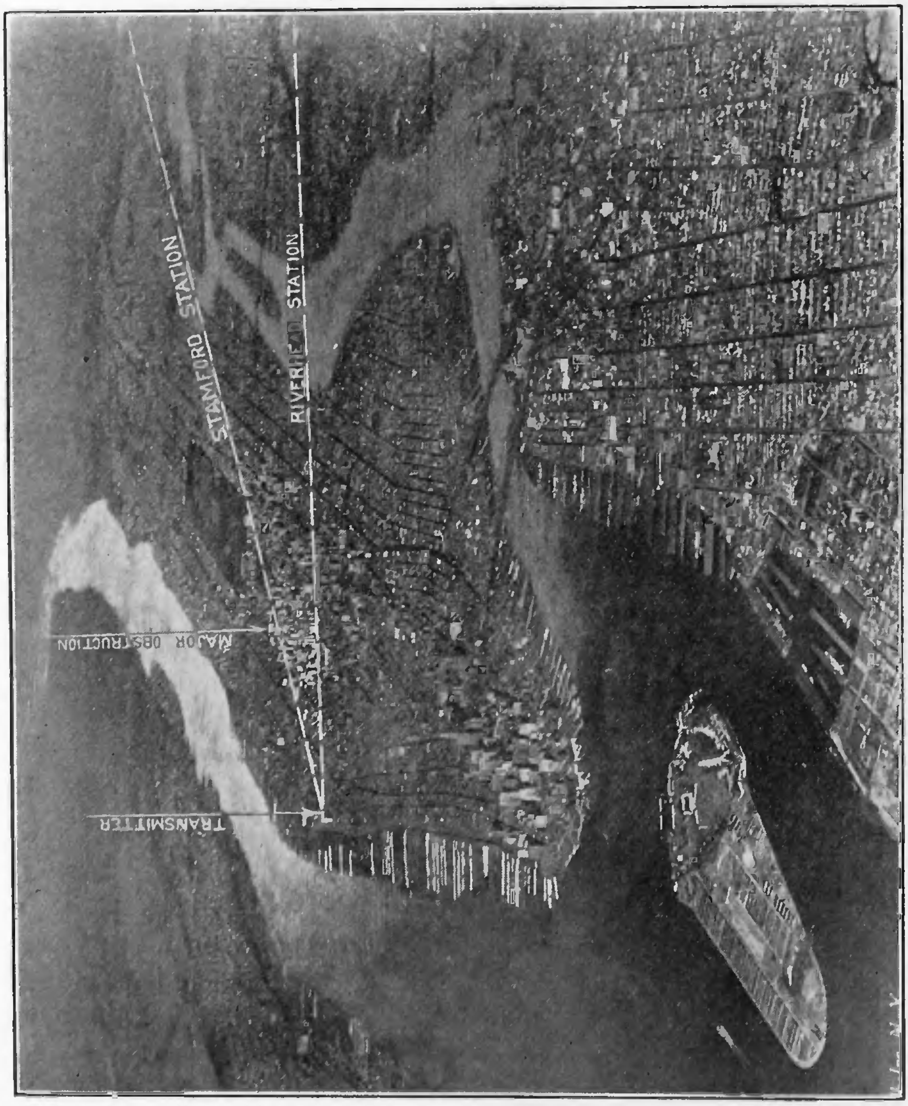


FIGURE 27—Idealized Picture of Equivalent Electrical Circuit Characterics of High Buildings

upward encounters an obstruction which we shall assume is near the earth plane. The net result of this encounter is a weakening of the wave over an area near this plane, and probably a distortion of the energy-bearing fields. We might then imagine this shadow to be a tunnel-like region extending along the earth beyond the obstruction, and as having definite vertical as well as horizontal limits.

The aerial photograph of Manhattan and adjacent territory, shown in Figure 28, will give a fairly clear idea of the conditions close to the transmitter. The major obstruction, the location of which has been previously described, is shown in its relation to



Hamilton Maxwell, Inc., N.Y.

FIGURE 28—Aerial Photograph of Manhattan Island Showing Locations of Transmitting Station and Obstructing High Building Area

the line of transmission toward the Riverhead and Stamford testing stations. Such barriers to wave travel, situated within a short distance from the source, seem, as we might expect, to have a more extensive and serious influence upon effective broadcast distribution than similar obstructions at greater distances.

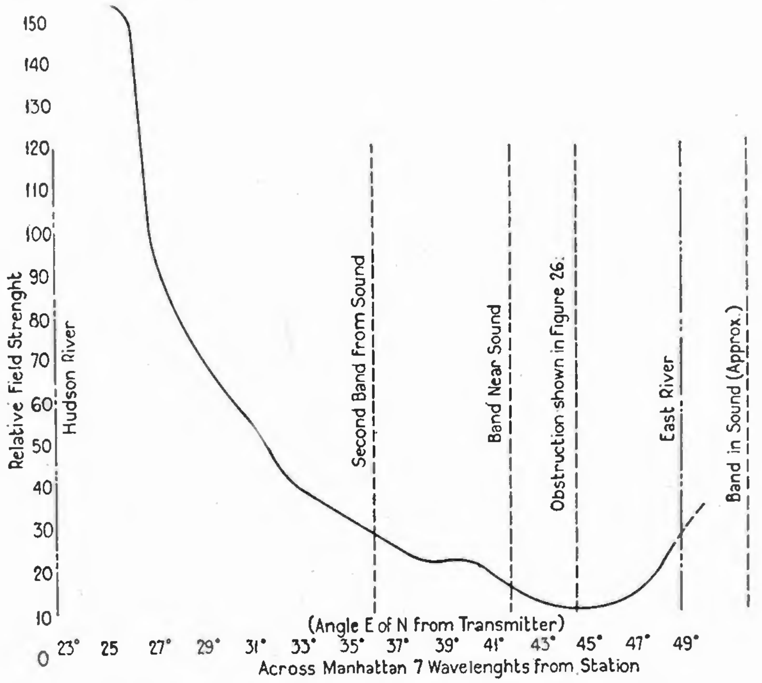


FIGURE 29—Cross-Section of Radio Shadow Caused by High Building Area

It will be noticed that the obstruction falls very nearly upon the direct line from the transmitter to the Stamford testing station. This will also be evident later after an understanding of Figure 29, wherein the position of the "Band Near Sound" represents also the bearing of the Stamford station. The Riverhead station is not directly in line with the major obstruction.

In certain sectors of the field strength contour map for station 2XB there appears to exist a kind of wavy displacement of the contour lines forming a partial pattern of peaks and depressions side by side. In general, this pattern must be differentiated from an ordinary shadow area. A remarkable example of this sort of field distribution is shown in Figure 1 which is one section of a field strength survey made for station 2XB. These contours are based entirely upon daytime measurements, and represent a condition which is stable throughout the daylight period. Considerable difference in signal level is apparent within short distances across the direction of wave propagation. Two pronounced low signal channels extend approximately northeast across this region. These shift with change in frequency of the transmitted wave. Figure 30 illustrates the space relations for such a movement. The full line curve shows a partial cross-section of the contour map of Figure 1 taken along a line approximately perpendicular to the direction of transmission 110 wave lengths from the transmitter. This represents relative field strength values for 610.0-kilocycle radiation. When the frequency is raised to 635.0 kilocycles, there occurs a movement of the peaks and depressions as is shown by the broken line of Figure 30. Apparently the increased frequency causes these channels to be crowded together.

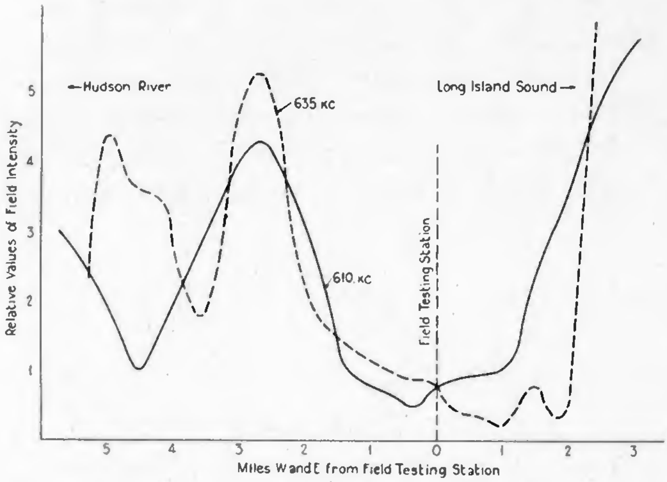


FIGURE 30—Cross-Section of Wave Interference Pattern Showing Change With Frequency

If we take sections of the field strength contour pattern in Figure 1 and examine carefully the relative amplitude of peaks and depressions represented by these wavy lines, we shall find that the ratio of field strength of the peaks to that in the depressions increases with distance from the transmitter. That is, the channels become more sharply defined as we move away from the transmitter. This ratio is shown approximately by the curves of Figure 31. If these peaks or depressions were simple shadows they would maintain their relative values at a distance from the source or even tend to "heal," causing the ratio to fall rather than rise as is actually the case.

Within 14.4 wave lengths (7.1 km.) of the transmitter the pattern so apparent beyond 30 wave lengths merges into one deep shadow a cross-section of which is shown in Figure 29. The abcsissa of this curve is in degrees measured from the transmitter so that the center of the two most distinct low field strength channels extending northeast may be inserted with their true radial relation. The two most evident in Figure 1 are shown to be west of the line extending from transmitter through the center of obstruction located in Figure 26. The presence of Long Island Sound east of the geometrical center of the shadow has made an extensive survey of this section impractical. However, a single section taken across the Sound at about 90 wave lengths from the station shows quite unquestionably the presence of a low channel about as indicated to the right of the obstruction designated in Figure 29.

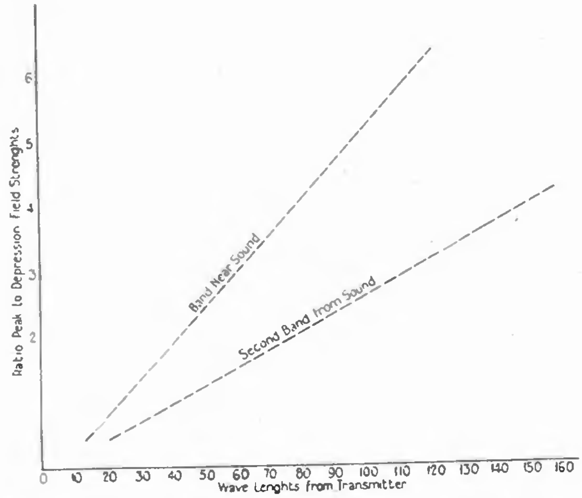


FIGURE 31—Plot Showing Intensity of Definition of Wave Interference Pattern

We have, therefore, a deep shadow with a more or less orderly array of maxima and minima within its limits. These maxima and minima grow more distinct at a distance from the transmitter, contrary to what we might expect for ordinary shadows. Furthermore, we find that they move as the frequency is changed. These facts lead to the belief that the phenomena in question are due to wave interference such as has already been described in connection with night-time fading, but characterized by very much smaller path differences. This daytime interference condition is fixed while we have seen that the nocturnal patterns appear to wander continually. To explain this more in detail let us return to the shadow and consider the phenomena which might accompany it in a little more detail.

The study of light has made available much information concerning the subject of wave interference. It is known, for instance, that the edges of shadows are not sharply discontinuous changes from light to darkness, but that a series of dark and light bands, called diffraction fringes, are interposed between the full light and full dark areas. In our radio case, the distance from the source to the obstruction and the dimensions of the obstruction are both very much smaller, in comparison with the wave length of the radiation, than for any ordinary case in light, but apparently the phenomenon is of the same general nature. By applying the ingenious principle of secondary sources used by Huyghens, we might theoretically determine the distribution of the field beyond an obstruction placed in the path of the advancing radio waves. The basis of this principle is the assumption that each elementary part of the advancing wave may be considered as a tiny transmitter. The effect at any point behind an obstruction, therefore, becomes the resultant effect, considering phase as well as amplitude, of the waves from all these miniature sources.

In Figure 32 the region between vertical lines (a) and (b) represents the geometrical limits of the cross-section of a well-defined shadow taken some distance behind the obstruction.

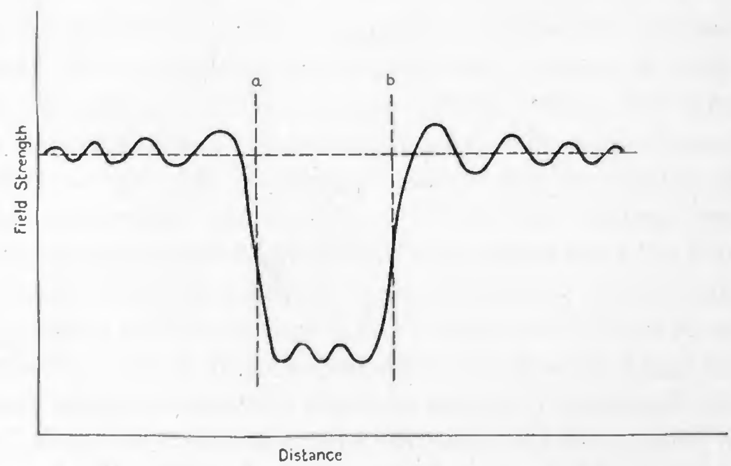


FIGURE 32—Theoretical Cross-Section of Radio Shadow and Associated Wave Interference Pattern

An analysis of the resultant field using Huyghens' construction would show variations in intensity somewhat as represented by the full line. In other words, the shadow will not be distinct, but will have alternate maxima and minima within its geometrical limits and similar variations beyond the edges.

It is very likely, of course, that even in case the foregoing speculative analysis of the contour pattern extending northeast of 2XB is fundamentally correct, a great many other influences than that of obstruction enter into the final field distribution. Relative attenuation of water and land appear to influence the distribution considerably though not as definitely as do steel structures close to the transmitter. Distinct minima appear both on the Hudson and on the Sound along radial lines extending from the transmitter.

Probably refraction of the wave front in passing across shore lines also enters into the shaping of this pattern.

Perhaps as good an elementary picture as any of the phenomena causing these patterns is that of a "dent" produced in the wave front by an encounter with a portion of New York City's impressive skyline. Since radio waves travel in a direction perpendicular to the plane containing the electric and magnetic fields, opposite sides of this "dent" would cross over one another with the result that an interference pattern would appear beyond the obstruction. An analogous situation exists when a water ripple passes a cluster of marsh grass which, damping its motion and retarding its progress, causes part of the advancing front to converge and cross beyond the obstruction.

There is evidently a relation between day patterns such as have been discussed and night-time conditions. Just what this relation is offers some further opportunity for conjecture. In the first place, quality distortion in transmission at night was, as previously explained, observed over parts of the region covered by the pattern shown in Figure 1. The worst distortion seemed to be somewhat associated with the low field strength regions in this daylight survey. The distortion seemed also to be worse along the low channel extending in the direction of New Canaan, Connecticut, and beyond the 100-wave-length circle. It was parricularly bad at a distance of some 140 wave lengths from the station along this low channel where the field strength became so low in the daytime as to be unmeasurable with the set employed for the work. Accompanying the poor quality were fading and marked directional shifts.

Quality distortion, though not so consistently severe at the Riverhead station as in the vicinity of Stamford, was at times easily detectable by audible tests. Due to rapid attenuation of the radio waves traveling from the site of 2XB across Manhattan and the length of Long Island the field strength around Riverhead is generally low with higher levels north and south on the open waters of the Sound and Ocean, respectively. Night-time fading at this point was representative of the variety which is usually found at distances of approximately one hundred miles from a broadcast transmitter.

The situation at Riverhead appears to be somewhat the same as that which may exist over a large part of the broadcast area at a distance from the transmitter, while in the Westchester region we have an extreme and rather special circumstance. Field strength surveys have shown that there are indications of a daytime interference pattern over the Riverhead area, but this pattern, such as it is, appears to be irregular and to lack the definition which makes the Westchester pattern so remarkable.

On the basis of the Westchester data alone we might build up a theory to the effect that night-time shifts of the stable daylight pattern were in some way responsible for quality distortion following the departure of daylight. Such a thought applied to the Riverhead case does not seem so reasonable, since here the pattern is about one-quarter as distinct in terms of the ratio of maxima to minima values as the Westchester pattern. If, however, we presume that quality distortion may be expected in areas where daytime signals arrive *considerably attenuated*, or so interfering as to simulate such an attenuated condition, both situations are satisfied. After a consideration of the evidence at present available, such a conclusion seems attractive; that is, a daytime wave interference pattern alone is only an agency in night-time quality distortion, in so far as its minima in combination with the general shadow effect are responsible for a low signal *directly* transmitted. Perhaps, in other words, the daytime field strength is a measure of *direct* night-time transmission, there existing in combination with this direct path at night a second, variable route of greater effective length. Probably close to the transmitter the "direct wave" is large compared to the "indirect," but shadows or interference may materially modify the ratio.

Night Distribution of Field Strength

By receiving simultaneously at several points the signal coming from a distant transmitter, it ought to be possible to detect the movement in space of these interference bands we have been discussing. The question immediately arises as to how far apart these distributed receivers can be placed without giving us an entirely discontinuous and misleading picture. For the first step toward recording space variations, in the vicinity of the Riverhead testing station, the receivers were spaced 1/16 wave length (30.5 meters), as illustrated in Figure 33. It is necessary in making such determinations to transmit a single radio frequency, since we have already found that the interference bands for one component of a modulated wave are likely to be in a different position than those for another.

