Transatlantic Radio Telephone Transmission[1]

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SYNOPSIS: 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 shown to be 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 transatlantic distance is essentially that given by the Inverse Distance Law. The normal daylight field strengths obtained in these tests can be aproximated 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 day-time the decrease with increase in frequency is linear in the 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.

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.[2] In respect to the clarity and uniformity of the reception obtained in Europe, the results represented a distinct advance in the art over the transatlantic 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 favorable to radio transmission, and it was realized that extensive study of the transmission obtainable during less favorable times would be required before the development of a transatlantic radio telephone service could be undertaken upon a sound engineering basis.

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[1] Presented before the Institute of Radio Engineers, May 6, 1925.

[2] "Transatlantic Radio Telephony," Arnold and Espenschied, *Journal of A.I.E.E.*, August, 1923. See also, "Power Amplifiers in Transatlantic Telephony," Oswald and Schelleng, presented before the Institute of Radio Engineers, May 7, 1924.

Consequently, an extended program of measurements was initiated to disclose the transmission conditions obtaining throughout 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 the measurements have been 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.

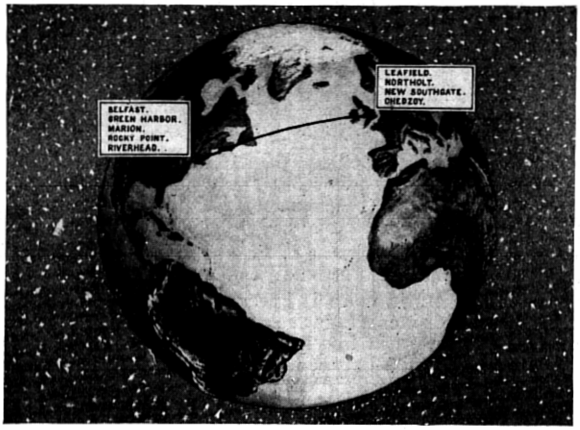

Fig. 1

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 through the cooperation of engineers of the following organizations: in the United States—The American Telephone and Telegraph Company and the Bell Telephone Laboratories, Inc., with the Radio Corporation of America and its Associated Companies; in England—The International Western Electric Company, Inc., and the British Post Office.

MEASUREMENT PROGRAM

The scene of these transatlantic experiments is shown in Fig. 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, and the normal radio telegraph transmitters at Rocky Point and Marion, Mass. 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, Mass., and continued at Belfast, Maine and Riverhead, L. I.

Fig. 2—Exterior of Riverhead Radio Receiving Station

The Riverhead receiving station, shown in Figs. 2 and 3, is typical of the receiving stations involved in the measurement program. The interior view of Fig. 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. The set 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 oscillograph and frequency meter. The third bay carries 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.

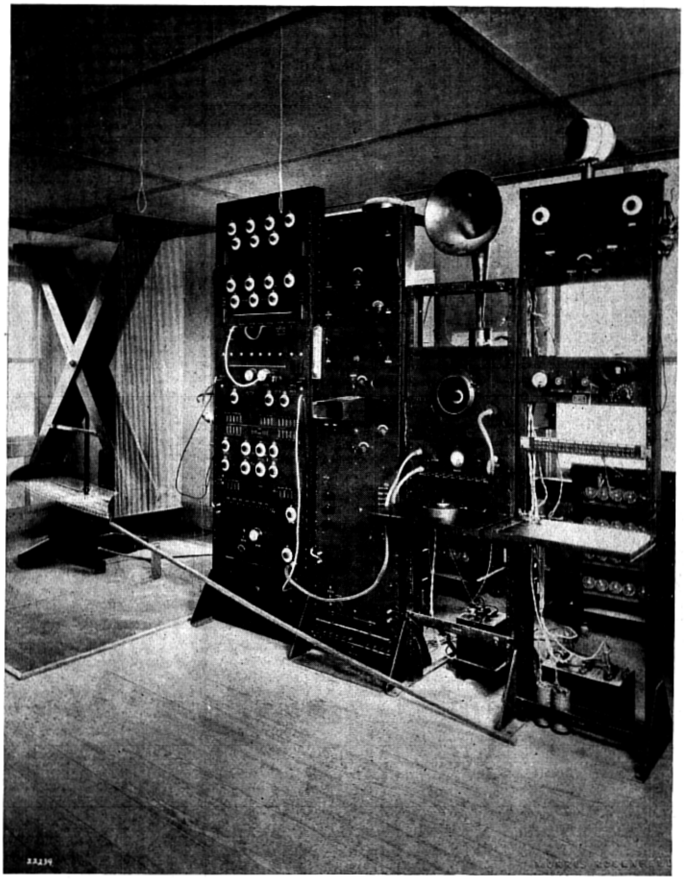

Fig. 3—Interior Riverhead Station

The measurements 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 (given in the chart of Fig. 4) lie in a range between 15 and 60 kc. The arrows indicate the single frequency transmissions which were employed for signal field strength measurements, 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 of 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.

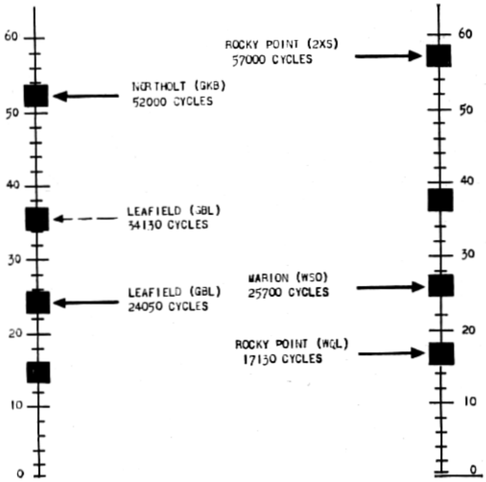

Fig. 4—Frequency distribution of measurements. Black squares denote band in which noise measurement was taken

MEASUREMENT METHODS

Although 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,[3] a brief review of the methods involved will facilitate an understanding of the data.

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[3] Radio Transmission Measurements, Bown, Englund, and Friis. Proceedings I.R.E., April, 1923.

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 through 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 fluctuation 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.

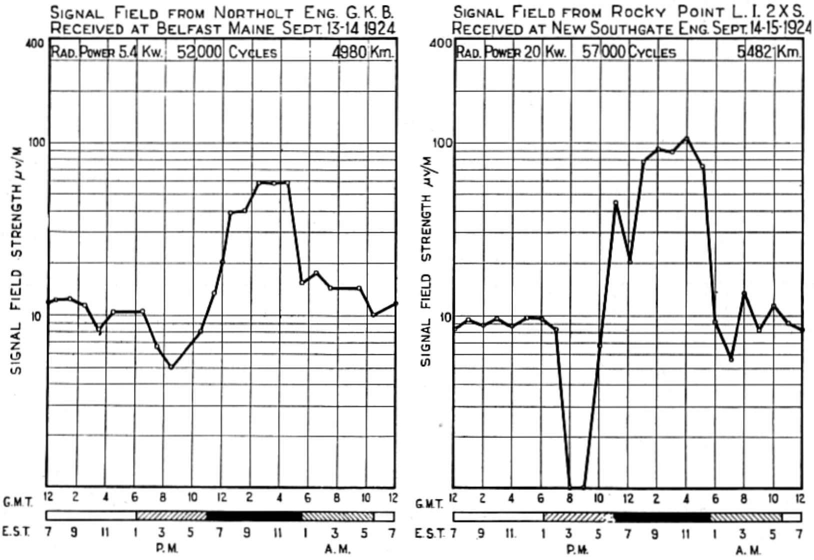

Fig. 5—Diurnal variation in signal field

Signal Field Strength

The curves of Fig. 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 throughout the day, but that they are not sufficiently continuous to disclose, in detail, the intermediate fluctuations to which the transmission is subject.

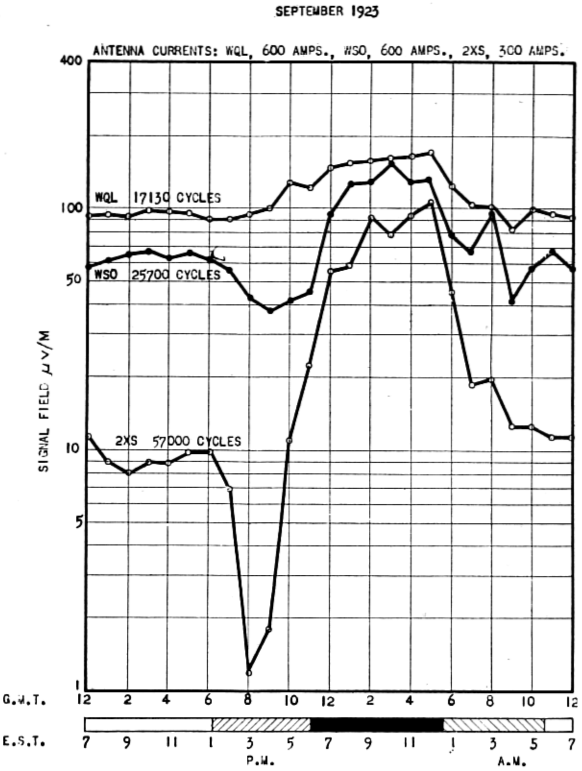

Fig. 6—Monthly average of diurnal variation in signal field transmission from American stations on various frequencies received at New Southgate, England, September, 1923

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 substantiate, that both transmissions are subject to substantially the same diurnal variation. The condition of the transatlantic 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 transatlantic 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 through 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 Fig. 5 are obtained each month. By taking the average of such curves for the month of September, 1923, the lower curve on Fig. 6 is obtained. The 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.

The mechanism by which the transatlantic 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 Fig. 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 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

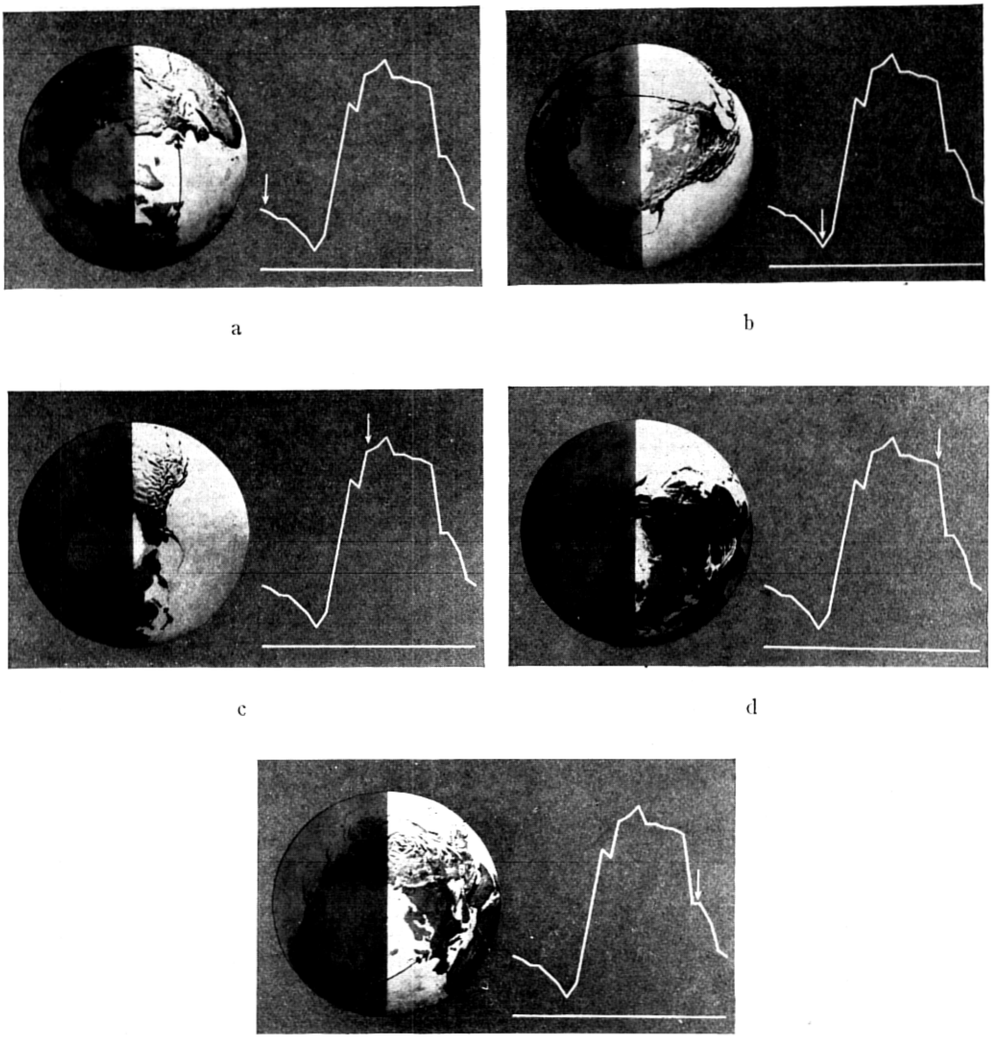
a
b
c
d
e

Fig. 7—Signal Field January—Variation with exposure of transmission path to sunlight

diurnal characteristic becomes evident. This is shown in Fig. 8, the data for which actually cover two years.

The outstanding points to be observed in this figure are:

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

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

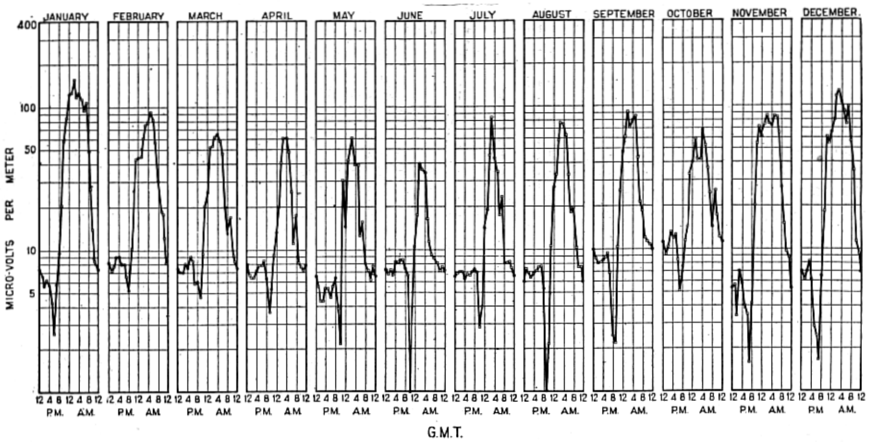

Fig. 8—Monthly averages of diurnal variation in signal field, Rocky Point, L. I. (2 X S) to New Southgate, England, 57,000 cycles—Ant. Current, 300 Amps—5480 Km. 1923–1924

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 Fig. 9. As the earth continues to revolve 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 transatlantic path lies fairly high in the northern latitude, it is not surprising 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 Fig. 10. This figure consists of the same monthly average diurnal curves as are assembled in Fig. 8, arranged one above the other instead of side by side.

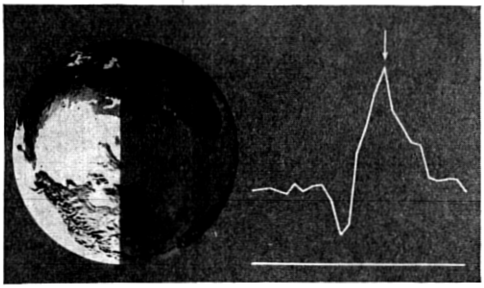

Fig. 9—Signal Field June—Night conditions showing proximity of transmission path to sunlit hemisphere

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 daylight 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 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 transatlantic path reaches at night during this season of the year is illustrated in Fig. 9.

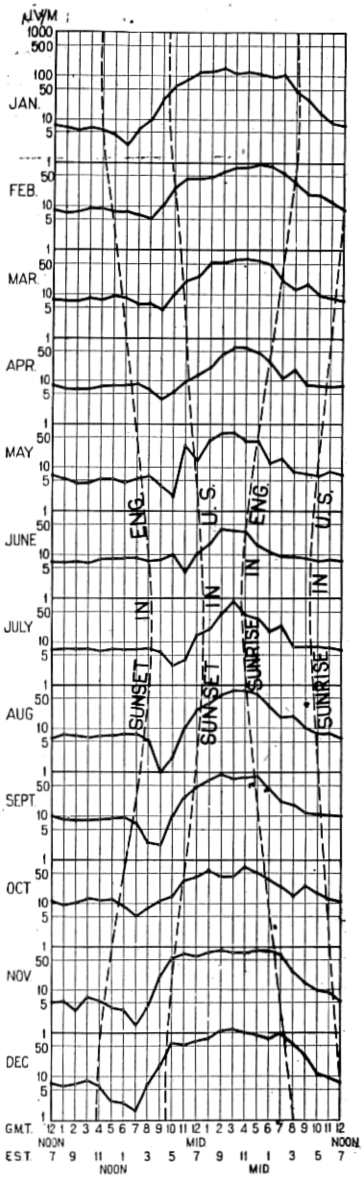

Fig. 10—Monthly averages of diurnal variation of signal field, Rocky Point, L. I. (2 X S) to New Southgate, England; 20.8 K.W. radiated power, 57,000 cycles, 1923–1924

As the sunlit hemisphere recedes southward after the summer solstice a time is reached, about the middle of August, at which 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 sun-lit 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 Fig. 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 Fig. 8 for the 57-kilocycle transmission, but shows up more strikingly in the curves of Fig. 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

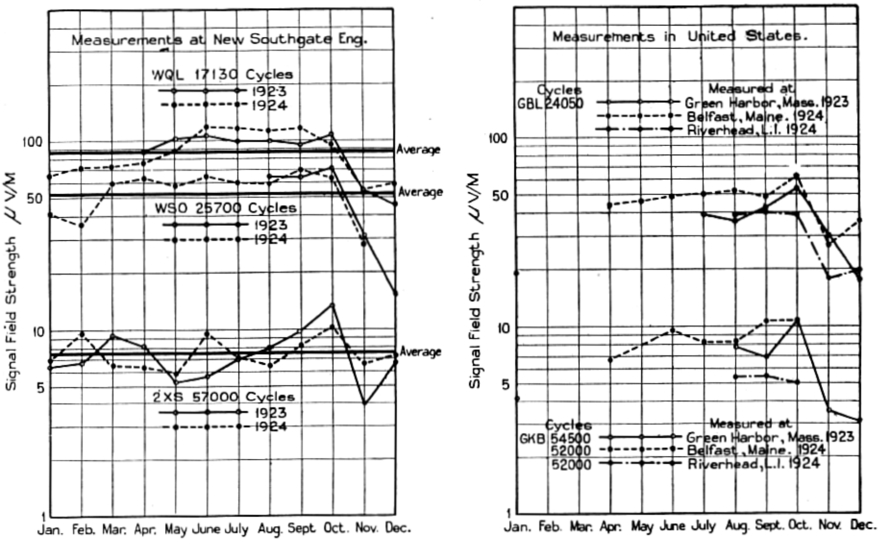

Fig. 11—Monthly averages of daylight field strength

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 Formulae. The two major phases of the diurnal variation of signal field strength which lend themselves to possible predetermination are the daylight values and the 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[4] that the high night-time values are merely the result of a reduction of the absorption experienced during the day. Fig. 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 formulae, values to be expected at any one time will be evident and the best that can be expected is to approximate the average. The formulae of Sommerfield, Austin-Cohen and Fuller take the form

$$E\mu v/M = \frac{377HI}{\lambda D}\, e^{-\frac{\alpha D}{\lambda^x}}$$

where the coefficient $\frac{377HI}{\lambda D}$ represents the simple Hertzian radiation field and the exponential $e^{-\frac{\alpha D}{\lambda^x}}$ the attenuation factor. From theoretical considerations, Sommerfeld (1909) gave $\alpha = .0019$ and $x = 1/3$. In the Austin-Cohen formula α is given as .0015 and $x = 1/2$. Fuller gives $\alpha = .0045$ and $x = 1.4$. The Austin-Cohen formula was tested out experimentally chiefly 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 .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