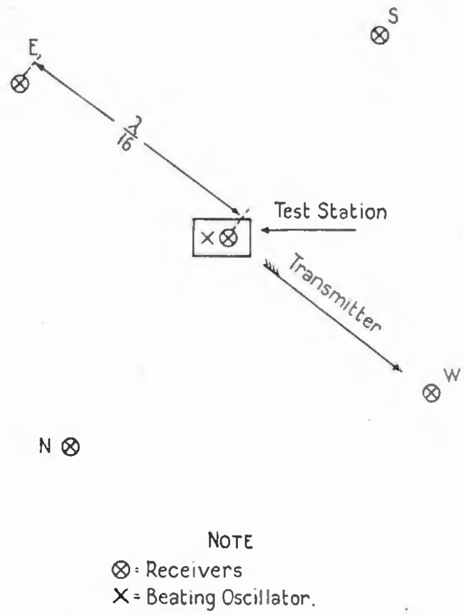


FIGURE 33—Diagram Showing Space Relation of Receiving Sets for Special Test

In order to receive and record the radio frequency wave it is, as has already been shown, convenient to use a local oscillator to beat it down to audible values. Since several oscillators for the separate sets are likely to produce mutual interference a common one was employed. This beating oscillator was situated at the testing station and the receiving antenna at this point was used as a radiator. In order to prevent overloading, the local receiver, the coupling to the receiver input coil, was balanced to give a minimum of the local signal.

Figure 34 is a sample of the record obtained. The continuous shadow band at the top represents the local receiver output. One oscillator element was used for the other four receivers, their signals being recorded successively by the commutating device. Incidentally the interaction between these receivers was checked by observing the output of any one, while changes were made in the tuning of the others. The antenna was, however, so nearly aperiodic that no recognizable distortion or reradiation phenomena could be detected.

Figure 35 illustrates compactly variations recorded by the oscillograph records (of which Figure 34 is a sample), for a representative period of about five minutes. Even within the dimensions of 1/16 wave length there appears to exist transient field strength gradients in the direction of transmission. This is

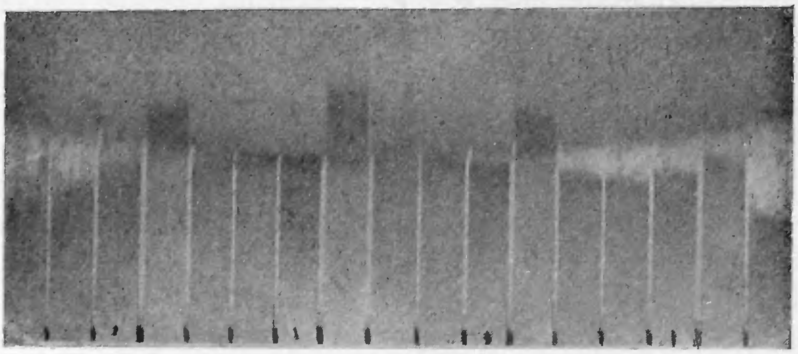


FIGURE 34—Sample Single Frequency Fading Record from Spaced Receiving Sets

shown by a change in relative values, in the upper set of curves which represents field strength at points 1/16-wave length apart in the direction of transmission. The deviation is particularly noticeable in the relation between values for the local receiver and the "West receiver" which is in the direction of the transmitting station.

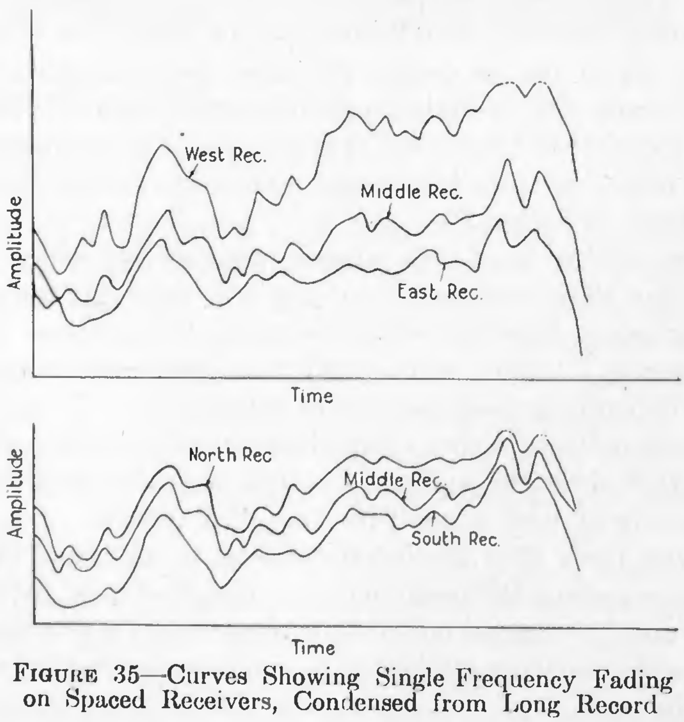


FIGURE 35—Curves Showing Single Frequency Fading on Spaced Receivers, Condensed from Long Record

The lower set of curves, representing similar values across the line of transmission are much more nearly parallel. From the data so far obtained for the Riverhead testing site, it seems that transient night-time field strength gradients are more generally evident in the direction of transmission than perpendicular to this direction. Upon these limited data one might be tempted to predict the presence of interference bands across the line of transmission.

The above discussion concerning space relation of field strengths has been included merely by way of contributing an additional bit of evidence to the theory that the erratic type of fading ordinarily experienced at night is due to wave interference. The picture is very small in terms of wave lengths but considering its content, its very limits seem to imply wave interference rather than attenuation alone.

In connection with the wave interference theory thus far suggested as responsible for a major part of fading, Figure 36 is introduced as added evidence. The middle record of this group represents amplitude changes in the night-time reception of a carrier wave upon a vertical antenna. The upper and lower records represent the same for two loops turned at right angles to one another in the horizontal plane. By daytime tests the interaction of this combination was found to be negligible. Night-time fading recorded simultaneously for these three separate receivers occupying as nearly the same point in space as was possible, show that a high-amplitude signal may be coming in on both loops while the vertical antenna pick-up approaches zero. Several points of this kind are marked by arrows below the middle trace in Figure 36.

There are at least two simple possibilities which might account for these relations. In case the wave approaches the receiving point from directly overhead, the vertical antenna would receive a "zero" signal while the loops would pick up an amount depending upon the state of polarization. If this be true, the records indicate a very rapid shift from the vertical direction of reception since the antenna minima are short lived, most of them lasting at best a small fraction of a second.

On the basis of wave interference it is apparent that two waves approaching the receiving point in a 90-degree space phase relation and 180 degrees out-of-time phase could give a maximum signal on the two loops while that received on the vertical antenna was a minimum.

A compromise between these two viewpoints is probably a better guess than either one of them taken alone. That is, the existence of minima on the vertical antenna at the same moment that a strong signal is coming in on the loops is perhaps due to the interfering combination of waves having components in both the vertical and horizontal planes.

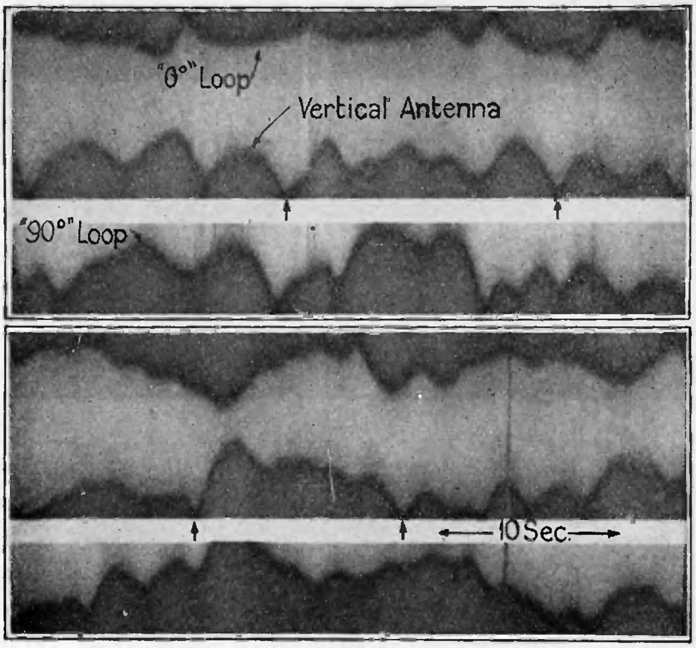


FIGURE 36—Single Frequency Fading Record from Vertical Antenna and Two-Loop Antenna Crossed at Right Angles

QUALITY DISTORTION

So far the data shown have been limited to the results of observations taken on special forms of transmission which are simplified for the purpose of clearly exposing the basic facts. We wish now to consider some of the more practical aspects of signal distortion. The first test which we made at our field test station was to record on slowly moving photographic paper tape and on the high speed film, the detected audio signal which resulted when the transmitter was modulated by a pure 264-cycle tone.

Figure 37 is a sample of the general type of audio signal record obtained and Figure 38 shows copies of the wave shape of the received signal, at particular times corresponding to the numbers of the oscillograms on the records in Figure 37. The abrupt displacement of the timing trace indicates the point on the long record at which the snapshot oscillogram was made.

A peculiar characteristic of these records is the dark shadowy lines weaving back and forth through the band recording the complete signal. These dark lines correspond to the kinks in the wave shape shown in Figure 38. As explained before, the dark-

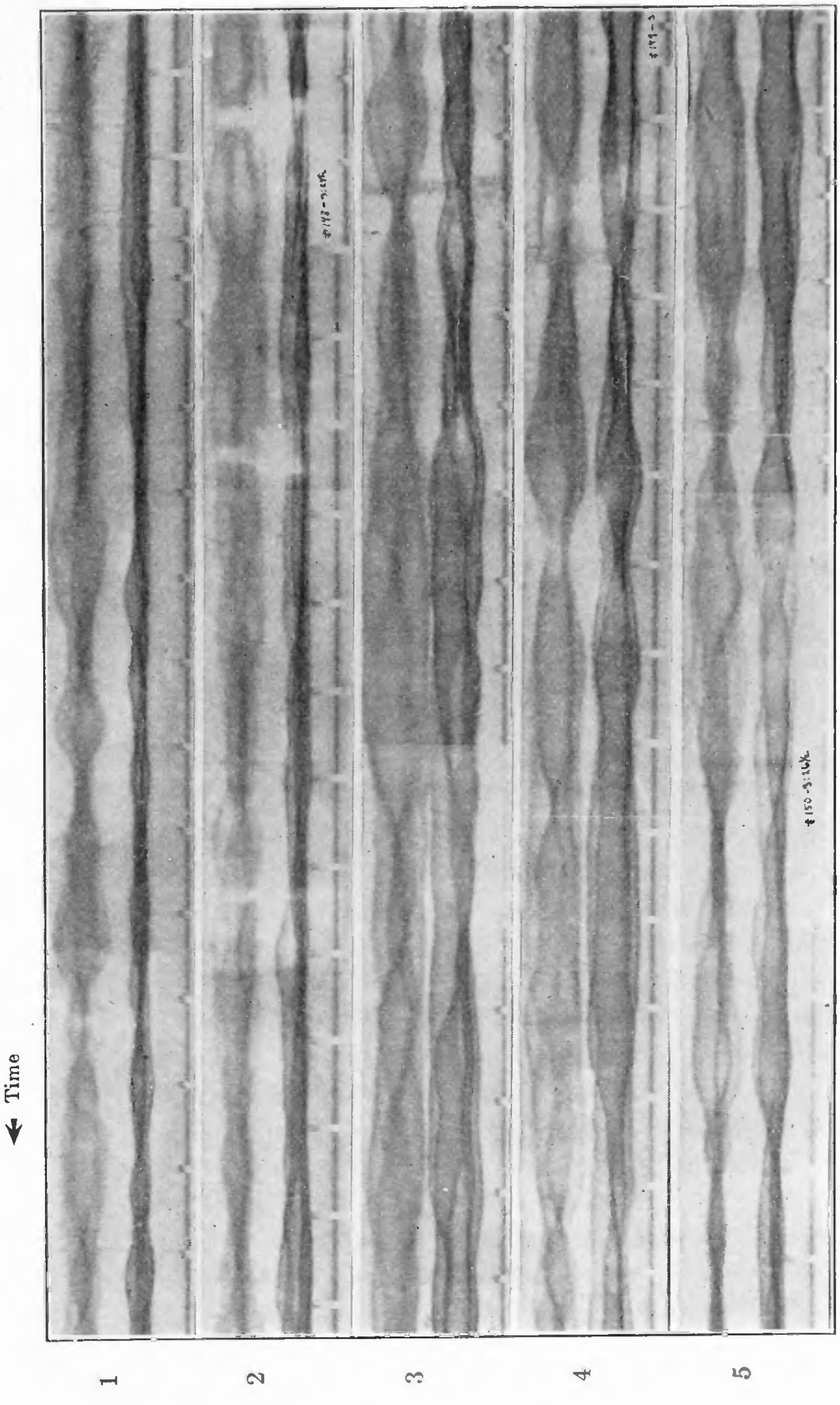


FIGURE 37—Slow Record of Signal Detected from Tone Modulated Transmission, Showing the Night-time Distortion. Made at Stamford, Conn., May 15, 1924, 2.25 A. M. Upper Trace Signal from Vertical Antenna Receiver and Lower Trace Signal from Loop Antenna Receiver, Timing Marks 2.6 Seconds Apart

ening of the record is caused by the greater quantity of light affecting the record at these peak points. At the same time these observations were made, the wave shape of the signal rectified from the antenna current at the transmitter was recorded by an oscillograph. These oscillograms showed the signal to be free from distortion at the transmitter.

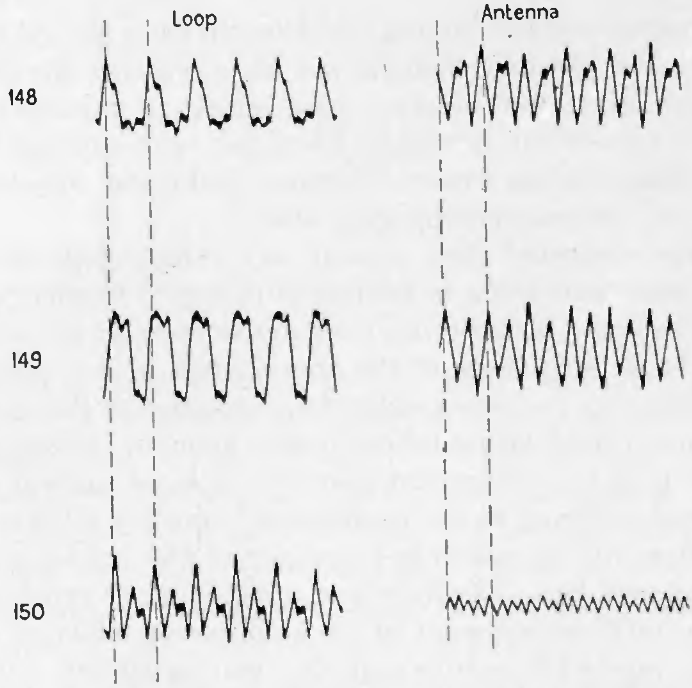


FIGURE 38—Wave Form of Signals Corresponding to Numbered Positions Indicated on Strips 2, 4, and 5, Figure 37

The weaving of these shadowy traces, together with their width gives a record of the change in phase and amplitude of the irregularities in the wave shape of the signal. Although the wave shape of the signal is continually changing, it persists in substantially the same form for a great many cycles. Thus the record shows that, in the transmission of this simple tone modulated signal from the transmitting to the receiving antenna, it has been so modified that entirely new frequencies appear at the receiver. This receiver was shown by local tests to be free of any appreciable distortion within itself. While these new frequencies look like harmonics of the modulating tone in the snapshot record it is obvious from the slow record that they are not true harmonics but that they differ from the harmonics by a very small amount and are incommensurable with the modulating tone since they undergo progressive but irregular phase changes with reference to it.

These records represent in a nutshell the signal distortion problem as it first presented itself to us. Our work then consisted in raveling out the complicated relations so that their nature could be ascertained and a theory of the causes established. In this paper, in the interest of clarity of presentation, we have departed considerably from the actual order of the experimental work, but at this point perhaps the actual order is best to follow for a moment.

With such a weird-looking distortion to analyze, and if possible eliminate, our first thought was as to whether the terminal apparatus might not involve unrecognized peculiarities which would be a contributing cause. Local tests and daytime tests of the receiving system absolved it from doubt and attention was focused on the transmitting apparatus.

It was suspected that present day radio telephone transmitters leave something to be desired in regard to what we may call, for lack of a better term, their dynamic frequency stability. A very large percentage of the transmitters in use throughout the world today produce amplitude modulation of the carrier by the action of modulating tubes directly upon an oscillating tube circuit. It is to be expected that the cyclic changes in circuit conditions occurring at the modulating frequency will have some cyclic effect on the absolute frequency of the carrier and that this effect will be in the nature of a wobbling or rapid shifting back and forth in frequency of the amplitude modulated carrier. In other words, the carrier and side bands, without change in their relative frequencies, would be subjected to "frequency modulation."

This sort of thing should be clearly distinguished from the slow wandering of frequency which, for instance, causes beat notes between carriers of different stations to drift gradually in pitch. What we have called "dynamic instability" is so rapid (being governed by the cyclic variations of the modulator) that it is difficult to observe by any aural method. Since the transmitter being used for our tests was a member of this almost universal class which employs modulating elements directly associated with the oscillator elements we determined to study this aspect of the transmission.