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[4] See also "Radio Extension of Telephone System to Ships at Sea," Nichols and Espenschied, Proc. I. R. E., June, 1923, pages 226–227.

of the Atlantic we found that approximately $\alpha=.005$ and $x=1.25$. The transmission formula then becomes

$$E\mu v/M=\frac{377HI}{\lambda D}\,e^{-\frac{.005D}{\lambda^{1.25}}}$$

or in terms of power radiated

$$E=\sqrt{P}\,\frac{298\times10^3}{D}\,e^{-\frac{.005D}{\lambda^{1.25}}}$$

where

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

The table shown on next page summarizes the data relative to daylight transmission.

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 Fig. 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.

Comparison of these data with that 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 in 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.

TRANSATLANTIC RADIO TELEPHONE MEASUREMENTS

Transmitting Terminal	Receiving Terminal	Freq.	Distance Km.	Power* Radiated Kw.	Daylight Field Strengths Observed			Daylight Field Strengths Calculated		
					1923	1924	Av.	Austin-Cohen	Fuller	This Paper
2 X S	New Southgate, Eng.	57,000	5,482	20.6	7.5	7.65	7.6	6.9	21.2	7.8
WSO	New Southgate, Eng.	25,700	5,282	8.95	(Aug.-Dec.) 48.7	(Jan.-Nov.) 54.6	52.7	16.6	78.5	50.2
WQL	New Southgate, Eng.	17,130	5,482	12.	(Apr.-Dec.) 86	87.3	86.8	27.7	116.	86.
GBL	Green Harbor, Mass.	24,050	5,149	4.06	(July-Jan.) 34.2			13.2	59.	39.
	Belfast, Maine	24,050	4,885	4.06		(Apr.-Dec.) 51(?)		15.6	54.7	41.8
	Riverhead, L. I.	24,050	5,363	4.06		(Aug.-Dec.) 31.5		11.4	55.2	34.5
GBL	Green Harbor, Mass.	34,130	5,149	4.85	(July-Jan.) 16.1			9.5	41.2	22.6
GKB	Green Harbor, Mass.	54,500	5,241	7.9	(Aug.-Dec.) 6.1			5.6	18.6	7.1
	Belfast, Maine	52,000	4,980	5.4		(Apr.-Oct.) 9.1		6.15	20.	9.05
	Riverhead, L. I.	52,000	5,457	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 (2 X S) on 57,000 cycles measured at Mexico City, July, 1924, give an average daylight field strength of 39.4 mv/M. Calculated value 42.5 mv/M.

The magnetic data have been supplied through the courtesy of the United States Geodetic 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 Fig. 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 Fig. 11 are due to the high daylight values which prevailed at the time of these disturbances.

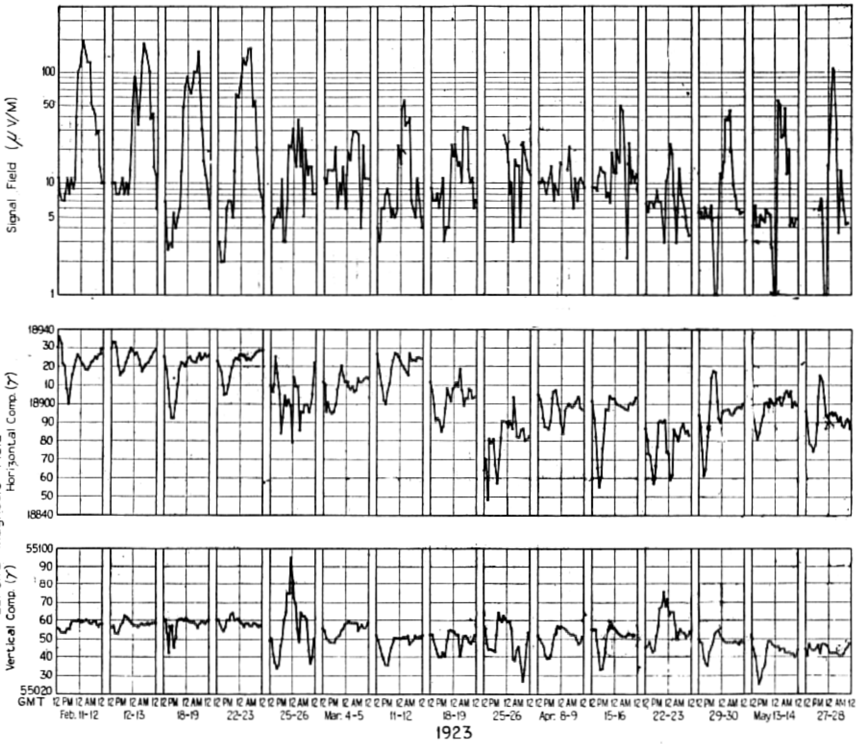


Fig. 12—Correlation of radio transmission and earth's magnetic field—Transmission from Rocky Point, U. S. A. (57,000 cycles) to London, Eng.—Earth's magnetic field measured at Cheltenham, Md., U. S. A.

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 variations is therefore of first order of importance.

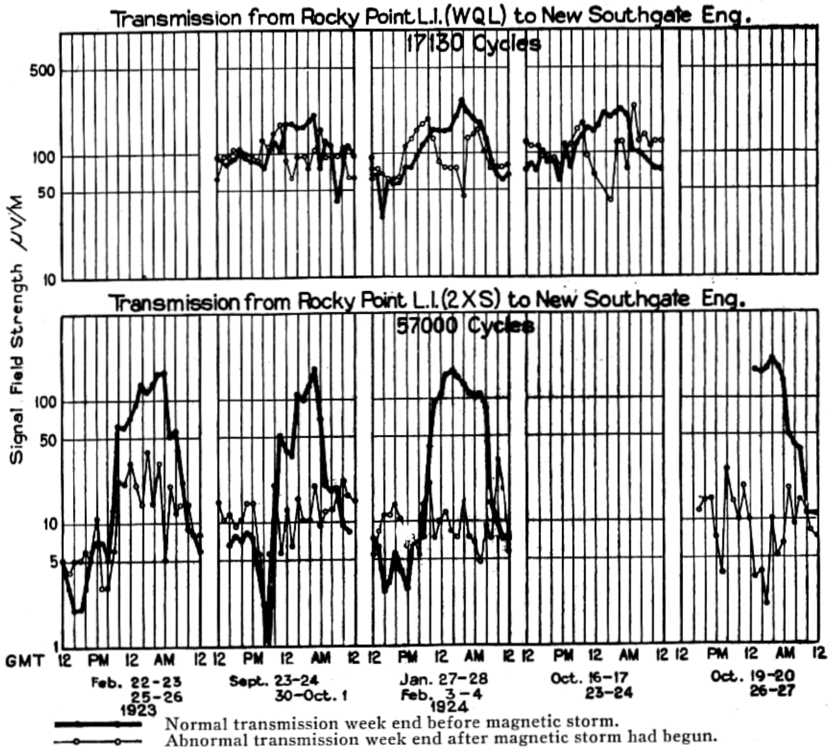


Fig. 13—Correlation between radio transmission and variations in earth's magnetic field

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

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 decrease accompanying sunrise. The curve for 15 kc. shows the existence of high values also in the afternoon. During the summer months high afternoon values are usual for all frequencies in this