The following test was made to find out the extent of the frequency variation during the period of the modulating cycle. A schematic diagram of the testing circuit arrangement is shown in Figure 39. The plan was to modulate the carrier with 33 cycles, a tone so low in frequency that it would not be efficiently transmitted through the audio frequency amplifier connected to the output of the radio receiver. Then upon beating the received modulated carrier signal down to a frequency of about 1,000 cycles, an oscillogram of this signal would show a 1,000-cycle signal with a 33-cycle modulation in amplitude. Frequency

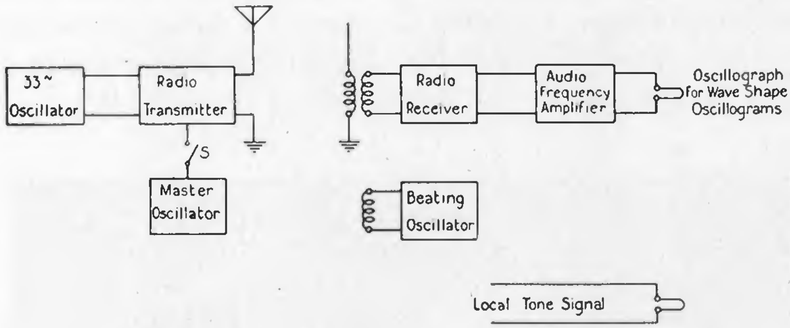


FIGURE 39—Diagram of System Used to Measure Frequency Modulation

modulation, if present, should then be easily discernible from the record. This experiment was made for daytime transmission, and oscillograms (A) and (B) shown in Figure 40 were obtained, one with the frequency of the beating oscillator greater than the carrier frequency, and the other with the beating oscillator frequency less than the carrier frequency. Both of these oscillograms show by the change in the frequency of the beat note signal that frequency modulation occurs in the transmitter circuit. The frequency change is very apparent on the oscillograms when the lengths of one cycle at maximum and minimum amplitudes are compared. The reality of the effect is demonstrated in the two records, which by their difference show the reversal of the increased and decreased frequency points with reference to the modulation cycle when the beating frequency is moved in frequency from one side of the carrier to the other.

The next step was to determine to what extent a stabilization of the carrier frequency to stop frequency modulation would affect the distortion of signals. True, master oscillator transmitters capable of giving the desired stability are not a new thing in the art. Several such transmitters were built by the Western Electric Company some years ago and used successfully in ship-to-shore radio telephone experiments [2] in which frequency stability was of considerable importance. To modify the ordinary

[2] See Figure 1 and accompanying discussion in: "Radio Extension of the Telephone System to Ships at Sea," by H. W. Nichols and Lloyd Espenschied. PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 11, number 3.

broadcasting transmitter to include this feature involves major mechanical changes, and in order to provide a suitable arrangement for these tests the Bell Telephone Laboratories engineers merely added to the existing transmitter at station 2XB a temporary separate oscillator and high-frequency amplifier which could be connected to drive the oscillator tubes of the set as amplifiers. That this was free from frequency modulation is seen by comparing (C) of Figure 40 with (A) and (B).

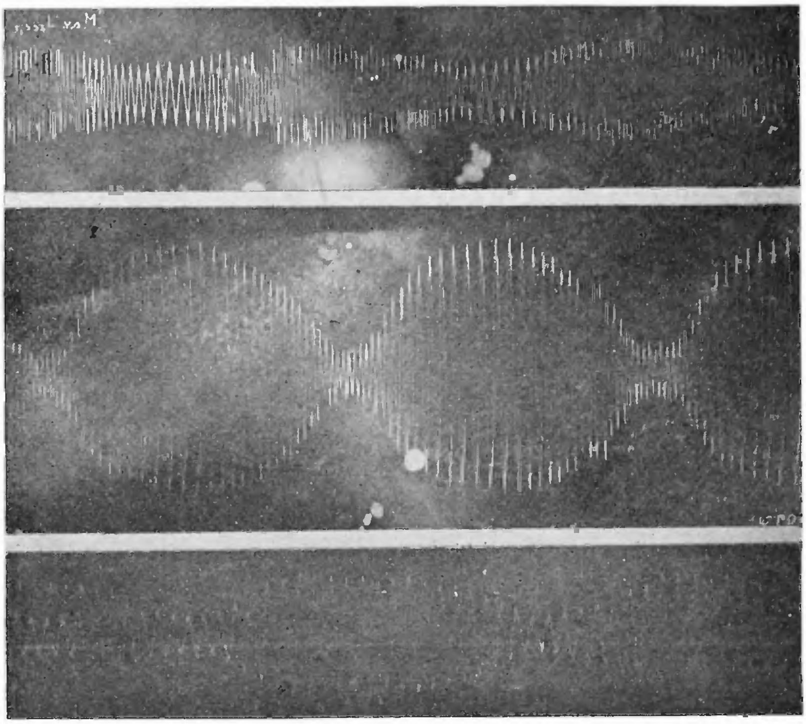


FIGURE 40—Oscillograms Showing Frequency Modulation Accompanying Amplitude Modulation

The transmission tests carried out with this arrangement yielded highly satisfactory results as indicated by a comparison of Figure 41 with Figure 37. Figure 41 like Figure 37 is the detected result of a signal which started from the transmitter as a pure tone modulated signal, but it shows that much of the wave form distortion has disappeared, there remaining only a residuum which characteristically appears at the lower amplitudes of the signal. The probable cause of this residual effect will be discussed later. Tests of speech and music were concurrent with these findings. Using the normal transmitter, night-time transmission as received at the test stations was seriously distorted. When the stabilizing arrangement was employed, this distortion was apparently eliminated except at the minima of fading.

Having arrived, then, at this practical result we wished to make further confirming tests, and tests to determine the whys

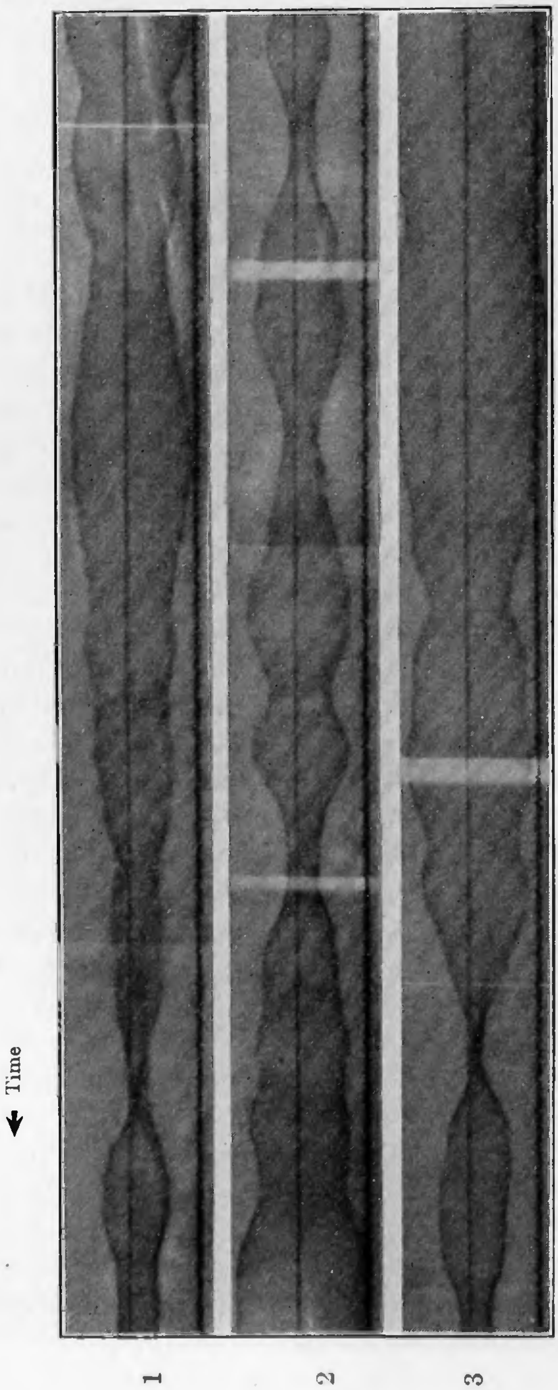


FIGURE 41—Slow Record of Signal Detected from Tone Modulated Transmission with Stabilized Carrier Showing Reduction in Distortion. Made at Stamford, Conn., Oct. 10, 1924, 3 A. M.

and wherefores of the result. We have already detailed the more basic of these tests in previous sections of this paper and are now ready to consider the practical distortion records more carefully and to build up a theory to explain them.

The records shown in Figure 42 are similar to the records in Figure 37. They are shown here to illustrate the difference in the characteristics of the wave form distortion variation that occurs from day to day. All these records were made at Stamford, Conn.

Strips 1 and 2—May 15, 1924—4:30 A. M.
Strips 3 and 4—Jan. 23, 1925—5:30 A. M.
Strips 5 and 6—Jan. 24, 1925—6:15 A. M.
Strips 7 and 8—Jan. 24, 1925—8:00 A. M.

There is a marked difference in the records obtained on January 23 and 24, which were made at the time an effort was being made to determine the effect of the solar eclipse on radio transmission. The peculiarly twisted appearance of the record obtained on January 24 is not very common in the records obtained. Most of the records have characteristics similar to those shown in Figure 37. In the January 24 records there is a marked change in the characteristic configuration of the variation.

In order to obtain a record of the amount of wave form distortion resulting from frequency modulation present in the detected audio signal the circuit arrangement shown in Figure 43 was used. This circuit was designed to analyze the wave form distortion when a 250-cycle signal was used to modulate the carrier. Special precautions were taken to obtain a pure 250-cycle modulating tone. The wave shape of the signal detected from the carrier at the transmitter was frequently checked by observations with an oscillograph. The signals detected from the antenna current at the transmitter, both for the normal transmitter with frequency modulation and for the stabilized carrier transmitter, were practically simple sine waves. The output circuit of the radio receiver was connected to a group of filters designed to transmit narrow bands of frequencies straddling the harmonics of 250 cycles.

While below we have referred to the frequencies passing these filters as "harmonics" it should be borne in mind that they are not necessarily *true* harmonics since they deviate very slightly from the true harmonic relation. The purpose of the test was to procure a record which would show at a glance the presence or absence of wave form distortion.

The input circuits of the filters were connected in parallel and the output circuits separately connected to the audio amplifiers arranged to operate the oscillograph elements. The input of one amplifier was arranged so that it could be switched either to the

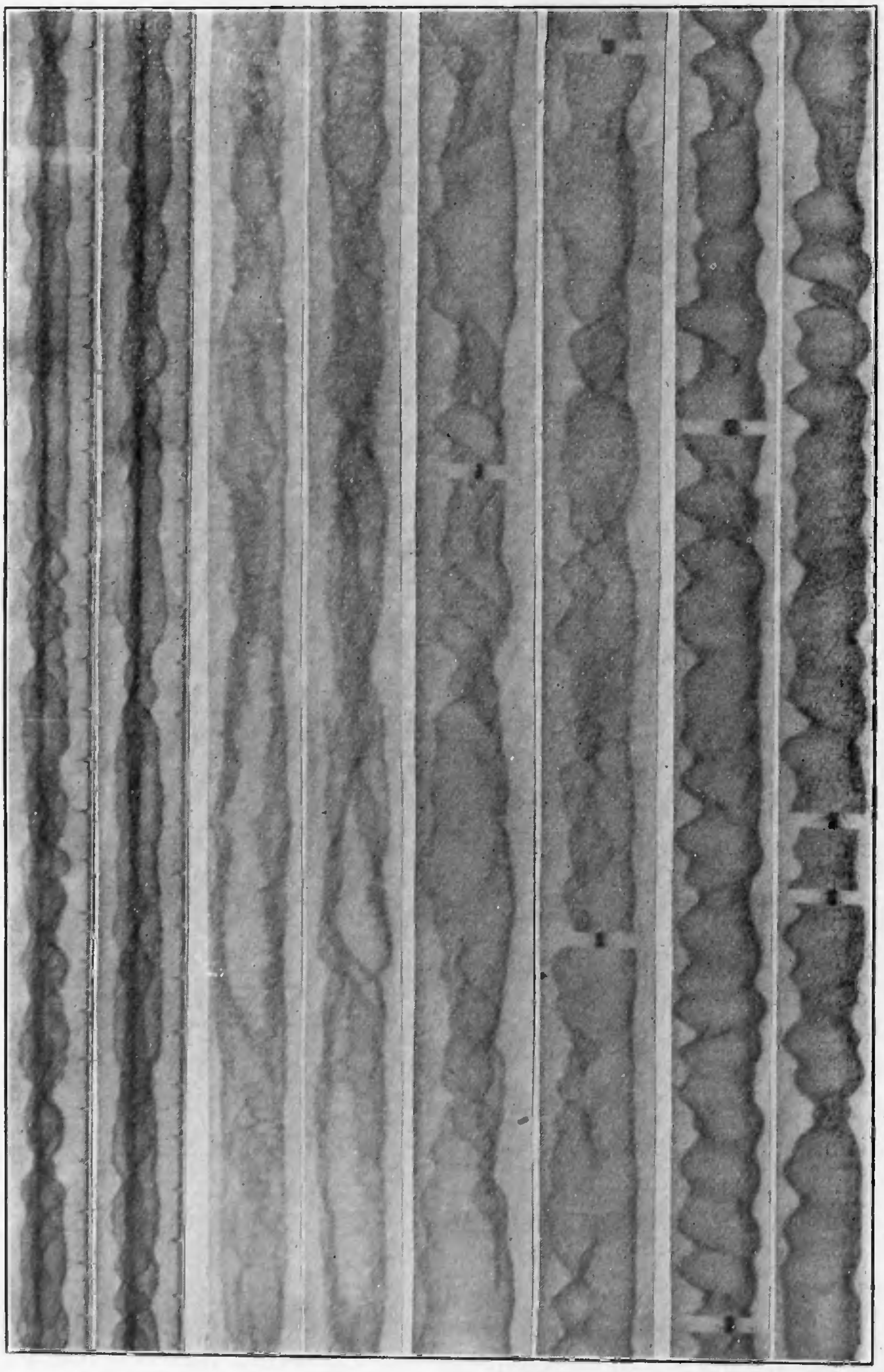


FIGURE 42—Slow Record of Signal Detected from Tone Modulated Transmission Taken on Different Days Showing the Changes in the Character of the Distortion

output of the filter passing 250 cycles or the output of the radio receiver. In this way a record could be obtained of either the whole tone from the receiver or only the 250-cycle component.

In Figure 44, strip 1 is a harmonic analysis record of the audio tone detected from the carrier and both side bands, transmitted with a stable carrier frequency. Strip 2 is a section of a record made a few minutes later when an unstabilized carrier was being used. On this record the lower trace is the 250-cycle component, the center trace the 500-cycle component, and the upper trace the 750-cycle component. The upper and lower traces have their zero lines at the edges of the strip. This record

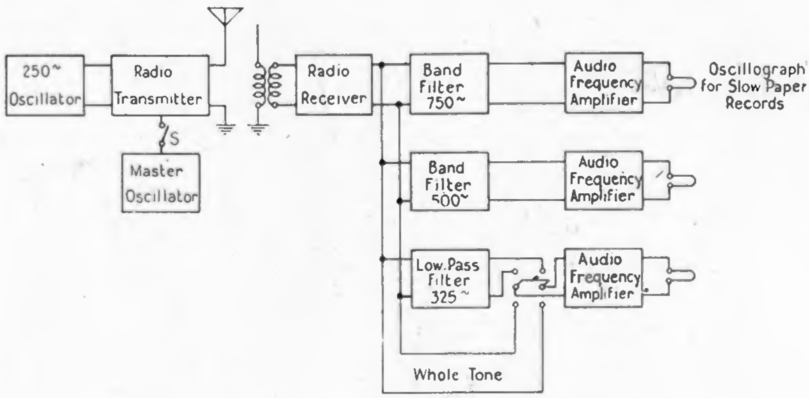


FIGURE 43—Diagram of System Used to Obtain "Harmonic" Analysis Distortion Records

was made at Riverhead, L. I., April 30, 1925, at 3:33 A. M. Strip 2 is a section of a record made a few minutes later when an unstabilized carrier was being used.

The gain in the audio amplifiers connected to the outputs of the filters was adjusted to give nearly uniform transmission through the receiving and recording apparatus for the frequencies recorded. Hence in these records the relative amplitudes of the fundamental and harmonics of the signal are directly comparable.

Strips 3, 4 and 5 in Figure 44 are taken from a record made for the purpose of obtaining a comparison of the wave form distortion sustained by the detected audio signal transmitted by the normal transmitter with frequency modulation present and by a stable frequency transmitter. In each strip the lower trace is the whole tone from the output of the radio receiver, the middle trace the second harmonic (500 cycles) and the upper trace the third harmonic (750 cycles). Strip 3 and half of strip 4 give the record obtained when the normal transmitter was used, and the remainder is the record obtained when the modified transmitter was used. There was a few minutes' difference in time between the ending of one transmitting condition and the beginning of the next, during which the master oscillator control was switched on at the transmitter. The receiving circuit was

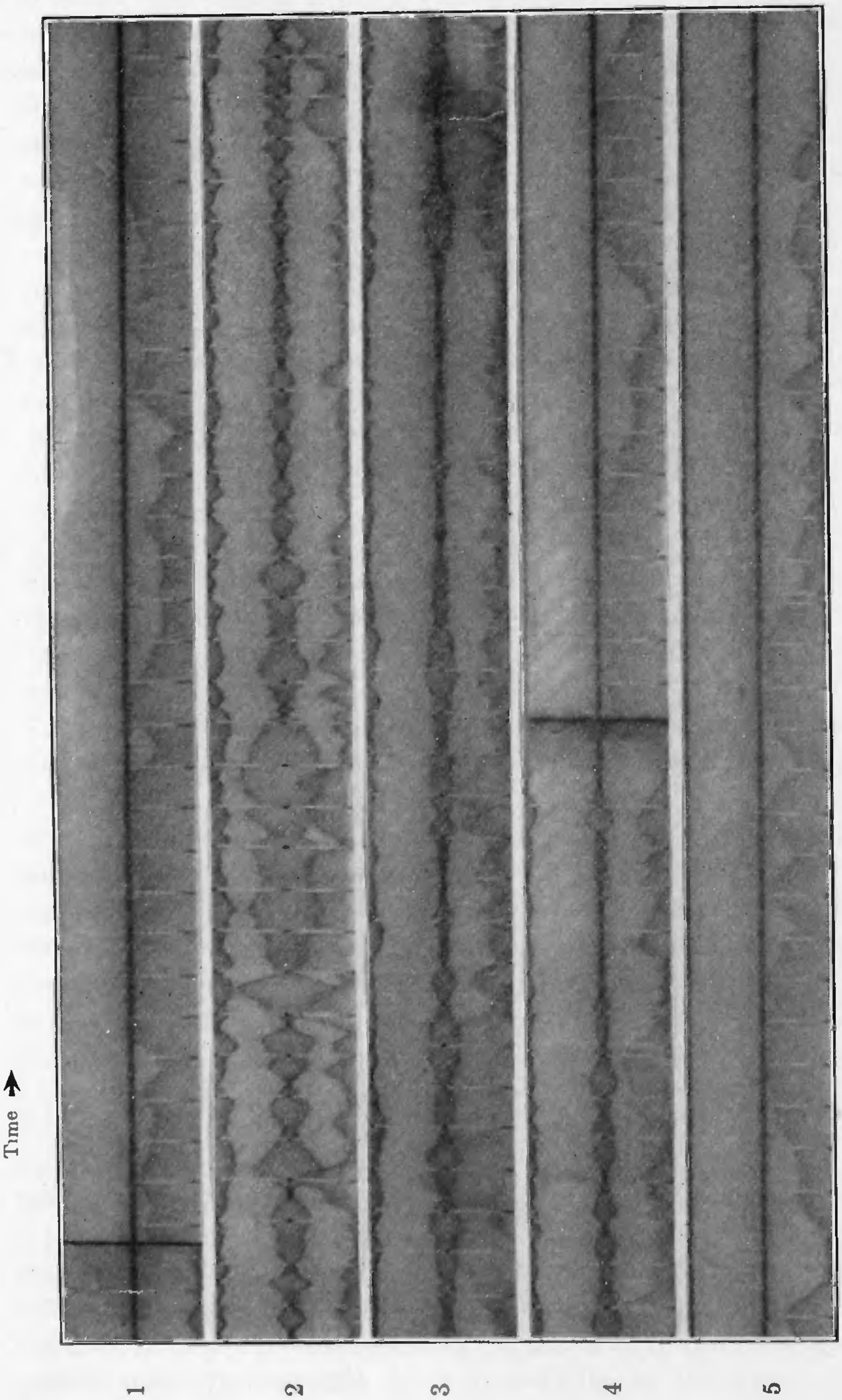


FIGURE 44—Slow Record Made with System Diagrammed in Figure 43. Contrasting the Distortion of Detected Tone Transmitted by Stabilized and Unstabilized Carrier Frequency

not changed during the making of this record, so that the results obtained from the two transmitters are directly comparable.

The record of the signal from the normal transmitter shows an abundance of second and third harmonics, at times equal in amplitude to that of the whole tone signal. The latter, of course, includes these harmonics. It will be noted also that dark line shadows run through the trace of the whole tone, indicating the presence of the wave form distortion. The signal from the stable frequency transmitter as shown by the record is practically free from wave form distortion. The trace of the whole tone is also free from any dark lines which would indicate wave form distortion. This record is substantial evidence that a great deal of the wave form distortion may be eliminated when the carrier is stabilized. However, the selective fading still remains.

The selective fading we have already explained more or less satisfactorily and we find that it does not materially affect the wave form of audible frequencies transmitted by a modulated stabilized carrier unless its changes are more rapid than any we have recorded. The crippled state of originally perfect tone waves after they have been transmitted by an unstabilized carrier, we have just observed. Now let us consider the possible causes of this difference. The carrier stabilization referred to here, may we repeat, is not stabilization against slow variations in frequency from second to second or from hour to hour, but rather against rapid variations within the cycle of the modulating frequency.

The reason for such changes over the modulating cycle is that the variation of the impedance of a vacuum tube across the oscillating circuit necessarily causes a variation in the nature period of the oscillation. As a simple case, the circuit in Figure 45 is given. H. J. Van der Bijl in his analysis[3] of this circuit gives the natural frequency of oscillation as

$$n = \frac{1}{2\pi}\sqrt{\frac{\left(1+\frac{r}{r_p}\right)}{L_2 C}} \tag{14}$$

when r_p is the plate resistance and the remaining constants are given in the illustration.

Direct modulation by the usual method involves a cyclic change in the value of plate resistance. Hence, according to the above equation, there results a cyclic change in frequency which, though relatively small, becomes of the utmost importance

[3] "Thermionic Vacuum Tube," by Van der Bijl, page 274.

when subjected to the peculiar phenomena of night-time transmission.

By making certain assumptions concerning the nature of frequency variation as amplitude modulation takes place, it is possible to work out distorted waves corresponding to various assumed wave interference conditions at the receiver. Perhaps the most simple and instructive means for producing these distorted waves is by a graphical method.

The equation for modulation of a high-frequency wave by a single tone may be written

$$e = (A + kA \cos vt) \sin pt \qquad (15)$$

When A represents the unmodulated amplitude of the wave, k is a factor determined by degree of modulation, v is an angular

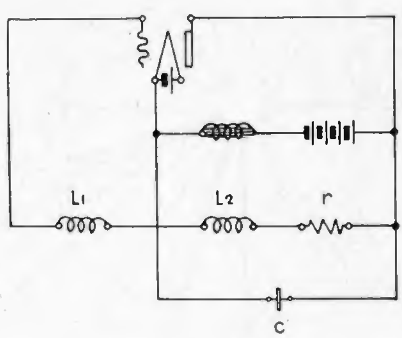


FIGURE 45—Diagram of an Oscillator Circuit

velocity of the tone wave and p is the angular velocity of the high-frequency wave. The amplitude factor in this equation may be considered as a vector which is undergoing a change in length in accordance with the term included in the brackets. For the purpose of our analysis we shall include the angular velocity imparted in this vector by the last term in the above equation, since we are interested in the envelope of the resultant high-frequency wave at the receiver and the relative phase relations for two waves directly and indirectly transmitted combining to form this resultant. Since both carrier waves are of the same mean frequency, only the relative position need be considered.

Now in our graphical determinations for the case of two transmission paths different in length, we represent the two effective fields by vectors varying in length in accordance with the amplitude factor of equation (15). However, due to the difference in length of path, the changes in length of one vector will *lag the changes in length of the other* by any amount

$$\phi = v\,(\Delta t) \tag{16}$$

when Δt equals the difference in time of transmission over the two paths and v is the angular velocity of the modulating tone. This angle ϕ for 500-cycle modulation may, according to the data thus far described, amount to more than 90 degrees at the receiving points selected for observation.

In addition to the lag in amplitude there will be a lag in frequency change over the frequency modulation cycle. This lag,

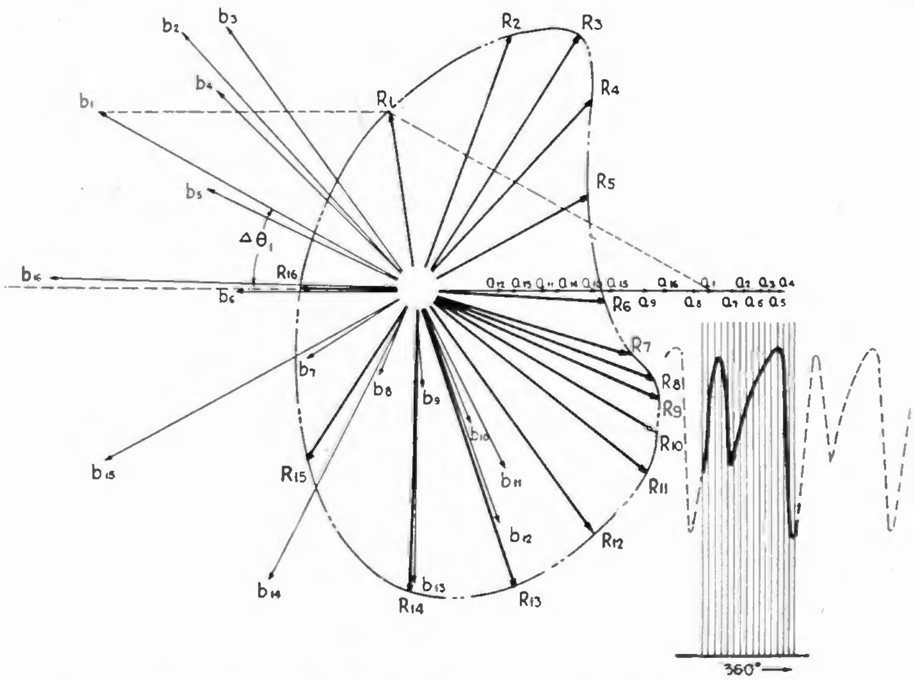


FIGURE 46—Graphical Method of Synthesizing Distorted Wave Forms Caused by Frequency Modulation

which has already been shown in connection with the analysis of distortion in certain types of band fading records (see Figure 22), becomes *a change in the relative phase angle* of the vectors under consideration. Thus our picture finally becomes one of two vectors changing in length, the changes in one continually lagging the changes in the other, the two vectors at the same time undergoing what we might term a relative angular wobble.

In Figure 46 these relations are produced graphically. For our purposes we might assume that the vector representing one field is fixed and allow the other one to wobble the relative amount. At an instant, for example, the directly transmitted field may be represented by a_1 in this figure. Assuming a difference in length of path, we may compute on the basis of the integral equation (13), the relative phase position of the vector representing the indirectly transmitted field b_1. The relative amplitude of this vector may also be determined by substituting $\Delta\phi$ in equation (15).

After establishing a sufficient number of vectors to represent the cyclic variation, we may combine the respective components to obtain the resultant representative of the successive instants. These are shown as R_1, R_2, R_3, etc., a broken line being drawn through their extremities to identify their positions. Now, if we plot these resultants as vertical ordinates in their successive time

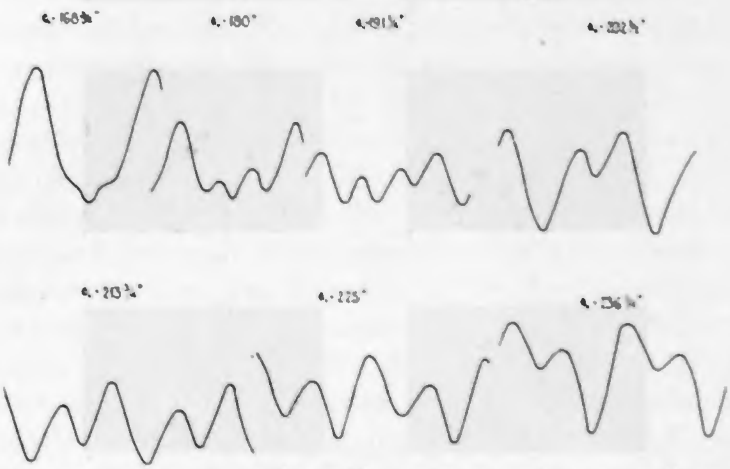


FIGURE 47—Synthetic Wave Forms Showing Distortion Due to Frequency Modulation

relation as shown on the lower right of Figure 46, we have the envelope of the resultant wave at the receiver.

When the mean position of the two vectors (a) and (b) in Figure 27 is 180 degrees separation, the signal is experiencing a fading minimum. When they are on the average in phase the amplitude is at a maximum. We can, therefore, trace a relation between quality distortion and fading by such an analysis, assuming a constant percentage modulation. Figure 47 shows a series of high-frequency wave envelopes obtained by this method of graphic analysis. The mean vector relation is represented by ϕ_o, and for $\phi_o = 180$ degrees the fading may be considered at a minimum. The waves shown in Figure 47 being envelopes of the high frequency, will undergo certain changes in the process of detection. These, however, would only slightly modify the wave.

For purposes of comparison, a set of oscillograph pictures of representative received wave shapes is shown in Figure 48. These represent the actual effect of night-time transmission with frequency modulation between 463 West Street, New York City and Stamford, Conn.; the modulating tone was a practically pure 264-cycle sinusoidal wave. The samples have been arranged in successive order to correspond with the order shown in Figure 47. There exists a striking similarity. Occasionally, however,

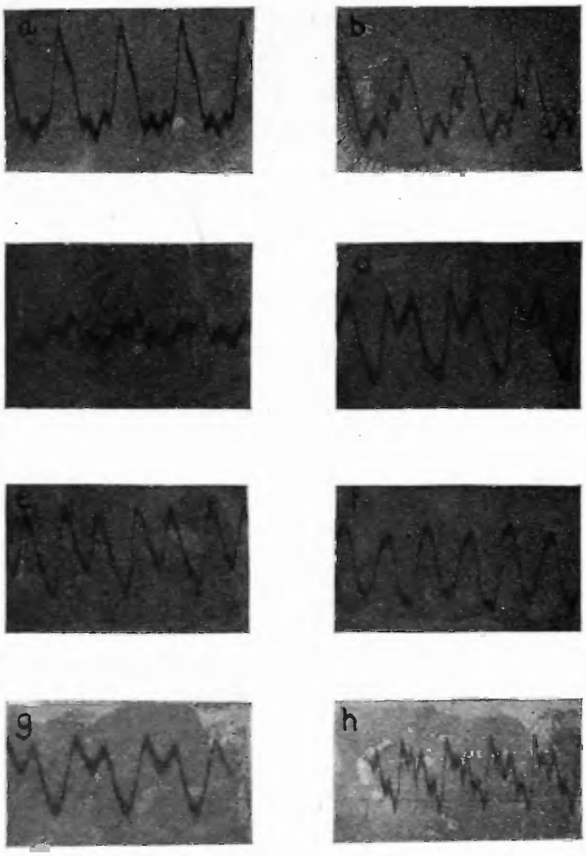


FIGURE 48—Oscillograms Showing Actual Wave Forms with Distortion Resulting from Frequency Modulation

the shapes predicted may depart considerably from those obtained experimentally. As an example of such a departure, the record (h) in Figure 48 has been included. Such unusual samples may be due to a combination of waves arriving over more than two paths or it may be that the time variation of the frequency is far from the simple sinusoid which we have assumed. As a matter of fact, a critical mathematical treatment of this case shows that only an approximation of such a sinusoidal condition is possible since, as has been shown by Carson,[4] a frequency modulated wave of this character consists of an infinite series of fixed frequencies spaced at regular intervals either side of a "fundamental" carrier wave. Obviously, only a small part of such a series could get out of the transmitter or into the receiver due to circuit selectivity. For the lower modulating frequencies, however, the approximation involved in the assumption of a simple sinusoidal variation is not far wrong since the amplitudes of these side frequency components fall off rapidly as their order in the series increases. While 150 wave lengths difference in path length has been assumed for the synthesis of the wave shapes in Figure 47, this difference may, according to the data obtained, amount to much more than this.

It may well be asked why this frequency modulation, since it produces such marked distortion at night in certain places, does not also give rise to distortion by day or in locations where transmission is steady. A full answer to this question would be far from simple. But in brief it is because the carrier and side bands shift in absolute frequency together as a unit so that their relative or difference frequencies which determine the audio signal remain unchanged. Another way to put it is that the detector operates on the envelope of the high-frequency signals and is blind to the frequencies contained within the envelope except insofar as they affect the latter. However, since frequency modulation appreciably widens the frequency band occupied by the radio signals, it is to be expected that the tuned circuits in the receiver would have some reaction on those louder portions of the signal for which the amplitude modulation and, therefore, the frequency modulation, is large. The perfection with which broadcast signals may be received under suitable conditions leads one to believe that this effect must be small.

Fading in Relation to Form of Transmission

It has been shown that serious wave form distortion of the reproduced signal may result if frequency modulation occurs with the amplitude modulation and the transmission is subjected to night-time conditions. This distortion from frequency modulation can be eliminated by stabilizing the carrier frequency. There remain some wave form distortion and the annoying amplitude changes caused by selective fading which is one of the most serious present day problems in radio transmission. Let us now

[4] See "Notes on the Theory of Modulation," by John R. Carson, February, 1922. Proceedings of The Institute of Radio Engineers.

consider the nature and cause of this residual wave form distortion and some further consequences of selective fading under the assumption that there is no frequency modulation involved.

The process of detecting audio signals from radio frequency signals is, at least in its simpler aspects, well understood, but it may not be generally appreciated that the action is such that the detected signals may be greatly modified by changes in the relative amplitudes and phases of the carrier and side-band components such as may result from their transmission through the medium. That the amplitudes and phases of the carrier and side-band signals are not necessarily received in the same relation that existed as they left the transmitter, has been pointed out earlier, in the discussion on selective fading.