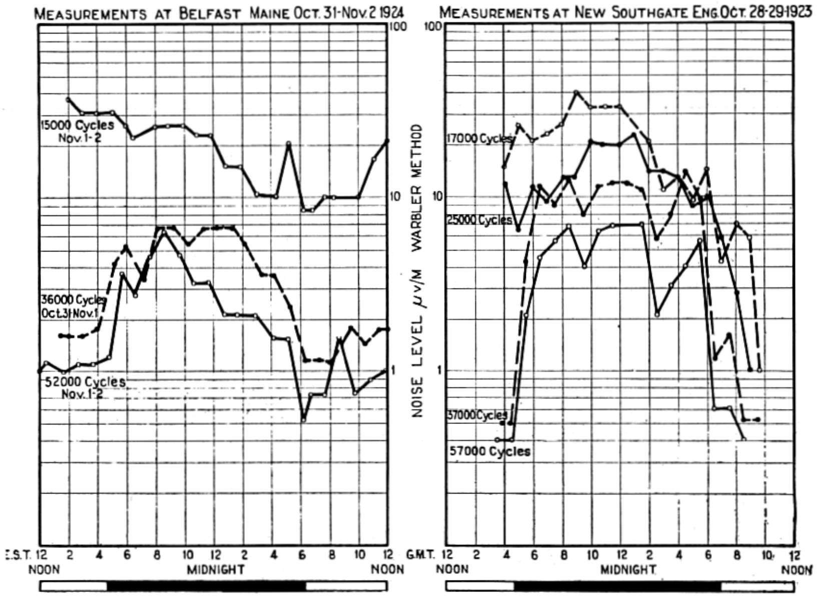


Fig. 14—Diurnal variation in noise

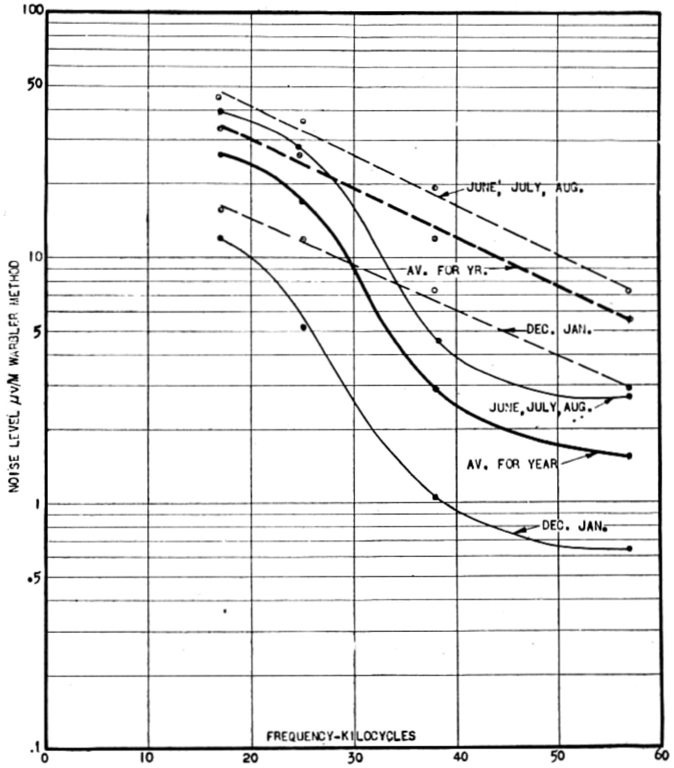


Fig. 15—Frequency distribution of noise, New Southgate, England—
Night time————Day time ————1923–1924

range. They extend later into the fall for the lower frequencies, and hence are in evidence on the date 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 Fig. 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.

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 Fig. 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 Fig. 16 show also the substantial difference in the noise level which exists at the three receiving points. As has been experienced in practice, the New Southgate curve indicates 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.

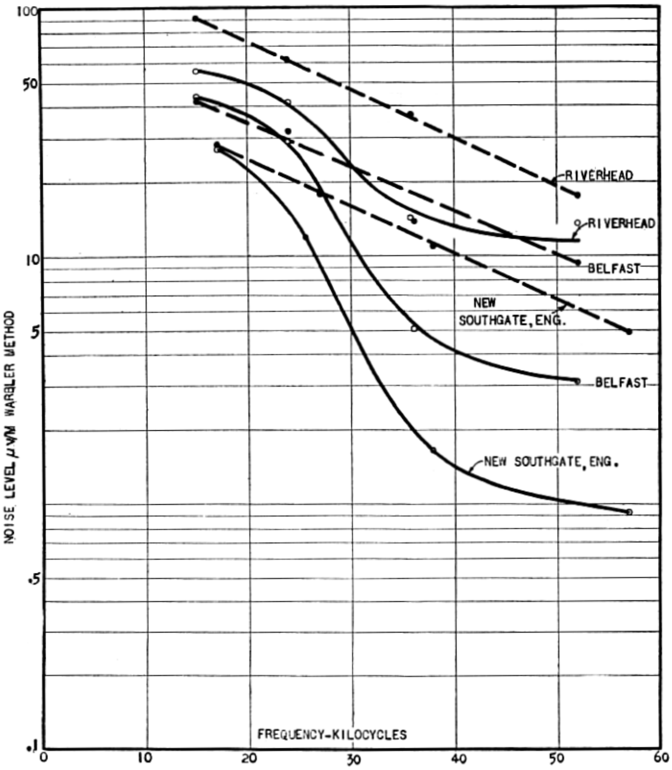


Fig. 16—Frequency distribution of noise, New Southgate, Eng., Belfast, Maine Riverhead, L. I.—Night time————Day time————Aug.–Dec., 1924

Seasonal Variation. Curves showing the diurnal variation in noise level for each month of the year together with the variation in time of sunset and of sunrise, are shown in Fig. 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 sun-

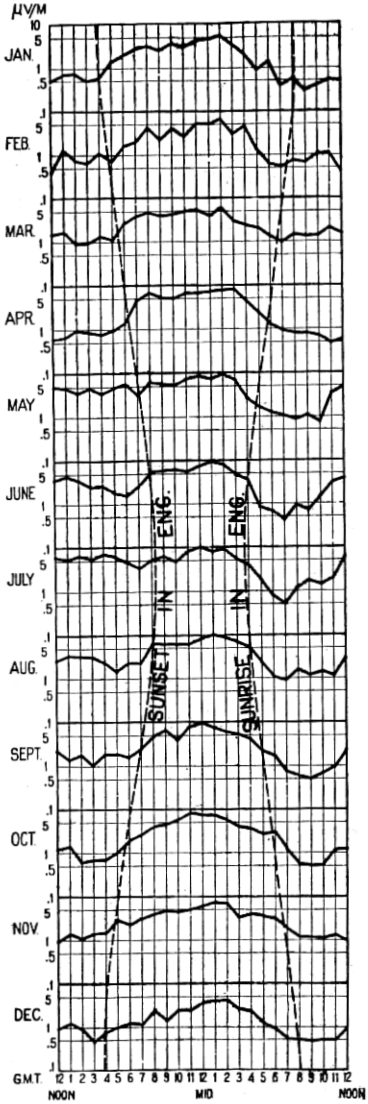


Fig. 17—Monthly averages of diurnal variation of noise, New Southgate, England—57,000 cycles—1923–1924

rise 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-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.

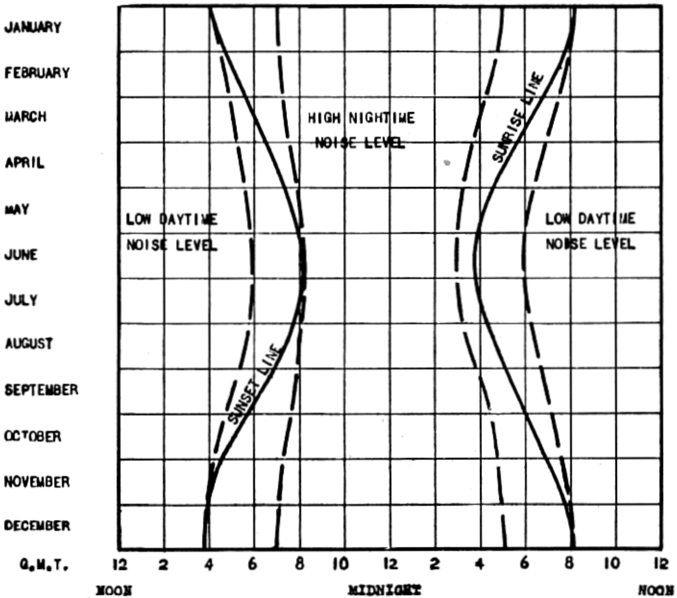
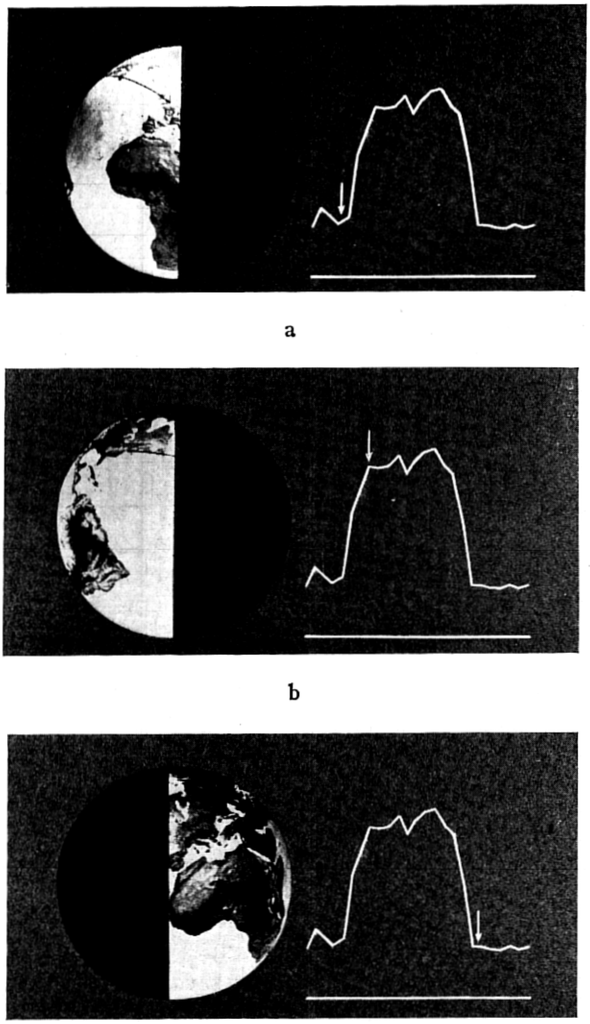


Fig. 18—Seasonal variation in distribution of daytime and night time noise with respect to sunset and sunrise, New Southgate, England—1923–1924

This is more definitely brought out in Fig. 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 the low daylight values. This discloses the fact that sunset and sunrise at the receiving



a

b

c

Fig. 19—Noise at New Southgate, England, in January—Variation with exposure of equatorial belt to sunlight

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.