The usual expression for a high-frequency carrier wave of frequency $p/2\pi$ modulated by a low-frequency wave of frequency $v/2\pi$ is

$$e = A[1 + a\ sin\ (vt + \phi)]\ sin\ pt$$

where A is the carrier amplitude, a, the percentage modulation and ϕ the starting phase of the modulating tone with reference to the carrier. Expanded into its components this becomes

$$e = \frac{A_1 a}{2} cos\ (pt + vt + \phi_1) \qquad \text{(the upper side band)}$$

$$- \frac{A_2 a}{2} cos\ (pt - vt - \phi_2) \qquad \text{(the lower side band)}$$

$$+ A_3\ sin\ pt \qquad \text{(the carrier)}$$

where $\phi_1 = \phi_2 = \phi$ and $A_1 = A_2 = A_3 = A$ as the waves leave the transmitting antenna.

In the receiving set this function is squared by the action of the detector and, neglecting direct currents and frequencies above the audio range, the result is

$$\frac{a}{2} A_3 [A_1 sin\ (vt + \phi_1) + A_2 sin\ (v + \phi_2)] +$$

$$A_1 A_2 \frac{a^2}{4} cos\ (2vt + \phi_1 + \phi_2) \qquad (17)$$

of which the first term represents the fundamental frequency of the original modulating tone and the second term the second harmonic.

From this expression several conclusions can be immediately drawn. Due to the action of the detector there is always some slight wave form distortion, as is evidenced by the presence in relatively small amplitude of the second harmonic. In the ordinary case this is negligible. The first term contains the carrier amplitude as a factor, but the second term does not. Thus, if selective fading erases the carrier at any time, reducing its amplitude to zero or a small value, the signal, represented by the fundamental tone, practically disappears, *even though the side bands have not faded out*, and there remains only the harmonic. This is the residual distortion shown in Figure 41 and which can often be heard during a fading-out period. It is caused by the two side bands beating together in the detector. We have here exposed a fundamental defect in the usual form of modulated signal transmission. The amplitude of the received signal is subject to all the whims of the carrier and, to paraphrase freely an old saying, we might remark that a signal is no stronger than its carrier. We may at once conclude that one way to reduce fading is to suppress the carrier and resupply a constant amplitude carrier at the receiving station.

Analyzing further the first term of the expression representing the detected signal, the first part of the bracketed portion results from beating together in the detector of the carrier and upper side band and the second part from the carrier and lower side band. It is clear that one of the side bands may fade out completely and the other will still bring in the signal, provided the carrier is not also lost, with a phase shift to be sure but nevertheless not seriously reduced in amplitude. In telephony this kind of phase shift is relatively unimportant. Here we have an evident advantage in transmitting both side bands since they support each other's frailties. But if the two side bands suffer phase shifts in transmission, as we have earlier shown may be produced by wave interference, such that ϕ_1 and ϕ_2 differ by π radians or 180 degrees, the two components will cancel each other provided their amplitudes A_1 and A_2 remain equal. In other words, all three components—carrier and both side bands—may arrive at the receiver with full amplitude and yet no signal will be detected from them except a second harmonic component. This is obviously a disadvantage of transmitting both side bands since, at such an instant, if one of them were eliminated, the signal would reappear.

We conclude that there is, on the basis of such a brief analysis, not much to choose between single side-band and double side-band transmission when the carrier is transmitted also.

But if we wish to realize the advantages of carrier suppression, a choice is not difficult. A carrier suppression system in which both side bands are transmitted requires that the replacement of the carrier at the receiving station be done with almost absolute accuracy as to frequency and phase, a thing which involves very serious practical problems. On the other hand, if but a single side band is transmitted, the difficulty is reduced to placing the carrier within a very few cycles of its correct position. The allowable departure will depend on a number of things, but there is reason to believe that for high quality transmission it must be very small, perhaps no greater than two or three cycles.

With the single side-band carrier suppression method, invented by John R. Carson, the radiation is stripped down to the minumum, which will fully transmit the telephonic signals, and this reduces to a minimum the exposure of the signals to the ravages of selective fading. If the spacing interval of the fading is relatively narrow, as in the cases we have examined hereinbefore, this form of transmission would not fade seriously in average volume, but would be subjected to a continual changing of its frequency-amplitude characteristic, that is to say, individual frequency components would fade progressively as the minima of the selective fading wandered back and forth across the frequency range encompassed by the single side band. If the spacing interval of the fading were very large so that the minima were very broad or if some other at present unexplored form of fading which covers a wide band at one time were acting, the signal would fade in average volume, but the range of its variation would be only the square root of that of a carrier transmitted signal, since only the side band would fade and the locally supplied carrier would remain unchanged.

The extent to which these theoretically drawn conclusions may be realized in practical application is yet to be determined, but we have a few records bearing upon the matter which at least do not run contrary to them.

All of the transmission tests where the radio signal was beat with a local oscillator and the detected beat note observed, were equivalent to single frequency single side-band transmission with carrier suppression, the local oscillator functioning as the carrier suppressed at the transmitter. In this case, for which a number of records have already been shown, the detected signal is in proportion to the product of the amplitudes of beating oscillator and received radio signal. The phase of either does not affect the amplitude of the audio signal. Hence the only important modification of the original signal is the variation in the amplitude resulting from selective fading.

Unfortunately, we have no records in which a direct comparison is made between single side-band transmission with and without carrier suppression, but the case can be visualized from the record shown in Figure 12 or 13. Here each one of the frequencies recorded may be looked upon as a single side-band frequency which has been detected through the agency of the resupplied carrier of the beating oscillator used to bring them down to audio frequency. If now we were to take two of these frequencies shown on the record and multiply their amplitudes together at each point, we would obtain the amplitude of the signal which would result if one of them were a single side band and the other its accompanying carrier. It is obvious that the fading variations would thereby be increased in amplitude and rapidity.

In order to obtain a comprehensive picture of the relative advantages of radio transmission using a carrier and one side band as compared with the common practice of transmitting both side bands, the following tests were made. The schematic diagram of the circuit arrangement is shown in Figure 49. At the

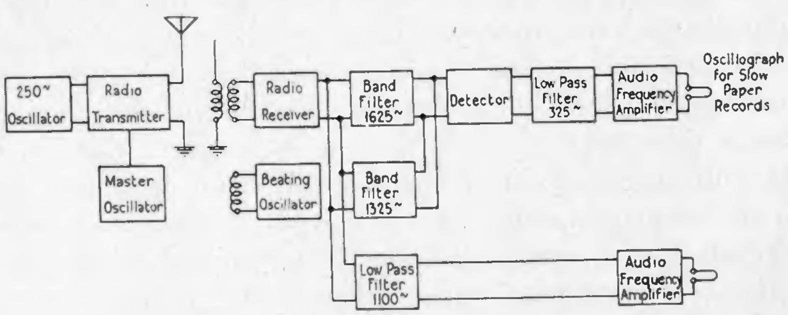


FIGURE 49—Diagram of System Used to Obtain Records of Transmission with Carrier and One Side Band and Carrier and Both Side-Bands

transmitter the carrier and both side bands are transmitted, and at the receiver they were selected out by means of filters in the manner previously explained. The signals from the filters corresponding to the carrier and lower side band were applied to the input of a detector circuit and from its output the detected difference signal was selected by a low-pass filter. This signal was equivalent to that which would be received if only the carrier and one side band were transmitted. From the output of the radio receiver a branch circuit goes to a low-pass filter which transmits only the signal detected from the carrier and both side bands, suppressing from this circuit the higher frequency signals corresponding to carrier and side bands produced by the beating oscillator and received signals.

By making simultaneously a record of these two signals a direct comparison is obtained of the effect of selective fading on their amplitudes. Figure 50 shows samples of several such records made at Riverhead, L. I. The modulating frequency for strips 1, 2 and 3 is 250 cycles, and for strips 4 and 5, 500 cycles. The record on strip 3 is shown on account of the peculiar characteristic of the signal fading, for considerable periods of time remaining at relatively low amplitude. In these oscillograms the upper trace is the record of the signal from the carrier and both side bands, and the lower trace the signal from the carrier and lower side band.

These records illustrate by giving a graphic comparison the effect of the phase changes of the component signals in the case where the signal is detected from both side bands. The amplitude of the signal from both side bands in some instances is very small, but appreciable amplitude is still indicated at the same instant for the signal from one side band. This is explained as meaning that the side-band phases were such as to make the component signals 180 degrees out of phase after detection and that the amplitudes of the components were practically equal. The reverse situation is also observed where the amplitude of the signal detected from the lower side band is zero and appreciable signal is recorded for the case where both side bands are used. This is interpreted to mean that the side-band signal was eliminated by selective fading. In this event it was, of course, not contributing to the signal which was detected from both side-band signals. The recorded signal comes from the other side band which evidently was not eliminated at that instant by selective fading.

Visual observations made with the cathode ray oscillograph, which unfortunately furnishes no permanent record of transient effects, confirmed the strip records in regard to the reality of there being side-band phase variations. From equation (17), it is seen that if these variations occur, the fundamental of the detected tone signal at the receiver will not bear a fixed phase relation to that detected from the transmitting antenna current, while if there are no such changes the phase between these two tones would remain constant. The locally detected tone and the tone detected from the transmitting antenna current and brought to the receiving station over telephone wires, were applied to the two pairs of deflecting plates in the cathode ray oscillograph. Since the deflections caused by these two pairs of plates are at right angles to each other, the resulting Lissajous figure from two sine waves of the same frequency will be a slanting line, an ellipse or a circle depending on their phase and amplitude relation. The actual figures were observed to change progressively through this range of shapes, the changes following roughly the magnitude

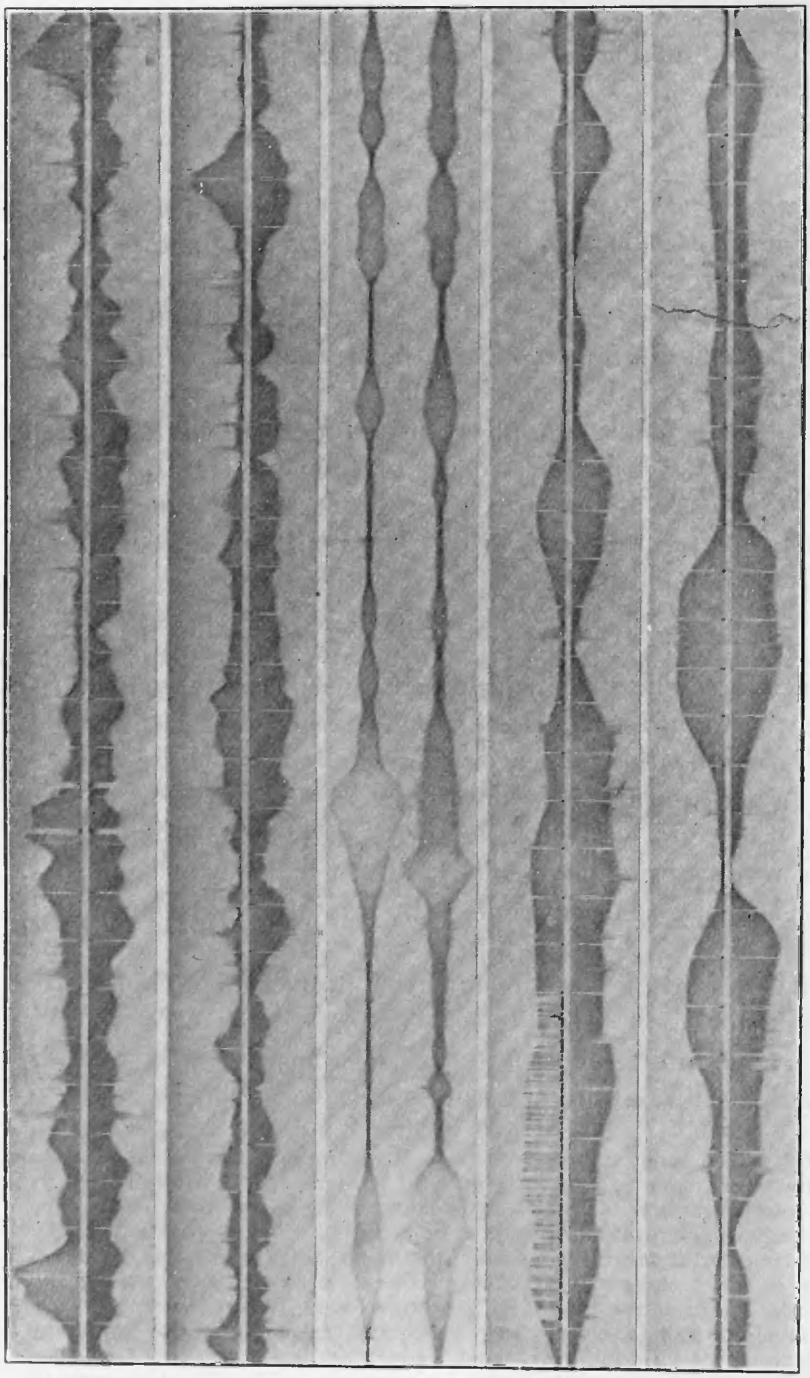


FIGURE 50—Slow Record Comparing the Signal Detected from Carrier and One Side Band with Signal Detected from Carrier and Both Side Bands. Made at Riverhead, L. I. Upper trace carrier+both side bands, lower trace carrier+one side band. Strips 1 and 2, July 22, 1925, 1.46 A. M. 250-cycle modulating tone. Strip 3, July 21, 1925, 3.10 A.M. 250-cycle modulating tone. Strips 4 and 5, July 23, 1925, 2.47 A. M., 500-cycle modulating tone

and rapidity of the fading. The effect of amplitude changes on such figures is quite distinct from the effect of phase changes, and there was no difficulty in separating out the evidence of large phase changes.

Considering only the above theories and facts, there appears to be a reasonable basis for a conclusion that the best form of radio transmission for use in broadcasting is single side band with carrier suppression. But on practical grounds we do not believe such a conclusion is justified. The fading and distortions which we have made much of in the preceding pages are not experienced by the majority of broadcast listeners when they listen to local stations. To require these listeners to provide themselves with more complicated and expensive receivers, simply to allow more distant or less favorably situated listeners to obtain better reception, seems neither reasonable nor desirable. The art offers several other possible avenues toward improvement much less difficult of application and it must be remembered that radio broadcasting is already reaching a degree of standardization and a volume of existing receiving equipment which rules that changes must come slowly and without serious prejudice to the existing order.

Conclusions

Subject to the limitations imposed by the scope of our investigations the following conclusions may be drawn:

Fading can be quite sharply selective as to frequency and the evidence points toward wave interference as the cause.

The evidence for wave interference indicates that some of the energy of received signals reaches its destinations by a circuitous route and suggests that this route is by way of upper atmospheric regions.

Quality distortion may result from dynamic instability of the transmitter.

Fixed wave interference patterns in connection with shadows sometimes exist in daytime transmission.

SYNOPSIS: The paper is based on radio transmission tests from station 2XB in New York City to two outlying field stations. It is a detailed study of fading and distortion of radio signals under night-time conditions in a particular region which may or may not be typical.

Night-time fading tests using constant single frequencies and bands of frequencies in which the receiving observations were recorded by oscillograph show that the fading is selective. By selective fading it is meant that different frequencies do not fade together. From the regularity of the frequency relation between the frequencies which fade together it is concluded that the selective fading is caused by wave interference. The signals appear to reach the receiving point by at least two paths of different lengths. The

paths change slowly with reference to each other, so that at different times the component waves add or neutralize, going through these conditions progressively. The two major paths by which the interfering waves travel are calculated to have a difference in length of the order of 135 kilometers for the conditions of the tests. Since this difference is greater than the distance directly from transmitter to receiver, it is assumed that one path at least must follow a circuitous route, probably reaching upward through higher atmospheric regions. Various theories to explain this are briefly reviewed.

The territory about one of the receiving test stations in Connecticut is found under daytime conditions to be the seat of a gigantic fixed wave interference or diffraction pattern caused in part by the shadowing of a group of high buildings in New York City. The influence of this pattern on nighttime fading is discussed. It is considered a contributing but not the controlling effect.

Tests using transmission from an ordinary type of broadcasting transmitter show that such transmitters have a dynamic frequency instability or frequency modulation combined with the amplitude modulation. At night the wave interference effects which produce selective fading, result in distortion of the signals when frequency modulation is present. It is shown that stabilizing the transmitter frequency eliminates this distortion. A theory explaining the action is given. The distortions predicted by the theory check with the actual distortions observed.

A discussion of ordinary modulated carrier transmission, carrier suppression, and single side band transmission is given in relation to selective fading. It is shown that the use of a carrier suppression system should reduce fading.

THE PRESENT STATUS OF RADIO ATMOSPHERIC DISTURBANCES*

By

L. W. Austin

(Laboratory for Special Radio Transmission Research)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

Our knowledge concerning the atmospheric disturbances is still very meager. The observed facts may be cataloged as follows: (1) In general, atmospherics are stronger at the longer wave lengths. (2) Except for the effects of local storms, they are nearly always stronger in the afternoon and night, while for the higher frequencies this increase in strength is confined usually to the night alone. (3) They are stronger in summer than in winter, (4) in the south than in the north, and (5) on the land than on the ocean. (6) A large proportion of them appear to be directive; that is, to come from definite regions, or centers, as mountain ranges, rain areas, or thunderstorms. It is also reasonably certain that (7) at least most of the long-wave disturbances travel along the earth with a practically vertical wave front,[1] like the signals; (8) that a considerable portion are oscillatory in character, though a certain portion are non-oscillatory and give rise to shock oscillations in the antenna at all wave lengths; and (9) that disturbances sometimes occur simultaneously at stations thousands of miles apart.[2]

The origin of the ordinary rumbling disturbances (grinders) has been the subject of many conjectures. Eccles[3] believed at one time that he had found the source of this type of disturbance, as far as England was concerned, in distant thunderstorms, espe-

---

*Presented at the annual meeting of the Section of Terrestrial Magnetism and Electricity of the American Geophysical Union, Washington, D. C., April 30, 1925.

Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce.

Received by the Editor, October 28, 1925.

[1] Jnl. Wash. Acad. Sci., volume 11, page 101, 1921.

[2] M. Baumler, Jahrb. d. Drahtlosen Teleg., volume 19, page 325; 1922. This matter of simultaneous crashes needs further investigation since a certain number of such coincidences may evidently occur by chance.

[3] Electrician (London), volume 69, page 75; 1912.

cially in Western Africa. DeGroot[4] has suggested that the grinders are due to the bombardment of the upper atmosphere by electrons from the sun or charged cosmic dust. The idea that this type of disturbance comes in some way from above has also been held by Weagant.[5] Mosler,[6] while ascribing the disturbances to thunderstorms, concluded in contradiction to the ideas of Eccles, that thunderstorms could give rise to atmospherics only over a radius of about 60 miles. This limitation in distance was very probably due to insensitive apparatus. A very systematic study of thunderstorms and atmospherics, undertaken by the British Meteorological Office and the Admiralty, has apparently settled the fact that thunderstorms can be located with modern apparatus up to about 1,500 miles.[7]

There is still much difference of opinion as to the proportion of atmospherics which is due to thunderstorms. Professor Appleton, at a symposium[8] on atmospheric ionization and radiotelegraphy, November 28, 1924, expressed the opinion that practically all atmospheric disturbances might be produced by thunderstorms somewhere in the world.

It is undoubtedly true that thunderstorms produce many atmospherics, but it is not by any means certain that the lightning flashes themselves are always the actual sources. There is a widely prevailing idea among radio operators that the lightning flash often produces only a harmless click in the telephone receivers. I have made some observations during thunderstorms, using a coupled circuit with rectifying vacuum tube and galvanometer, which indicated that lightning flashes, even within three or four miles, were not as powerful in their effects on the receiving apparatus as many of the disturbances which occurred when no flashes were apparent. This comparatively feeble effect of the flashes is difficult to understand if the current rise at the beginning of the flash is as steep as is often assumed, but would be understandable if the lightning discharge curves were of the form and duration of the atmospheric disturbance curves observed by Appleton and Watt (Figures 1 to 5). On the other hand, it is quite possible that the small deflections from the lightning flashes were due to a paralysis of the detector tube, a phenomenon which often occurs when the tube is exposed to very high electro-

[4] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, page 75; 1917.

[5] PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, 7, page 207; 1919.

[6] Elektrot. Zeits., page 1134; 1912.

[7] World Power, volume 3, page 20; 1925.

[8] Proc. Phys. Soc., London, volume 37, Page 2D-50D (appendix), 1925.

motive forces. It must, therefore, be concluded that the connection between lightning and atmospherics is still not clear, and valuable work can be done by anyone who will watch the lightning and listen to the atmospheric crashes from thunderstorms in the neighborhood.

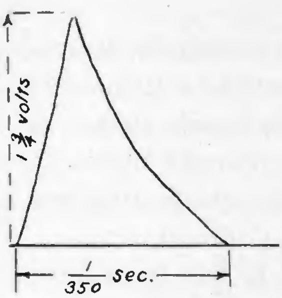


FIGURE 1

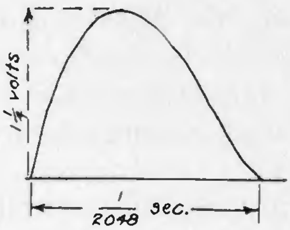


FIGURE 2

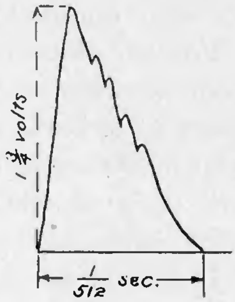


FIGURE 3

At the London Physical Society symposium already mentioned, Professor C. T. R. Wilson discussed the probability of there being discharges of thunderclouds to the upper conducting region of the atmosphere. His calculations indicated that thunderclouds of common electric moment might very readily discharge to a conducting layer at a height of 60 or 80 kilometers, since the electric force required to produce discharge decreases even more rapidly with the height than the electric force of the thundercloud. Discharges of this kind, probably non-luminous, may possibly furnish the explanation of the strong atmospherics heard from thunderclouds when no flashes are visible.

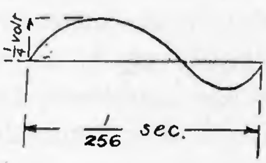


FIGURE 4

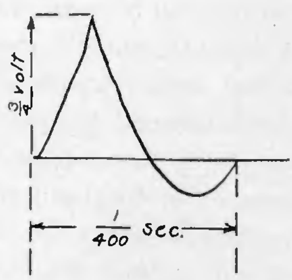


FIGURE 5

Mr. Watson Watt, in analyzing the records of European[9] direction-finding stations, concluded that in only about 35 percent of the cases could thunderstorms be identified as the sources of atmospheric disturbances, though in about 75 percent of the cases the identified sources were rain areas of some kind.

[9] Nature, 110, page 680, 1922.

Captain Bureau[10] of the French Meteorological Office has recently published papers in which he shows that many of the atmospheric disturbances in France are closely connected with the advance of meteorological cold fronts and that the atmospherics are accentuated when these air movements come in contact with mounted ranges.

For the determination of the direction from which atmospheric disturbances come, Mr. Watt[11] has invented an automatic recording apparatus in which a radio compass coil, tuned to about 30,000 meters, is rotated slowly and continuously by clockwork, the atmospheric crashes being recorded on a drum attached to the coil.

It should be said in this connection that it has been very common in Europe to estimate the strength of atmospherics by the number of disturbances occurring in a given time. This method, of course, would hardly seem to be applicable to our Washington summer conditions, or to the conditions during the disturbance season in the tropics, where often in the afternoons and evenings the noise in the telephones forms an almost continuous rumbling through which no signal can be heard unless it is strong enough to rise above the background of disturbing sounds.

If, indeed, there is a physical difference between the atmospherics, crashes, grinders, etc., it is not at all certain that what is being measured in Europe by the counting method is the same thing that is being measured in America, either by direct estimates of the average disturbance strength, or by measuring the strength of signal which can be read through the disturbances.

On the Atlantic and Pacific coasts of the United States, except for occasional local thunderstorms, very little certain connection has been noticed between the direction of the atmospheric disturbances and rain areas. On the Atlantic coast, the main disturbances seem to come roughly from the southwest, but it seems uncertain whether the sources are in the Allegheny Mountains or much farther removed, perhaps in Yucatan. Experiments reported by the Navy Department in New Orleans have indicated the more southerly origin.

Unfortunately, very few triangulation experiments have been made in America for fixing the exact positions of sources of atmospherics. In most cases, therefore, the direction is all that is known.

[10] C.-R. Acad. Sci., volume 176, page 556 and page 1623, 1924; L'Onde Electrique, volume 3, page 385, 1924.

[11] Proc. Roy. Soc., A, volume 102, page 460, 1923; and Phil. Mag., volume 45, page 1010, 1923.

Observations made at Madison, Wisconsin, by Professor Terry of the University of Wisconsin, covering the last two years, show conditions in the Middle West which are similar to those described by the continental European observers; that is, there is no single prevailing direction of the atmospherics, but a more or less definite connection with thunderstorms and other rain areas. This absence of any prevailing southerly source of atmospherics in the central portion of the country casts doubt on the Mexican origin of those observed in the Atlantic Coast region, since the distance from Yucatan to Madison, Wisconsin, is about the same as from Yucatan to Washington.

On the Pacific Coast of the United States it is pretty well established that at least at San Francisco and San Diego the sources of disturbance are largely local, lying in the mountain ranges not far from the coast. These centers seem to be permanently fixed, resulting in very constant directional conditions.

It seems to be pretty well settled, in all parts of the world where observations have been made, that there is a very definite connection between the intensity of the disturbances and the position of the sun. In the northern hemisphere during the winter when the sun is far in the south, the disturbances are generally moderate even as far south as Panama, within 9 degrees of the equator. But as the sun comes north in the spring, there is often a rapid and, sometimes, very sudden increase in strength, and it is reported that stations close to the equator experience two disturbance maxima, corresponding to the two periods when the sun is nearly overhead.

In addition to the study of the sources of the disturbances, the question of their wave form is of much importance. Messrs. Watt and Appleton[12] in England, working under the Radio Research Board, have made some investigations of this problem, making use of the cathode-ray oscillograph (Braun tube). In their work the atmospheric disturbance, after being received on an aperiodic antenna and amplified by an aperiodic resistance-coupled amplifier, was impressed on one pair of plates of the oscillograph, while a source of 60-cycle current was connected to the other pair of plates for the purpose of drawing out the spot of light into a line on the fluorescent screen. The resulting movement of the spot of light could not be photographed, but could be observed and sketched with some accuracy. Five typical curves are shown in the figures. Most of these appear to be aperiodic though some are feebly oscillatory.

[12] Proc. Roy. Soc., A, volume 103, page 84, 1923.

In Figure 3 it is seen that there are minute oscillations superposed on the main curve. It will be noted that the period of the main oscillation is, in all cases, of audio frequency; and Ecklersley[13] has pointed out recently that the relatively prolonged impulses of Watt and Appleton cannot account for the observed intensity of the atmospherics ordinarily experienced in radio reception. He suggests that possibly the ripples, such as are shown in Figure 3, may be the actual atmospheric waves. Mr. Watt in the symposium cited accepts this view and adds that more recent experiments in Egypt and elsewhere in the tropics show that there the fine ripple structure is much more common and of much greater amplitude than in England. Professor Appleton, on the other hand, holds that the low-frequency wave forms shown in the figures are capable of producing the observed disturbances at all wave lengths by shock excitation.

In conclusion, the differences of opinion mentioned in this paper show that there is still much to be done before the sources of the disturbances are identified with certainty. While many of the atmospherics undoubtedly come from thunderstorms, many appear to come from regions where no such storms are occurring. It is also believed that even in thunderstorms some of the heaviest disturbances do not come from the lightning itself, but the nature of these non-luminous sources of such great power is still a matter of conjecture.

Bureau of Standards,
Department of Commerce,
Washington, D. C.

SUMMARY: The paper gives a résumé of our present knowledge concerning atmospheric disturbances. It is found that in Europe about thirty percent of these come from thunderstorms, while 75 percent are associated with rain areas of some kind. In the United States, near the Atlantic Coast, disturbances in general come from the southwest, while on the coast of California they come from permanent centers in the neighboring mountains. In the Middle West the direction is variable, depending on thunderstorms, rain areas, etc. In England, cathode-ray oscillograms have been taken of the atmospherics. The main disturbance is of audio frequency and usually aperiodic. Some of the curves show high-frequency ripples on the main waves. These may be the real sources of atmospheric troubles.

[13] Electrician (London), volume 93, page 150. 1924.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued November 3, 1925—December 29, 1925

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,559,723—F. E. MANN, Cherrydale, Virginia. Filed December 10, 1923, issued November 3, 1925.

CRYSTAL DETECTOR, where a crystal holder is arranged to be mounted adjacent a panel and an adjustable arm mounted within the panel and controllable from the front thereof for properly setting the detector.

1,559,743—H. J. J. M. DeBELLESCIZE, Paris. France. Filed August 29, 1921, issued November 3, 1925.

RADIO RECEIVING SYSTEM for reception of continuous wave signals without a heterodyne in which a periodic antenna is provided with a tuned and detuned receiver associated therewith, the receiver being differentially coupled with an indicating device for securing response to the continuous wave signaling energy.

1,559,776—H. S. READ, New Haven, Connecticut. Filed December 9, 1919, issued November 3, 1925. Assigned to Western Electric Company.

THERMIONIC REPEATER OR OSCILLATOR CIRCUITS, in which an electron tube having a heated cathode and a controllable cathode heating circuit is provided with means for maintaining the energization of the cathode heating circuit at a predetermined value for a desired condition of oscillation of the circuit.

1,559,802—G. H. STEVENSON, Rye, New York. Filed May 16, 1921, issued November 3, 1925. Assigned to Western Electric Company.

ELECTRICAL SWITCHING CIRCUITS, whereby inductance and capacity changes in a circuit may be conducted simultaneously.

1,559,869—R. V. L. HARTLEY, East Orange, New Jersey. Filed September 23, 1919, issued November 3, 1925. Assigned to Western Electric Company.

SELECTIVE CURRENT PRODUCTION AND AMPLIFICATION by means of electron tubes in which a harmonic producer having an output circuit and a control circuit is provided with a plurality of selective paths in said output circuit and an individual coupling between each of the selective paths and the control circuit. Harmonics of different frequencies are developed from a given space frequency.

1,559,974—G. J. MULLIGAN, Columbus, Ohio. Filed March 8, 1924, issued November 3, 1925.

VARIABLE ELECTRIC CONDENSER, in which a tank containing mercury has its mercury content displaced by the lowering of an adjustable member therein for varying the capacity with respect to an outer plate.

1,559,992—W. SCHAFFER, Berlin, Germany. Filed August 18, 1922, issued November 3, 1925. Assigned to Gesellschaft fur Drahtlose Telegraphie.

ARRANGEMENT FOR FREQUENCY TRANSFORMATION PARTICULARLY FOR OPERATING RELAY STATIONS, in which an electron tube circuit is operated at a receiver by incoming signaling energy and the output circuit of the tube system arranged to control the grid

*Received by the Editor, January 16, 1925.

potential of the transmission system for reradiating the received signaling energy.

1,560,056—J. W. HORTON, Bloomfield, New Jersey. Filed May 1, 1923, issued November 3, 1925. Assigned to Western Electric Company.
SOURCE OF WAVES OF CONSTANT FREQUENCY, in which a tuning fork having a fundamental frequency equal to the frequency of the generator is arranged for controlling the operation of a synchronous motor so as to operate in synchronism with the generator for performing various purposes where constant frequency is required.

1,560,206—E. L. CHAFFEE, Belmont, Massachusetts. Filed April 25, 1918, issued November 3, 1925. Assigned to John Hays Hammond, Jr.
METHOD AND SYSTEM FOR THE TRANSMISSION OF RADIANT ENERGY and the reception of signaling energy where the detector is protected against excess static effects by means of parallel arranged tubes in circuit therewith.

1,560,310—C. PFANSTIEHL and W. O. BELL. Highland Park, Illinois. Filed January 2, 1924, issued November 3, 1925. Assigned to Pfanstiehl Radio Company.
GRID LEAK CONDENSER, in which alternate dielectric and conductive plates are provided with apertures in the dielectric plates through which a grid leak passes in parallel with the conductive plates.

1,560,390—J. G. LIEBEL and E. S. FLARSHEIM, of Cincinnati, Ohio. Filed September 24, 1923, issued November 3, 1925
SPARK GAP for high frequency discharge circuits in which a plurality of spark gaps are adjustably arranged in a frame with means for preventing excess heating of the gaps.

1,560,431—A. SCHMIDT, JR., Schenectady, New York. Filed July 3, 1923, issued November 3, 1925. Assigned to General Electric Company.
SIGNALING SYSTEM, in which an electron tube oscillator is modulated by means of an auxiliary tube system which is varied in resistance in accordance with a simultaneous change in negative potential upon the grid of the oscillator tube for the production of signals.

1,560,690—W. G. HOUSEKEEPER, New York. Filed April 21, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the plate is formed in the shape of a depending metallic cup sealed to the glass container and enclosing the other electrodes within the tube.

1,560,691—W. G. HOUSEKEEPER, New York. Filed May 28, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the filament is maintained taut by means of a spring carried by an insulated member which extends across the top of all of the electrodes.

1,560,692—W. G. HOUSEKEEPER, New York. Filed June 13, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the anode is formed by a pair of plates joined at their outer edges and locked together to form a substantially continuous plate member.

1,560,737—P. SCHWERIN, New York. Filed May 22, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, where an insulated block is provided across the top of the tube electrodes with a tubular member passing therethrough and supporting a spring device by which the cathode is maintained under tension.

1,560,740—J. L. STELLING, New York. Filed July 22, 1923, issued November 10, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of a collar which embraces the re-entrant stem of the tube where the stem is sand-blasted or roughened to insure a good support for the tube electrodes.

1,560,761—L. COHEN, Washington, D. C. Filed June 5, 1922, issued November 10, 1925.
VARIABLE CONDENSER, where the stationary and variable plates of the condenser are varied in special relationship by axial movement of a central shaft.

1,560,854—J. H. PRESSLEY, Oceanport, New Jersey. Filed October 16, 1924, issued November 10, 1925.
RADIO RECEIVING APPARATUS, in which the circuits of an electron tube oscillator are balanced by a mesh circuit or wheatstone bridge so that the tuning of the receiving circuit does not affect the tuning of the local oscillator circuit in a continuous wave receiver.

1,560,911—C. F. M. HAYES and L. GRINSTEAD, London, England. Filed February 10, 1923, issued November 10, 1925. Assigned to Mullard Radio Valve Company, Limited.
VACUUM TUBES where the electrodes are mounted from a band which encircles the stem within the tube, the band being wedged against the stem to insure rigid support for electrodes.

1,561,001—I. LANGMUIR, Schenectedy, New York. Filed February 7, 1921, issued November 10, 1925. Assigned to General Electric Company.
ELECTRIC OSCILLATOR of the two-electrode variety in which a cathode and anode are sealed within a vessel filled with an inert gas at a pressure of the order of 0.005 to 0.075 millimeter of mercury.

1,561,228—J. H. HAMMOND, JR., Gloucester, Massachusetts. Filed February 16, 1921, issued November 10, 1925.
CAPACITY COMPENSATING DEVICE for an antenna system which is subject to change in position. A condenser is provided with automatic means for varying its capacity in proportion to the variation in capacity of the antenna circuit, due to the movement of the antenna with respect to the earth.

1,561,258—S. LOEWE, Berlin, Germany. Filed July 27, 1921, issued November 10, 1925.
PROCESS FOR TESTING SPARK STATIONS, which consists in connecting a direct-current instrument to a part of the system undergoing periodical electrical changes and observing whether the direct-current instrument gives a constant reading

1,561,273—H. W. NICHOLS, Maplewood, New Jersey. Filed November 24, 1924, issued November 10, 1925. Assigned to Western Electric Company.
RADIO SYSTEM for high power speech transmission, where energy is supplied to rectifying devices at several thousand volts and the energy of the amount of 100-kilowatts or more supplied to the transmission circuit. The high power amplifier of the transmission system is supplied with direct-current potential from a two-phase alternating-current source and a rectifier in which the ripple component resulting from rectification is supplied to the space path of the amplifying tube at the same time that the filament electrodes of the amplifying tubes are supplied directly from alternating current.

1,561,559—J. O. MAUBORGNE, LOUIS COHEN and GUY HILL, Washington, D. C. Filed April 8, 1921, issued November 17, 1925.
ELECTRICAL SIGNALING employing wave coils upon which are developed wave formations independent of undesired interference and the desired signaling energy selected by means of a receiving circuit coupled with the wave coils.

1,561,619—R. R. BEAL, Palo Alto, California. Filed January 5, 1920, issued November 17, 1925. Assigned to Federal Telegraph Company.
RADIO-TELEGRAPHY, in which an arc converter is employed with a signaling circuit for transmitting by means of a single wave, eliminating the compensating wave.

1,561,837—J. J. DOWLING, Rathgab, Dublin. Filed July 30, 1924, issued November 17, 1925.
THERMIONIC INDICATING MEANS RESPONSIVE TO LIGHT VARIATIONS, in which an electron tube amplifier is actuated by means

of variation in a source of light for actuating a relay which may be employed to operate any desired form of circuit.

1,561,914—H. F. ELLIOTT and J. A. MILLER, Palo Alto, California. Filed January 9, 1922, issued November 17, 1925. Assigned to Federal Telegraph Company.
RADIO FREQUENCY SYSTEM employing a plurality of arcs connected in branch circuits of an antenna system for supplying high frequency energy to the antenna system with impedance in series with each arc for preventing cross currents between the arc.

1,561,933—B. W. KENDALL, New York City. Filed August 7, 1918, issued November 17, 1925. Assigned to Western Electric Company.
SOURCE OF ALTERNATING CURRENT of constant frequency, where an electron tube is provided with an oscillation circuit and the anti-resonant circuit for determining the frequency of the oscillations generated. The anti-resonant circuit contains a magnetic core inductance with means for excluding uni-directional current from the inductance.

1,562,056—C. W. RICE, of Schenectady, New York. Filed April 21, 1921. issued November 17, 1925. Assigned to General Electric Company.
RADIO RECEIVING SYSTEM, in which a plurality of widely separated receiving antennas are connected by transmission lines to a central receiving station for avoiding interference from undesired signals and static.

1,562,172—W. G. HOUSEKEEPER, New York. Filed August 30, 1920, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, having a plate electrode formed of a tubular member, through which cooling water may be circulated.

1,562,209—B. J. EGERT and C. J. DE COSTER, of Brookfield and Moline, Illinois. Filed March 2, 1920, issued November 17, 1925. Assigned to Western Electric Company.
VACUUM TUBE EVACUATING OVEN, in which electron tubes are treated during the manufacturing process.

1,562,396—F. E. WARD, Corona, New York. Filed June 4, 1923, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of wire members provided with flat integral ears placed on opposite sides of a supporting plate member.

1,562,403—J. R. WILSON, New York. Filed December 19, 1924, issued November 17, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the cathode is supported by means of a helical spring and hook device for maintaining the cathode under tension with respect to the other electrodes.

1,562,485—H. A. AFFEL, Brooklyn, New York. Filed May 5, 1923, issued November 24, 1925. Assigned to American Telephone and Telegraph Company.
MOVEMENT AND POSITION INDICATOR, by which the speed of a moving station with reference to two fixed stations is determined. The method of determing this speed consists in simultaneously receiving waves of the same frequency radiated between the moving station and each of the fixed stations respectively, producing an indication proportionate to the relative phases of the received waves, which corresponds to the movement of the moving station, and determining from the number of cycles of relative phase shift per unit of time the number of wave lengths traveled by the moving station within that unit of time.

1,562,629—H. GERNSBACH, New York City. Filed September 27, 1923. issued November 24, 1925.
VARIABLE CONDENSER, in which a flexible metallic plate is adjusted with respect to a flat metallic plate, for varying the mutual capacity therebetween.

1,562,812—H. TRESS, Camp Alfred Vail, New Jersey. Filed March 26, 1924, issued November 24, 1925.
VARIABLE CONDENSER, in which the rotor and stator plates are aligned relative to each other by pin connectors extending into aligned sockets in each of the plates.

1,562,820—J. B. BRADY, Somerset, Maryland. Filed August 22, 1923, issued November 24, 1925. Assigned to Morkrum Company.
RADIO RECEIVING SYSTEM employing an automatic printer recorder by which signals are received and directly transcribed in print for transmission and reception of print by radio.

1,562,877—W. G. ELLIS, Philadelphia, Pennsylvania. Filed June 16, 1922, issued November 24, 1925.
RADIO RECEIVING SYSTEM, in which a loop receptor is employed with a circuit for improving the null or minimum point of reception in the receiving circuit for increasing the efficiency of the loop as a direction finder.

1,562,952—L. F. FULLER and G. C. SWEET, of Palo Alto, California and Waterloo, New York, respectively. Filed March 16, 1921, issued November, 24, 1925. Assigned to Wireless Improvement Company.
ARC CONVERTER, which is operated in polyphase, for the transmission of high-frequency signals.

1,562,961—R. A. HEISING, Milburn, New Jersey. Filed May 16, 1921, issued November 24, 1925. Assigned to Western Electric Company.
DIRECTIVE RADIO TRANSMISSION SYSTEM, where a long horizontal antenna is employed, which is progressively loaded for causing the antenna to radiate a uniform quantity of supplied energy per unit length of the antenna.

1,563,416—H. M. WOLFSON, New York City. Filed June 19, 1922, issued December 1, 1925.
VARIABLE CONDENSER, where the movable plates are helically formed and are advanced or retracted in an axial direction with respect to the rotor plates.

1,563,425—R. E. MARBURY, Edgewood Park, Pennsylvania. Filed June 17, 1920, issued December 1, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM, in which a local source of current of audible frequency is connected in circuit with a device so adjusted as to establish parallel resonance, one of the resonating elements embodying the audion bulb or amplifying device, the effect of the parallel resonance being to substantially prevent the flow of currents of audible frequency through the receiving device. Upon the occurrence of an incoming signal, the impedance of the amplifying device is modified and, consequently, the condition of parallel resonance is partially or wholly destroyed. As a consequence, currents of audible frequency traverse the receiving device, and clear and easily readable signals are produced therein.

1,563,440—A RUSSELL, Baltimore, Maryland. Filed February 3, 1925, issed December, 1, 1925. Assigned to Russell Radio Corporation.
VARIABLE CONDENSER, in which the plates are arranged in the form of concentric cylinders, which may be axially adjustable with respect to each other.

1,563,557—W. W. COBLENTZ, Washington, D. C. Filed September 18, 1923, issued December 1, 1925.
OPTICAL MEANS FOR RECTIFYING ALTERNATING CURRENTS, where a substance having inherent unidirectional selective conductivity when exposed to light is subjected to light rays for rectifying an alternating-current source.

1,563,620—W. S. GORTON, East Orange, New Jersey. Filed May 4, 1921, issued December 1, 1925. Assigned to Western Electric Company.
OSCILLATION GENERATOR, having means for predetermining the amplitude of the oscillating current produced by the generator, and also automatically operative to substantially compensate variations in the amplitude of said current.

1,563,644—H. W. NICHOLS, Maplewood, New Jersey. Filed December 13, 1924, issued December 1, 1925. Assigned to Western Electric Company.
WAVE RECEIVING SYSTEM, in which both the sum and difference components of the incoming signal wave and a locally generated oscillation, i. e., the sum and difference components resulting from intermediate

frequency detection are selected, separately detected, and combined in a receiver.

1,563,709—P. G. JACOBSON, Chicago, Illinois. Filed January 19, 1925, issued December 1, 1925.

ELECTROSTATIC CONDENSER construction where the rotor and stator plates are secured by clamping finger supports which extend between notched-out edges of the rotor or stator plates.

1,563,754—M. LATOUR, Paris, France. Filed August 19, 1921, issued December 1, 1925. Assigned to Latour Corporation.

ELECTRICAL CONDENSER of the fixed type where the conductive plate is bent into a U shape on opposite sides of an intermediate plate separated, therefrom by dielectric.

1,563,758—J. F. LINDBERG, Chicago, Illinois. Filed July 5, 1922, issued December 1, 1925. Assigned to Reliance Die and Stamping Company

CONDENSER of the variable type, where micrometer adjustment of capacity may be obtained by shifting the rotor by means of an auxiliary cam after an initial setting thereof.

1,563,893—S. COHEN, Brooklyn, New York. Filed March 14, 1925, issued December 1, 1925. Assigned to General Instrument Corporation.

MULTIPLE VARIABLE CONDENSER, in which a plurality of condenser elements are mounted on the same shaft and carried in the same condenser frame for simultaneous tuning of several electrical cirucits.

1,563,958—J. B. BRADY, Somerset, Maryland. Filed December 28, 1921, issed December 1, 1925. Assigned to Morkrum Company.

RADIO RECEIVING SYSTEM, in which automatic printers are used for setting down received signal impulses directly in print at a radio receiving station.

1,564,070—H. K. HUPPERT, San Francisco, California. Filed January 19, 1923, issued December 1, 1925.

RADIO VACUUM TUBE, in which the electron flow is varied by means of a magnetic field.

1,564,209—I.B. CRANDALL, Wyoming, New Jersey. Filed June 9, 1921, issued December 8, 1925. Assigned to Western Electric Company.

ELECTRICAL CIRCUITS FOR THE PRODUCTION OF MUSICAL TONES, for testing sensitiveness of the ear to sound.

1,564,627—H. J. ROUND, London, England. Filed March 31, 1920, issued December 8, 1925. Assigned to Radio Corporation of America.

RADIO TELEGRAPH AND TELEGRAPH TRANSMISSION, wherein a thermionic valve has a rapidly fluctuating voltage of square wave form applied to it and the energy developed in harmonics of the fundamental frequency is absorbed outside the device.

1,564,641—R. T. ST. JAMES, Chicago, Illinois. Filed April 10, 1922, issued December 8, 1925. Assigned to Chicago Miniature Lamp Works.

DETECTOR FOR RADIO SYSTEMS, in which a cylindrical plate electrode is supported by prongs which extend upwardly from the glass press within the electron tube.

1,564,672—C. J. HENSCHEL, Arlington, New Jersey. Filed June 15, 1922, issued December 8, 1925.

COMBINED SHIELD PLATE, DIAL AND VERNIER, where the rotatable dial is mounted upon a shield adjacent the apparatus panel and is adjusted at micrometer angular degrees for selectively setting the apparatus.

1,564,694—E. H. LERCHEN, East Orange, New Jersey. Filed October 10, 1922, issued December 8, 1925.

SHIELD FOR AMPLIFIER OR DETECTOR TUBES, where a metallic shield is fitted directly over an electron tube for preventing stray electromagnetic fields from affecting the operation of the tube.

1,564,807—E. F. W. ALEXANDERSON, Schenectady, New York. Filed May 4, 1918, issued December 8, 1925. Assigned to General Electric Company.

RADIO SIGNALING SYSTEM, in which an arc is modulated by means of a control system associated with the antenna circuit, said control system comprising an inductance which is variable by magnetic saturation with means for varying the inductance to produce a substantial change in the effective resistance of the control system and at the same time maintain its resultant reactance substantially constant.

1,564,851—A. W. HULL, Schenectady, New York. Filed November 13, 1920, issued December 8, 1925. Assigned to General Electric Company. DYNATRON SYNCHRONOUS DETECTOR, in which a cathode and an anode are arranged within an evacuated vessel and a variable magnetic field produced therearound by the incoming signaling current.

1,564,852—A. W. HULL, Schenectady, New York. Filed September 9, 1921, issued December 8, 1925. Assigned to General Electric Company. ELECTRON DISCHARGE APPARATUS, in which the current through the device may be controlled by means of the grid electrode to perform any of the functions for which a three-electrode electron tube is adapted. When the magnetic field produced is properly proportioned, the device may possess several operating advantages over three-electrode devices of similar type, as previously operated. When such devices are employed as amplifiers, the degree of amplification which may be obtained depends upon the slope of the curve representing the relation between grid potential and output current. By the use of a magnetic field control in conjunction with the electrostatic field control the slope of this curve may, over a well defined operating range of grid potential, be greatly increased over its value in the absence of the magnetic field.

1,564,940—F. S. CHAPMAN, Greensburg, Indiana. Filed November 12, 1919, issued December 8, 1925. METHOD OF DETECTING THE PRESENCE AND APPROXIMATE LOCATION OF METALLIC MASSES by balancing a receiving system with respect to directively propagated signaling energy which is reflected by the hidden metallic masses which are to be discovered.

1,565,088—J. O. GARGAN, Brooklyn, New York. Filed September 22, 1922, issued December 8, 1925. Assigned to Western Electric Company. CONDENSER, in which the rotor plates are cast integral and move between stator plates which are also formed integral as a casting and where the rotor plates are tapered for securing a particular law of capacity variation.

1,565,092—H. C. HARRISON, Port Washington, New York. Filed June 23, 1921, issued December 8, 1925. Assigned to Western Electric Company. ATTACHMENT FOR OSCILLATION GENERATORS for mechanically controlling the selection for a desired frequency in an oscillation generator system.

1,565,150—J. W. HORTON, Bloomfield, New Jersey. Filed July 9, 1923, issued December 8, 1925. Assigned to Western Electric Company. OSCILLATION GENERATOR for developing oscillations of constant frequency of a higher degree of purity than is obtainable from the usual form of oscillation generator. In accordance with one modification of the present invention an oscillation generator, comprising a main amplifier having a regenerative feed-back circuit containing an auxiliary amplifier, is provided with two frequency determining circuits, one in the input circuit of the main amplifier and the other in the input circuit of the auxiliary amplifier. A step-down transformer couples the output circuit of each amplifier with the input circuit of the other amplifier, thereby tending to reduce the effect of the output circuit impedance of the amplifier upon the frequency determining circuit of the oscillator. A relatively low resistance in shunt to the low voltage winding of each step-down transformer tends to reduce the effect upon the main frequency determining circuit of the transformer impedance or the impedance of circuits associated with the transformer.

1,565,151—W. G. HOUSEKEEPER, New York City. Filed December 27, 1919, issued December 8, 1925. Assigned to Western Electric Company. ELECTRIC DISCHARGE DEVICE having automatic means for disconnecting the plate voltage supply system when the plate temperature becomes excessive.

1,565,152—W. G. HOUSEKEEPER, New York City. Filed November 28, 1920, issued December 8, 1925. Assigned to Western Electric Company.
VACUUM INSULATOR AND ITS ASSEMBLY for use in passing an electrical conductor through the wall of a high-power electron tube.

1,565,157—J. B. JOHNSON, New York City. Filed April 7, 1919, issued December 8, 1925. Assigned to Western Electric Company.
CIRCUIT ARRANGEMENT FOR DISCHARGE DEVICES, where a plurality of groups of parallel connected tubes are provided for feeding a common oscillation circuit.

1,565,200—H. T. Reeve, East Orange, New Jersey. Filed October 10, 1902, issued December 8, 1925. Assigned to Western Electric Company.
METHOD OF MAKING CORES FOR CATHODES OF VACUUM TUBES which comprises mixing metals including platinum and nickel and subjecting the mixture to heat treatment.

1,565,316—W. A. EATON, Arlington, Virginia. Filed March 25, 1920, issued December 15, 1925. Assigned to Radio Corporation of America.
METHOD OF AND APPARATUS FOR CONTROLLING ALTERNATING CURRENTS, particularly intended for signaling by means of an arc where only a single wave is radiated and the compensating wave suppressed. A radiating circuit and an idling circuit are provided upon which the arcs may be alternately operated during the production of signals without the radiation of a compensating wave.

1,565,351—H. S. DODSON and W. H. SHIREY, Detroit, Michigan. Filed July 26, 1922, issued December 15, 1925.
CONDENSER, in which a conical movable plate is arranged within a conical outer plate and the distance between the plates varied by axial movement of the condenser shaft.

1,565,416—L. W. CHUBB, of Edgewood Park, Pennsylvania. Filed February 14, 1921, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
ELECTRON TUBE OSCILLATOR which comprises a plurality of plate elements, a source of electron emission and means included in an oscillatory circuit whereby an electron stream may be selectively controlled to impinge upon predetermined groups of the plate elements to cause the oscillations in the oscillatory circuit to be sustained.

1,565,478—D. G. LITTLE, Wilkinsburg, Pennsylvania. Filed April 6, 1923, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
RADIO TRANSMITTER, including a plurality of electron tubes in which switching means are provided in the plate circuit of the tube for controlling the parallel connection of the tube for varying the effective circuit arrangement through said transmitting system.