MAJOR REGIONAL SOURCE OF STATIC NOISE

A broader conception as to the causes underlying the diurnal and seasonal variation is obtained by considering the time of sunset and sunrise over a considerable area of the earth's surface. Fig. 19 shows a series of day and night conditions for three representative parts of the diurnal noise characteristic at England for January. 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, although the sun is just rising in England, the African equatorial belt is in sunlight, subjecting the static transmission path to high daylight attenuation.

The sunset conditions which existed for the afternoon and evening of the day upon which the diurnal measurements of Fig. 14 were taken are shown in Fig. 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.

Fig. 21 shows the sunrise conditions in relation to the decrease in static from the high night-time values to the lower daylight 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 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 Fig. 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

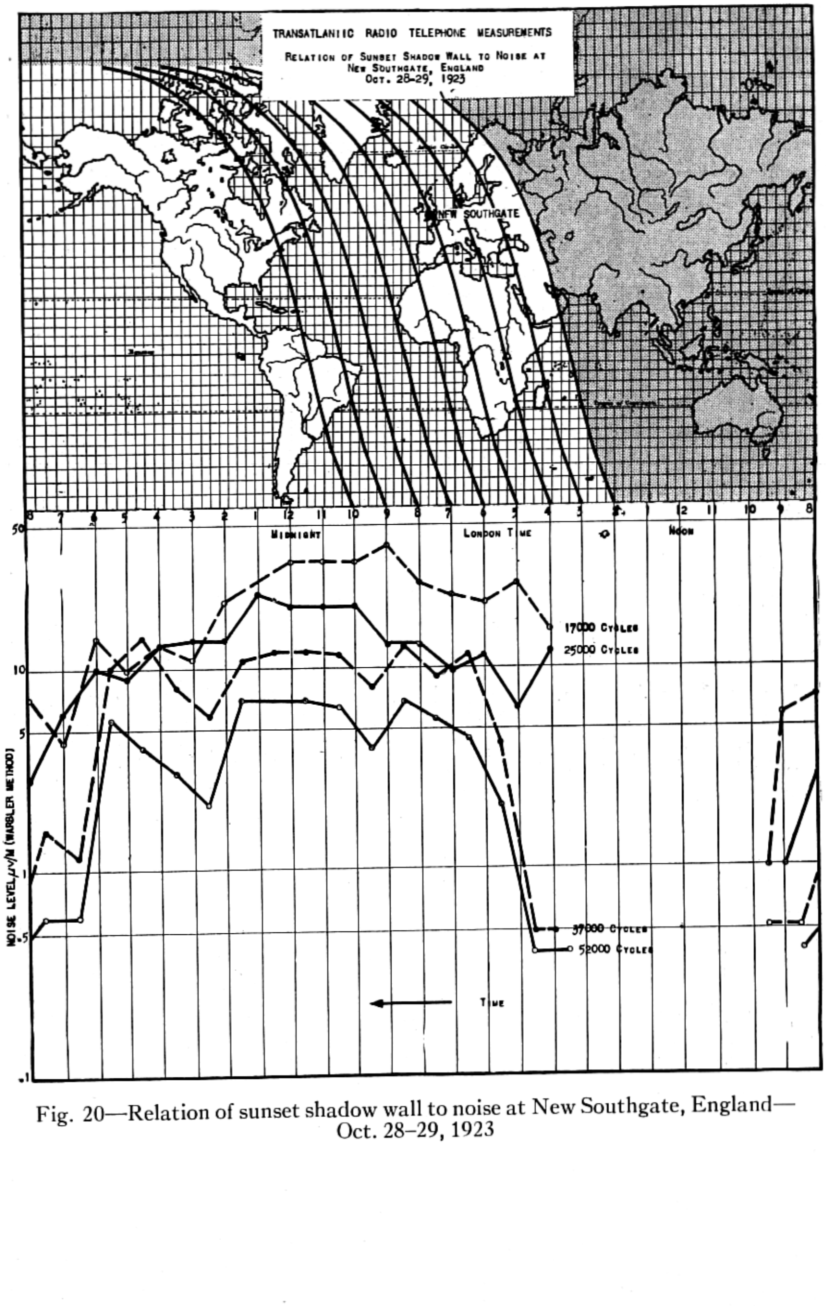


Fig. 20—Relation of sunset shadow wall to noise at New Southgate, England—Oct. 28–29, 1923

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 Fig. 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 Fig. 18 it will be evident

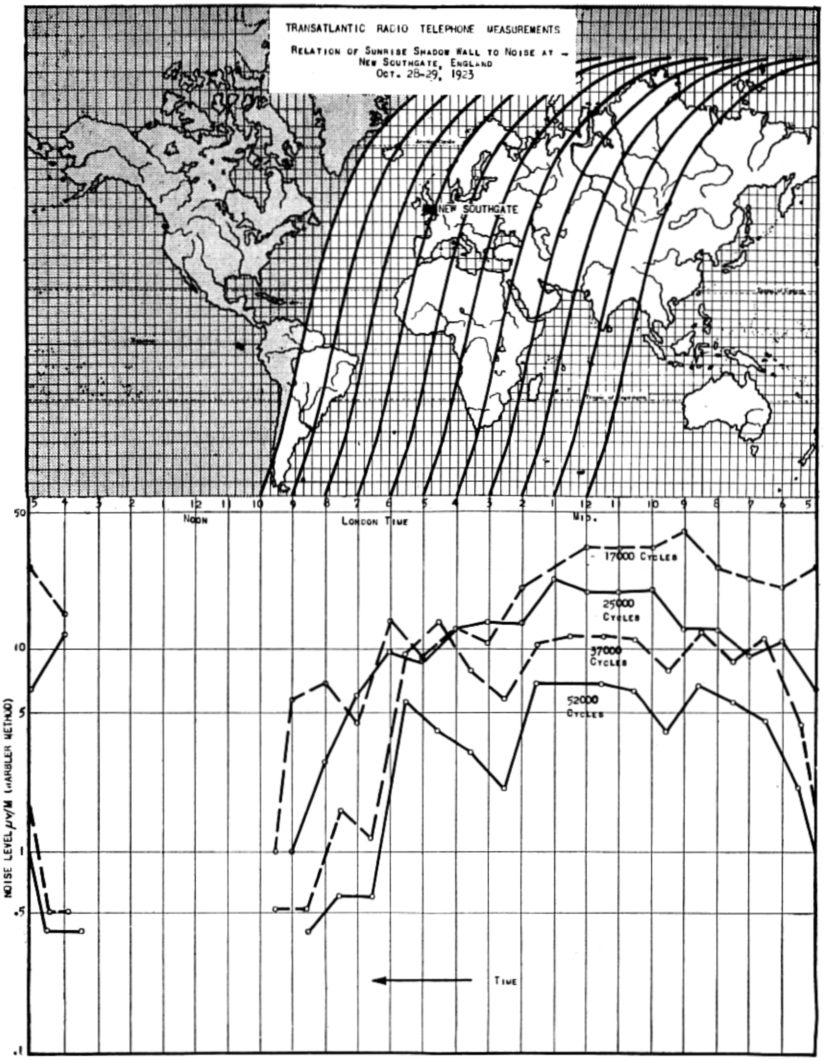


Fig. 21—Relation of sunrise shadow wall to noise at New Southgate, England—Oct. 28–29, 1923

that this occurs during the winter at about sunrise, at the equinox about an hour later, and during the summer some two hours later.

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 extend 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.

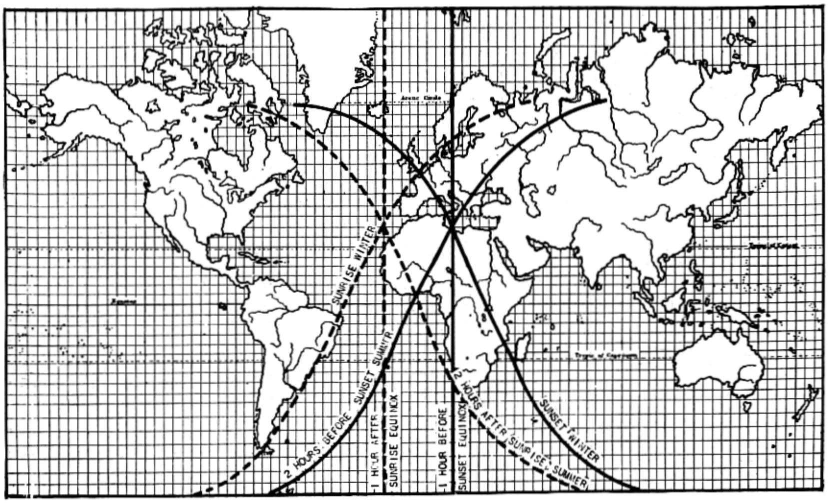


Fig. 22—Position of sunset lines at sunset dip and sunrise lines at sunrise dip in noise level in England for various seasons

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 Fig. 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 level curves are the same as those shown in Fig. 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 Fig. 24. Although