1,565,505—F. M. RYAN, East Orange, New Jersey. Filed August 14, 1924, issued December 15, 1925. Assigned to Western Electric Company.
RADIO TRANSMITTER of high power in which control circuits are provided for starting the electron tube system by first energizing the cathodes of the tubes and then gradually energizing the anode circuit for bringing the transmitter into operating condition.

1,565,521—J. S. STONE and C. C. ROSE, San Diego, California and East Orange, New Jersey, respectively. Filed December 8, 1920, issued December 15, 1925. Assigned to American Telephone and Telegraph Company.
SECRET COMMUNICATION SYSTEM, which consists in dividing each of a plurality of message frequency bands into sub-bands, and translating each sub-band into corresponding radio frequency bands. The radio frequency bands are so arranged that sub-bands of different messages will be intermingled in the frequency spectrum, but may be selectively separated out for forming intelligible signals at the receiver.

1,565,530—P. THOMAS, Edgewood, Pennsylvania. Filed August 18, 1921, issued December 15, 1925. Assigned to Westinghouse Electric and Manufacturing Company.
MERCURY VAPOR SPARK GAP for use in the production of high

frequency oscillations in which an H-shaped vessel is provided having the lower portions of each of the uprights formed into pockets containing mercury with a spark discharge gap formed across the H portion of the gap.

1,565,544—R. BOWN, Wyoming, New Jersey. Filed September 18, 1924, issued December 15, 1925. Assigned to American Telephone and Telegraph Company.
RADIO TRANSMISSION SYSTEM having a circuit arranged to compensate for the changes in volume of the signaling current for maintaining reception at a distant station uniform regardless of variable conditions intermediate the stations.

1,565,562—T. R. GRIFFITHS, Dover, New Jersey. Filed February 21, 1925, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the filament of the electron tube is supported by a gripping device positioned around a central support through the tube.

1,565,569—W. G. HOUSEKEEPER, New York. Filed July 21, 1922, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE of high power construction in which the electrodes are mounted upon a central rod and the plate is formed in the shape of a metallic cup sealed to the glass vessel at the base.

1,565,570—W. G. HOUSEKEEPER, New York. Filed October 29, 1923, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the plate electrode comprises a cylindrical sheet of metal with a rib extending longitudinally thereof and a rod passing through the rib for supporting the plate with respect to the other electrodes.

1,565,595—W. O. SNELLING, Allentown, Pennsylvania. Filed February 28, 1923, issued December 15, 1925.
CURRENT-RECTIFYING DEVICE for use in detectors which is prepared by contacting a metal with the vapor of an element of the sulfur group at a temperature above the reaction temperature of the two materials, but below the temperature of fusion of the reaction product formed.

1,565,596—H. C. SNOOK, South Orange, New Jersey. Filed November 15, 1923, issued December 15, 1925. Assigned to Western Electric Company.
SIGNAL SYSTEM, wherein impulses of equal time duration are produced by a swinging pendulum which permits the passage of light upon a photo-electric cell for actuating an amplifier circuit connected therewith.

1,565,600—E. R. STOEKLE, Milwaukee, Wisconsin. Filed August 30. 1920, issued December 15, 1925. Assigned to Western Electric Company,
ELECTRON DISCHARGE DEVICE of high power construction, in which a metallic tubular anode surrounds the electrodes of the tube and is provided with glass end portions through which the leads to the electrodes pass.

1,565,603—R. F. TRIMBLE, Elizabeth, New Jersey. Filed October 4, 1918, issued December 15, 1925. Assigned to Western Electric Company.
ELECTRON DISCHARGE DEVICE, in which the electrodes are supported by means of an arbor anchored into the stem of the tube by wires estending out from the arbor.

1,565,659—J. E. LILIENFELD, Kew Gardens, New York. Filed September 3, 1921, issued December 15, 1925.
HIGH VACUUM DEVICE FOR INFLUENCING CURRENTS comprising an envelope evacuated to such a degree that ionization is substantially prevented, electrodes including an unheated cathode having an active surface or surfaces of small radius of curvature in close proximity to an anode for producing an electronic discharge and means for producing a separate field of force to modify the character of the discharge.

1,565,708—W. R. BULLIMORE, London, England. Filed October 11, 1922, issued December 15, 1925.
THERMIONIC VALVE having an arched cathode support therein, with a hollow grid having flat sides meeting along a curved edge disposed parallel to said filament, grid electrode being formed of looped wires

enclosing said filament. A sheet metal anode of similar shape is provided enclosing both the filament and the grid.

1,565,799—W. DUBILIER, New Rochelle, New York. Filed February 19, 1921, issued December 15, 1925. Assigned to Dubilier Condenser & Radio Corporation.
INSULATING STRUCTURE FOR HIGH POTENTIAL CONDENSERS, in which an insulator is supported in the head of a condenser casing in such a manner that losses due to puncture, creepage and brush discharge or corona effects are reduced to a minimum.

1,565,857—M. J. KELLY, New York. Filed June 30, 1921, issued December 15, 1925. Assigned to Western Electric Company.
VACUUM TUBE MANUFACTURE, in which the tubes are supported in inductance coils through which high frequency current is passed for inductively heating the electrodes of the tubes and removing occluded gases therefrom.

1,565,873—H. J. VAN DER BIJL, New York. Filed August 10, 1920, issued December 15, 1925. Assigned to Western Electric Company.
VACUUM TUBE AND METHOD OF OPERATING THE SAME by producing a narrow beam of rays from a cathode and placing an apertured body in the path of the rays with a screen for receiving the rays. The cathode, apertured body and screen, are surrounded by an atmosphere of gas at such a pressure that electrons discharged from the cathode produce a sufficient number of positive ions to overcome the defusion of the cathode ray beam.

1,566,162—DAVID H. MOSS, Newark, New Jersey. Filed (Original) February 9, 1924; (divisional) Mar. 4, 1925, issued December 15, 1925. Assigned to Brandes Laboratories, Incorporated.
METHOD FOR MAKING SUPPORTS FOR SOUND REPRODUCERS, in which the parts for a loudspeaker are manufactured by pressing and punching operations and with the parts designed for assembly in large numbers for uniform operation. This is the patent covering the method of making the Brandes Table Talker.

1,566,243—Q. A. BRACKETT, Springfield, Mass. Filed September 2, 1921, issued December 15, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO TELEPHONE SYSTEM, in which an oscillation generator system is modulated by means of a variable space current device which is filled with hydrogen gas for decreasing the temperature variations necessary for effective modulation.

1,566,293—H. J. VAN DER BIJL, New York. Filed September 4, 1919, issued December 22, 1925. Assigned to Western Electric Company, Incorporated.
THERMIONIC DEVICE, in which the electrodes are supported by wires which pass through and are sealed in the horizontal glass rod member.

1,566,469—J. F. FARRINGTON, New York. Filed December 23, 1920, issued December 22, 1925. Assigned to Western Electric Company.
TWO-WAY COMMUNICATION SYSTEM for the simultaneous transmission and reception of signals without interference of the adjacent transmitting circuit upon the receiving circuit. The effect of the outgoing signals upon the receiving circuit is neutralized by a connection of the oscillator with the receiver in an opposite sense.

1,566,634—H. P. TRAMBLEY, San Francisco, California. Filed June 18, 1923, issued Dec. 22, 1925.
APPARATUS FOR TREATING DISEASE, including an oscillatory electron tube circuit with electrodes by which high frequency oscillations may be impressed upon the body.

1,566,657—W. T. DITCHAM, Lebanon Park, England. Filed December 18, 1920, issued December 22, 1925. Assigned to Radio Corporation of America.
RADIO TRANSMITTER, in which signals are produced by shunting

a resistance interposed between the source of supply and the electron tube oscillator of the radio transmitter.

1,566,680—A. MEISSNER, Berlin, Germany. Filed September 3, 1921, issued December 22, 1925. Assigned to Gesellschaft fur Drahtlose Telegraphie M.B.H. Hallesches.
SENDING ARRANGEMENT where an antenna circuit is provided with a plurality of grounded loop circuits for preventing the radiation of harmonics from the transmitting station.

1,566,928—M. C. RYPINSKI, New York. Filed March 4, 1925, issued December 22, 1925. Assigned to Brandes Laboratories, Incorporated.
LOUDSPEAKER having a plurality of sound reproducing diaphragms each of which are efficient for a particular range of tone frequencies. The diaphragms are operated simultaneously from the same electromagnetic mechanism for efficiently reproducing sound over a broad range of tone frequencies.

1,567,067—J. F. LINDBERG, Chicago, Illinois. Filed July 20, 1922, issued December 29, 1925. Assigned to Reliance Die & Stamping Company.
CONDENSER, in which a set of stationary plates in the form of concentric cylinders are interleaved by a set of similarly arranged movable plates which are axially adjustable in the direction of the stationary plates.

1,567,068—J. F. LINDBERG, Chicago, Illinois. Filed (original) April 17, 1922; (divisional) January 26, 1924, issued December 29, 1925. Assigned to Reliance Die and Stamping Company.
ELECTRIC CONDENSER constructed of flattened coiled sheets of dielectric material and sheet metal. The sheet metal surrounds the dielectric material and forms one side of the condenser and a fiat sheet of metal is provided forming the other side of the condenser.

1,567,204—J. S. STONE, San Diego, California. Filed January 29, 1925. issued December 29, 1925. Assigned to American Telephone & Telegraph Company.
RADIO TRANSMITTING SYSTEM, in which two transmitters and two receivers, operating on the same frequency, are provided with a secondary relay station, each receiver being rotated at a point where the waves build up from one transmitter, while the relay station is located at a point where the waves are substantially null for increasing the transmission range of a radio system.

1,567,260—W. GARITY, Brooklyn, New York. Filed March 17, 1923, issued December 29, 1925. Assigned to De Forest Radio Telephone & Telegraph Company.
AUDION ELECTRODE STRUCTURE, wherein a plate electrode is blanked out from a flat sheet of metal and rolled into a cylindrical electrode.

1,567,293—E. PFIFFNER, Fribourg, Switzerland. Filed April 7, 1923, issued December 29, 1925.
ARRANGEMENT FOR PREVENTING MARGINAL DISCHARGES by providing margins of a great electric resistance and by making the condenser independent from the marginal discharges.

1,567,409—A. E. BERDON, Detroit, Michigan. Filed May 29, 1922, issued December 29, 1925.
CONDENSER particularly arranged for connecting radio receiving equipment with lamp sockets in which insulated bushings are provided having an entrance for the power line and an outlet for the connection to the receiving set with a condenser disposed between the bushings.

1,567,542—G. W. PICKARD, Newton Center, Mass. Filed June 30, 1921, issued December 29, 1925. Assigned to Wireless Specialty Apparatus Company.
CLOSED TUNED COIL OR LOOP AERIAL for direction finders, in which two loops are arranged at right angles to each other, with a magnetic field which coincides with the direction of the transmitted waves located within the looped conductors

1,567,544—I. P. RODMAN, Newark, New Jersey. Filed March 8, 1924, issued December 29, 1925. Assigned to Garod Corporation.
INSULATOR STRUCTURE FOR ELECTROSTATIC CONDENSERS AND THE LIKE, in which the stator plates are supported on insulated columns carried at opposite ends by pointed members extending through the end plates of the condenser.

1,567,562—H. H. YOUNG and E. A. RYDER, Keyport, New Jersey. Filed March 26, 1924, issued December 29, 1925.
SUPPORT FOR ELECTRICAL APPARATUS for radio receiving sets, in which the tuning condensers are interposed between the electron tube sockets, the tuning condensers forming walls between the sockets and providing means for supporting the socket members in a relatively small unit construction.

1,567,565—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed March 30, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RECEIVING SYSTEM having an amplifying system included as an element in a balanced circuit, the resistance of the amplifier being changed by the received signal to unbalance the receiving circuit for securing resonance to incoming signalling energy.

1,567,566—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed April 12, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RECEIVING SYSTEM for detecting signal current in which a local audio-frequency circuit is unbalanced by the incoming signaling energy for actuating a responsive device.

1,567,567—Q. A. BRACKETT, Pittsburgh, Pennsylvania. Filed April 18, 1922, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEIVING SYSTEM for the reception of undamped wave signals without the employment of a heterodyne by means of a balanced circuit arrangement which is disturbed from normal balance by incoming signaling energy for actuating a telephone receiver.

1,567,734—R. A. HEISING, East Orange, New Jersey. Filed October 1, 1919, issued December 29, 1925. Assigned to Western Electric Company.
RADIO TRANSMISSION SYSTEM for the duplex transmission of radio telephone messages, where transmission is carried on at one wavelength and reception at another wavelength without interference of the transmitter upon the receiver.

1,567,764—J. SLEPIAN, Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued December 29, 1925. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO RECEPTION, in which the signal current operates to change the amount of unbalancing in a plurality of directions in a Wheatstone bridge across a diagonal of which a local source of high frequency alternating current is connected.

1,567,848—L. L. KUMEILIKE, Napa, California. Filed March 9, 1922, issued December 29, 1925.
RADIO FREQUENCY TRANSMISSION SYSTEM particularly adapted for signaling by means of an arc where an intermediate un-tuned loop circuit is coupled to the oscillatory and antenna circuits, by which the power may be balanced and the antenna de-tuned in the production of signals.

1,567,856—DAVID HENRY MOSS, NICHOLAS J. CELENZA and WILLIAM H. GERNS, of Newark, New Jersey, Brooklyn, New York, and East Orange, New Jersey, respectively. Filed March 20, 1925. issued December, 29, 1925. Assigned to Brandes Laboratories, Incorporated.
TERMINAL BLOCK AND CONNECTIONS FOR TELEPHONE RECEIVERS, in which rigid mechanical connections and good electrical contact may be made between the flexible cords leading to the external electrical circuit, an electrostatic shield surrounding the conductors, and the electromagnets and case of the telephone receivers.

1,567,928—H. F. ELLIOTT and J. A. MILLER, Palo Alto, California. Filed January 9, 1922, issued December 29, 1925. Assigned to Federal Telegraph Company.

RADIO FREQUENCY SYSTEM having an arc converter for the transmission of signals with a tuned circuit in series with the arc and impedance also in series with the arc and a load circuit closely coupled to the impednace and a resistor connected in parallel to the impedance for the stabilized operation of the arc transmitting system.

1,567,978—F. G. NIECE, Cleveland, Ohio. Filed March 24, 1920, issued December 29, 1925.

ROTARY SPARK GAP, in which spark electrodes are rotated past a plurality of stationary circuits for securing high frequency discharge. A construction of spark gap is provided where the rotor extends between two adjacent stators and a spark discharge path established therebetween when the electrodes are aligned.

1,568,026—J. B. ZETKA, Nutley, New Jersey. Filed June 24, 1924, issued December 29, 1925. Assigned to Brightson Laboratories, Incorporated.

ELECTRON DISCHARGE DEVICE, iu which a spring device is provided for supporting the filament under tension for preventing short circuit between the filament and the other electrodes within the tube structure.

Re 16,231—E. E. CLEMENT, Washington, D. C. Re-issue filed July 7, 1925, issued December 15, 1925. Assigned to Edw. P. Colladay.

RADIOPHONE SYSTEM, in which a broadcasting station transmits to a plurality of subscribers each having receiving circuits connected by line wire with the broadcasting station for enabling the operator at the broadcasting station to know the condition of operation of each of the subscriber circuits.

Des. 68,686—C. D. WHITE, East Orange, New Jersey. Filed August 29 1925, issued November 20, 1925. Assigned to Brandes Laboratories Incorporated.

DESIGN FOR A CABINET TYPE RADIO REPRODUCER, having a horizontal cabinet behind which a sound amplifying horn is mounted connected with an electromagnetic driver.

Des. 68,898—STEPHEN BOURNE, New York. Filed July 27, 1925, issued December 1, 1925. Assigned to Brandes Laboratories, Incorporated.

DESIGN FOR A LOUDSPEAKER, where the base of the loudspeaker is cast in an ornamental shape and provides means for supporting an electro-magnetic driver therin.

Des. 69,004—LE ROY W. STAUNTON, Jackson Heights, New York. Filed December 12, 1924, issued December 8, 1925. Assigned to Brandes Laboratories, Incorporated.

DESIGN FOR A LOUDSPEAKER RADIO REPRODUCER, in which the electromagnetic driver is mounted within an ornamental cabinet from which the reproduced sound emanates.

Obituary

DR. HAROLD W. NICHOLS, Fellow of the Institute, died at his home in Maplewood, New Jersey, on November 14, last. Dr. Nichols was born in Iowa, on February 23, 1886. He gained his technical education at the Armour Institute of Technology, Chicago, from which institution he received the B.S. degree in 1908, and E.E. in 1911. From the University of Chicago he received the degrees of M.S. and Ph.D.

At the time of his death, Dr. Nichols was a Manager of the Institute, and had been for several years an earnest and valuable worker on important committees. At the October, 1925, meeting of the Board of Direction his name was placed in nomination for the Presidency of the Institute. His untimely death is deeply regretted by his associates on the Board of Direction.

GEORGE Y. ALLEN, a Member of the Institute, died on November 12, last, as a result of injuries received in a train wreck in New Jersey. Mr. Allen was born at Bernardsville, New Jersey, in 1893, and graduated from Stevens Institute of Technology, Hoboken, New Jersey, in 1915 with the degree of M.E. After graduation he was engaged in research work for the Western Electric Company, and at the outbreak of the late war was appointed radio aide to the U. S. Navy Engineering Bureau. In 1919 he entered the service of the Westinghouse Electric and Manufacturing Company, New York, and at the time of his death was assistant to the manager of the radio department of that company.

Mr. Allen served the Institute on several active committees in recent years, and at the time of his death was returning from the Fourth Annual Radio Conference called at Washington by Secretary Hoover.