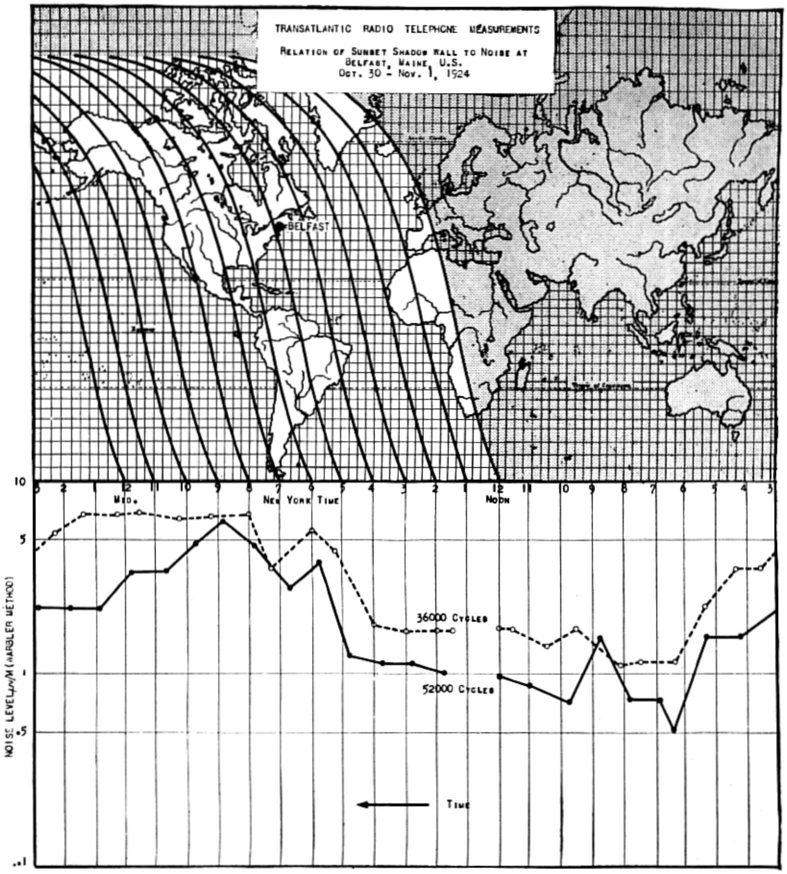


Fig. 23—Relation of sunset shadow wall to noise at Belfast, Maine, U. S.—Oct. 30—Nov. 1, 1924

high night-time values started to fall off some five hours before sundown in Belfast, the more rapid drop was within some 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.

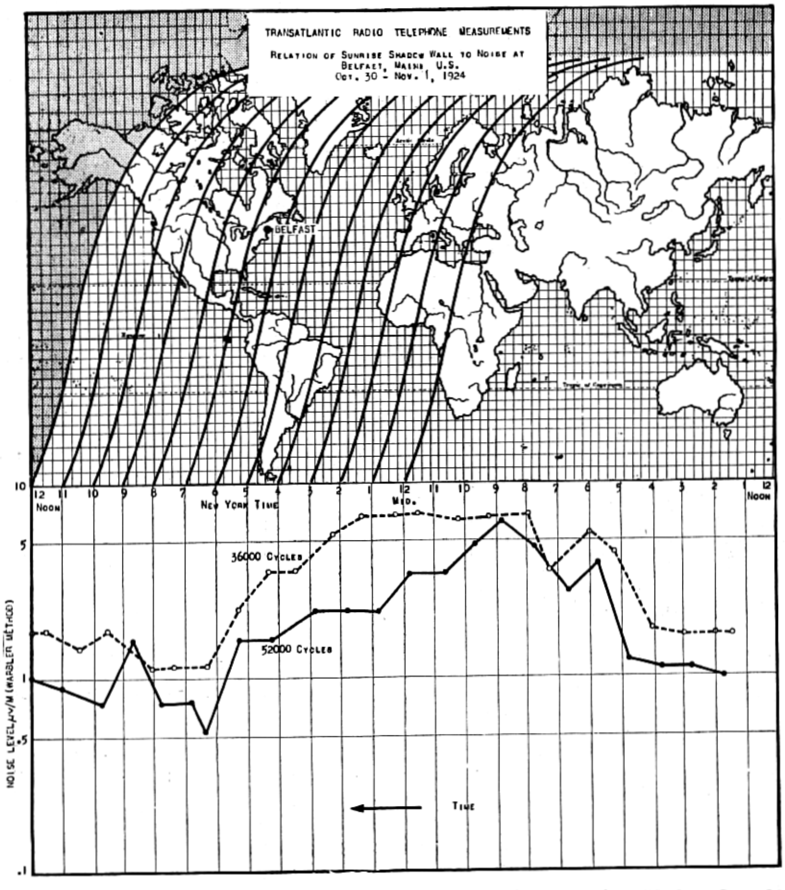


Fig. 24—Relation of sunrise shadow wall to noise at Belfast, Maine, U. S.—Oct. 30—Nov. 1, 1924

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 determines the communication merit of a radio transmission channel.

Variation with Frequency. A comparison for representative summer and winter months is given in Fig. 25 of the signal-to-noise ratio for the two extreme frequencies measured. Both of these transmissions were effected from the same station, Rocky Point, and similar antennae were employed. Comparison is made of the overall 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 better ratio, it is subject to a much more severe sunset

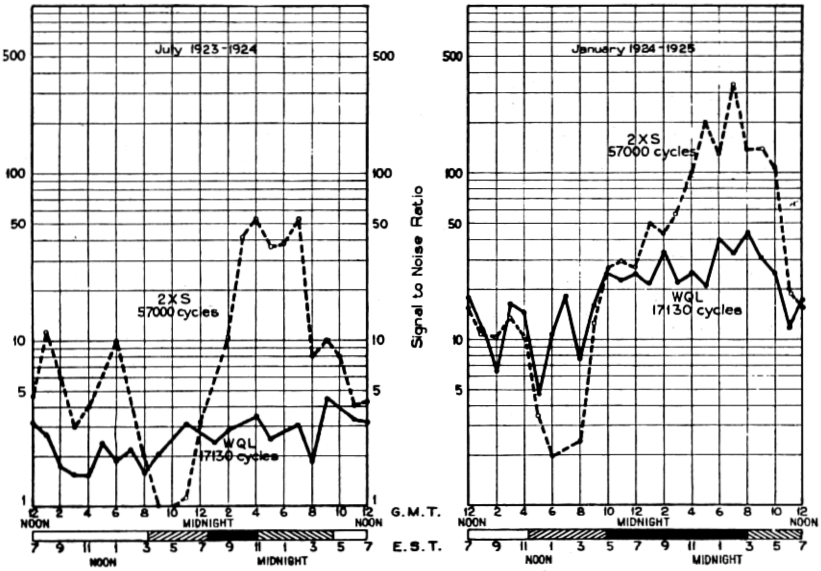


Fig. 25—Variation of signal to noise ratio with frequency. Corrected to same antenna input power (68.5 KW) in Rocky Point antenna—Reception at New Southgate, England

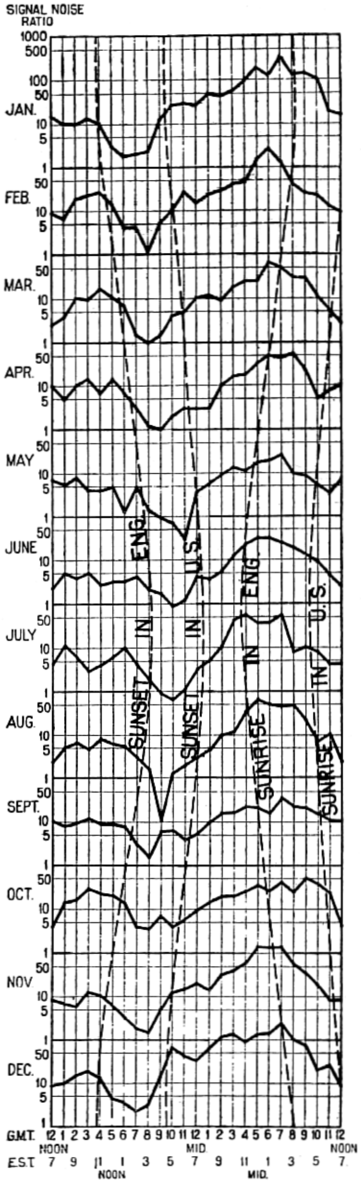


Fig. 26—Monthly averages of diurnal variation of signal to noise ratio; Rocky Point, L. I. (2 X S) received at New Southgate, England; 20.8 KW radiated Power —57,000 cycles—5480 Km—1923-24

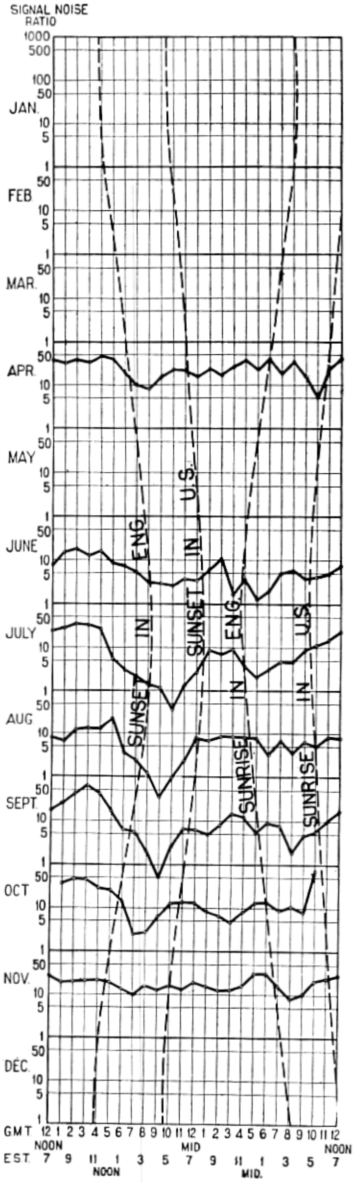


Fig. 27—Monthly averages of diurnal variation of signal to noise ratio, Northolt, Eng. (GKB) received at Belfast, Maine—20.8 KW radiated power—4980 Km—52,000 cycles—1924

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 in Fig. 26, for each month of the year, 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.

Fig. 27 presents the signal-to-noise ratios for such data as have 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 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. Comparisons 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, corresponding 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 ANTENNAE

The picture which has been given of the transmission of static northward from the tropical belt suggests that the signal-to-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 transatlantic radio telegraphy wherein the Radio Corporation 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 antennae.

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 antennae 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 Fig. 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 is for 1924 while that for the United States is for the corresponding period of 1925. The United States results will be seen to be generally similar to those obtained in England. Although these experiments are still in an early stage, the results do give a measure of the order of improvement which can be expected.

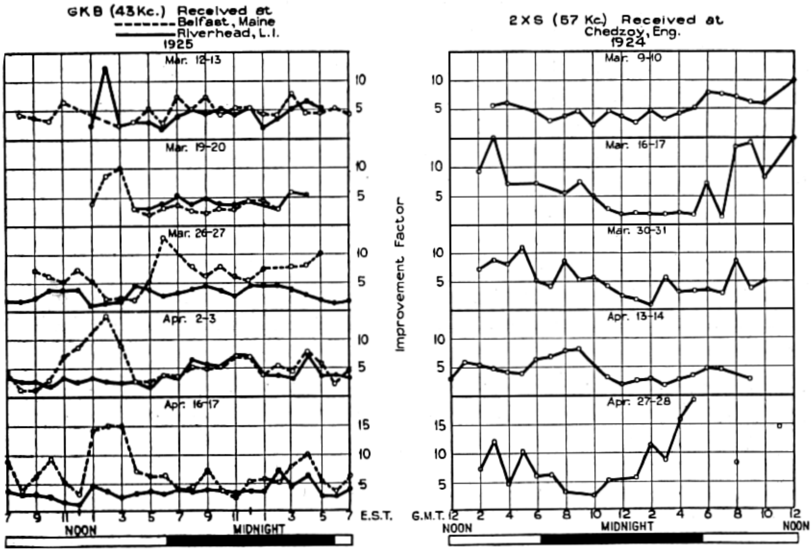


Fig. 28—Improvement in signal noise ratio of wave antenna over loop reception

Test of Words Understood. Perhaps the most convincing measure of the efficiency of directional receiving systems for transatlantic transmission is the improvement effected in the reception of intelligible words. Fig. 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% of the words for but 9 of the 24 hours on the loop, whereas with the wave antenna reception continued for 18 hours.

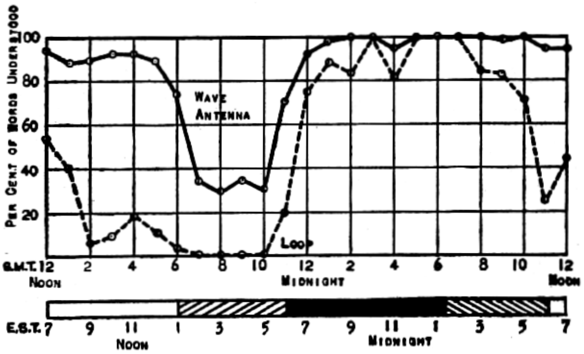
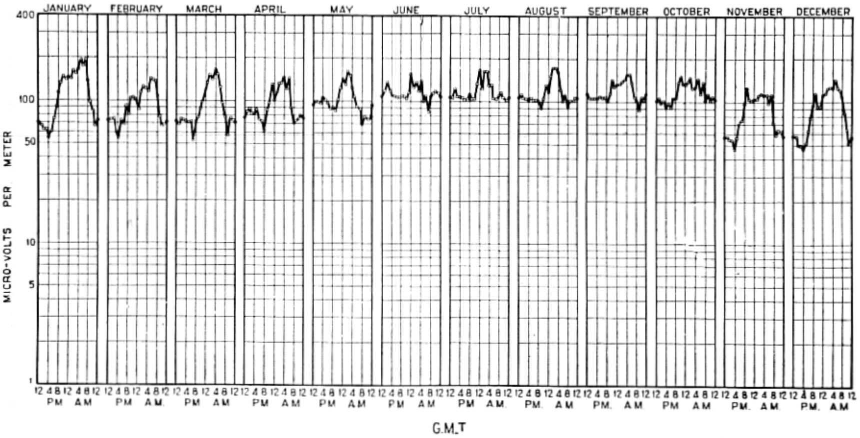


Fig. 29—Comparison of reception on wave antenna and loop. Per cent of words understood—Reception of Rocky Point (2 X S) at Chedzoy, England, March, 1924

APPENDIX

Transatlantic Radio Telephone Measurements
1923, 1924, 1925

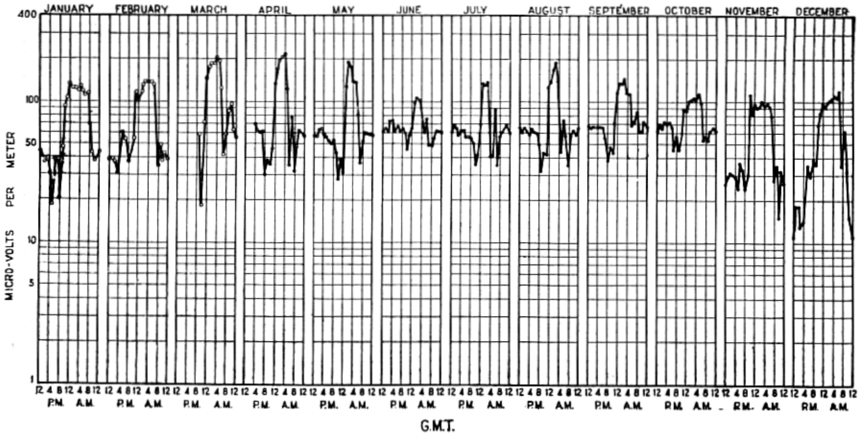
Month by Month Record of Noise and Field Strength



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

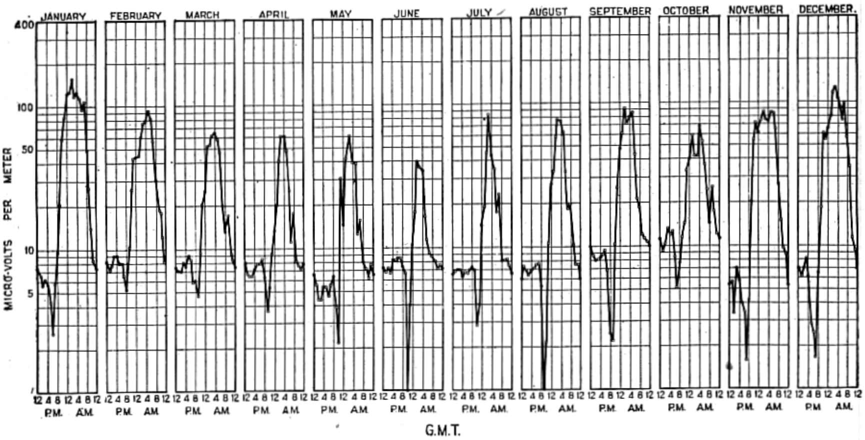
April, 1923—Feb., 1925



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

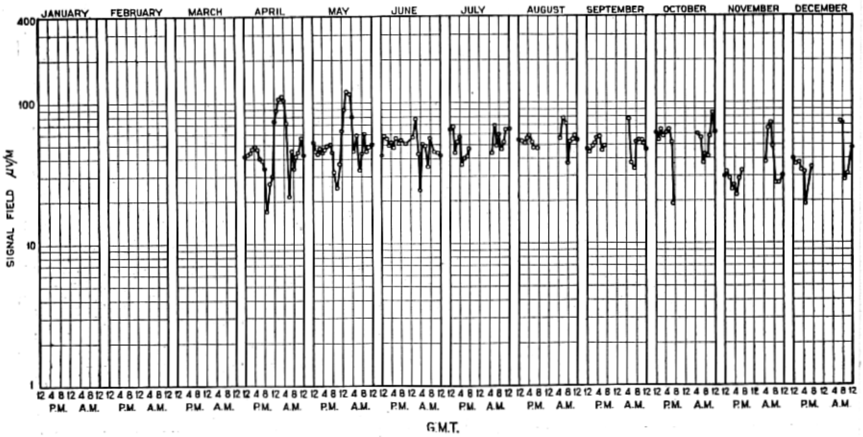
Aug., 1923—Feb., 1925



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

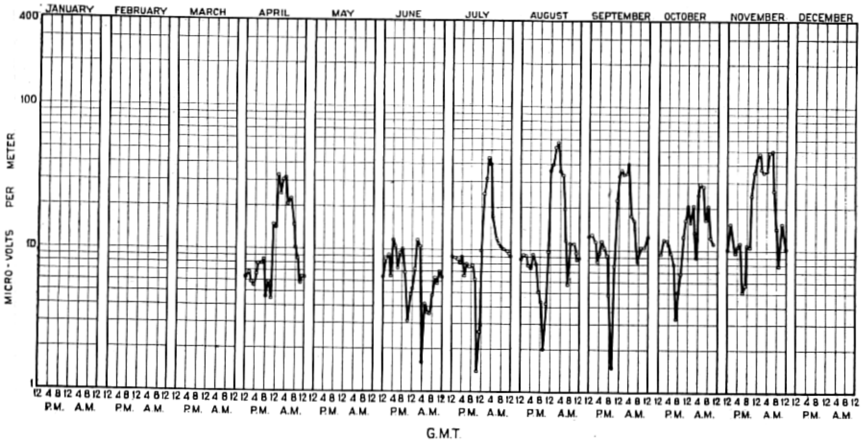
Jan., 1923—Dec., 1924



Monthly Averages 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

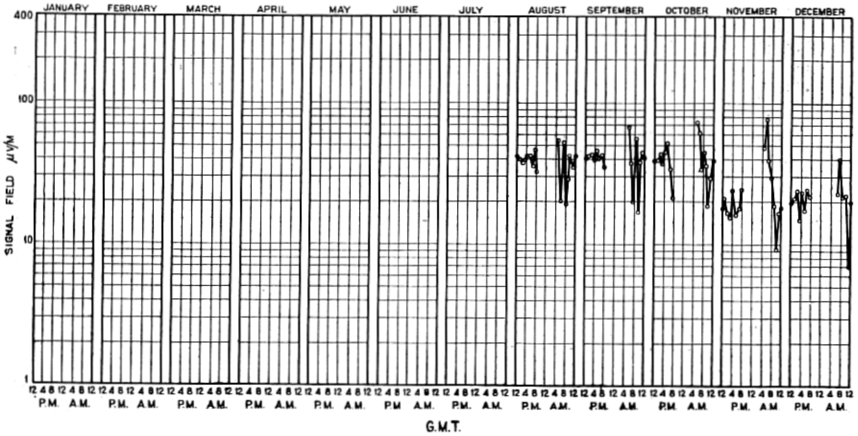
1924



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

4,885 Km. 52,000 Cycles

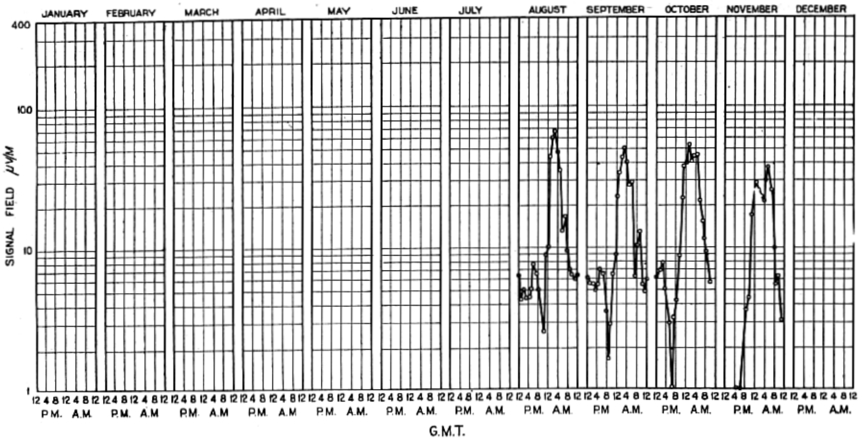
1924



Monthly Averages 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

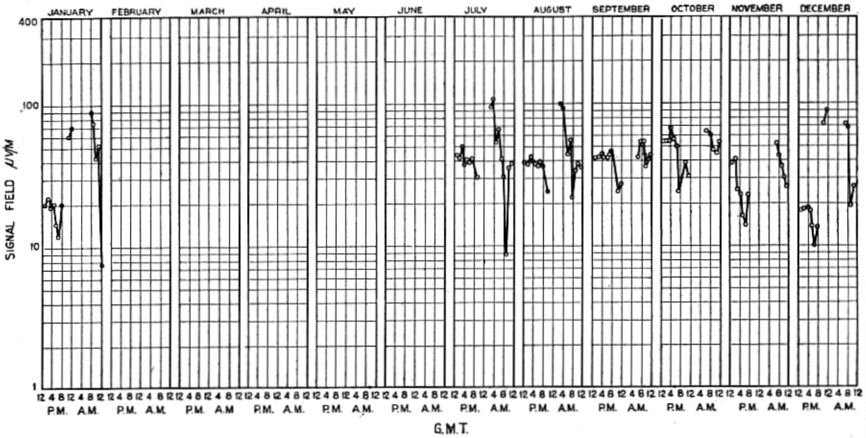
1924



Monthly Averages Diurnal Variation of Signal Field Strength
Northolt, England (GKB) Measured at Riverhead, L. I.

5,460 Km. 52,000 Cycles

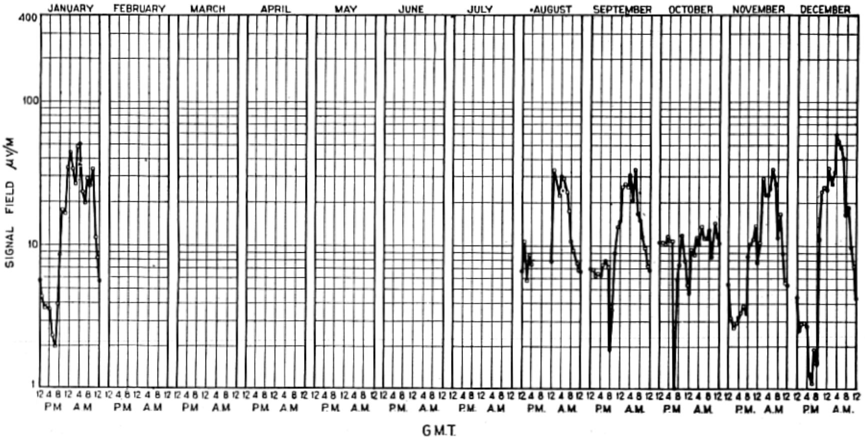
1924



Monthly Average 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

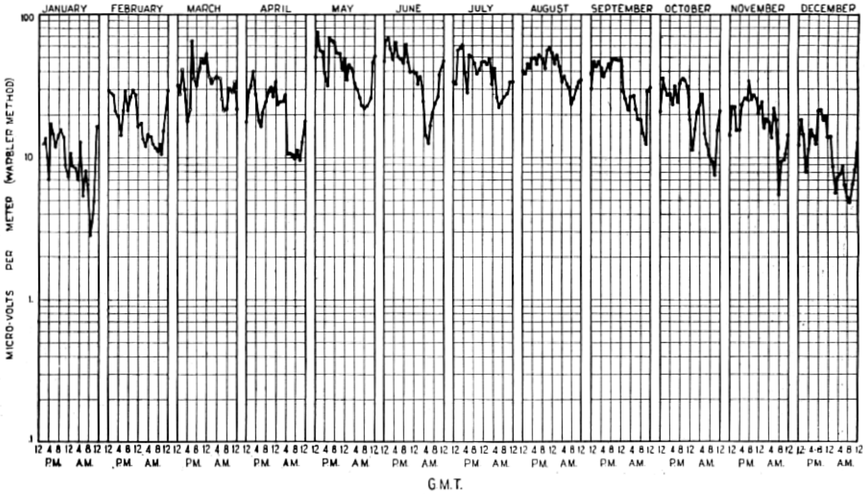
July, 1923—Jan., 1924



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

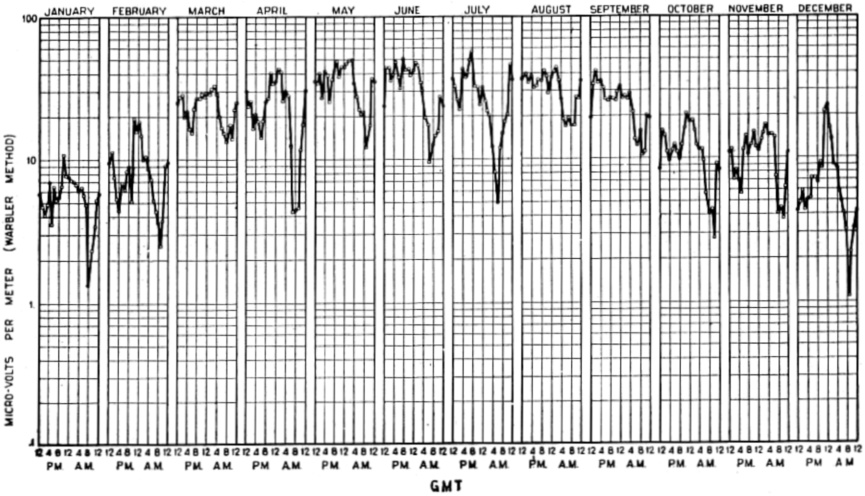
5,240 Km. 54,500 Cycles

Aug., 1923—Jan., 1924

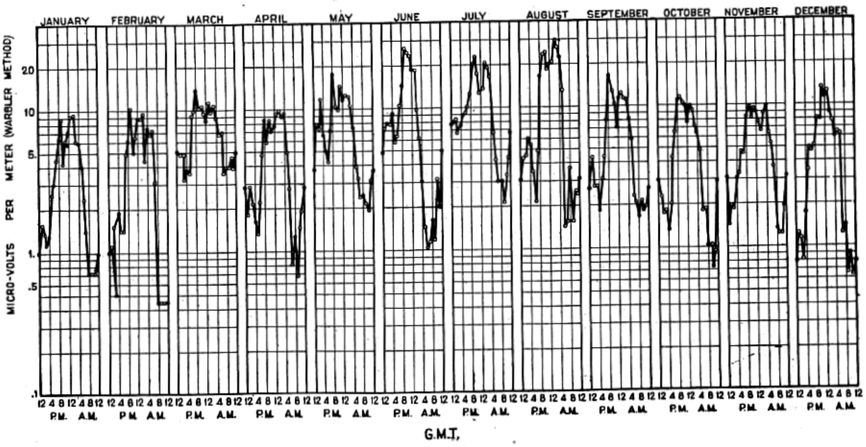


Monthly Averages of Diurnal Variation of Noise
New Southgate, England 17,000 Cycles

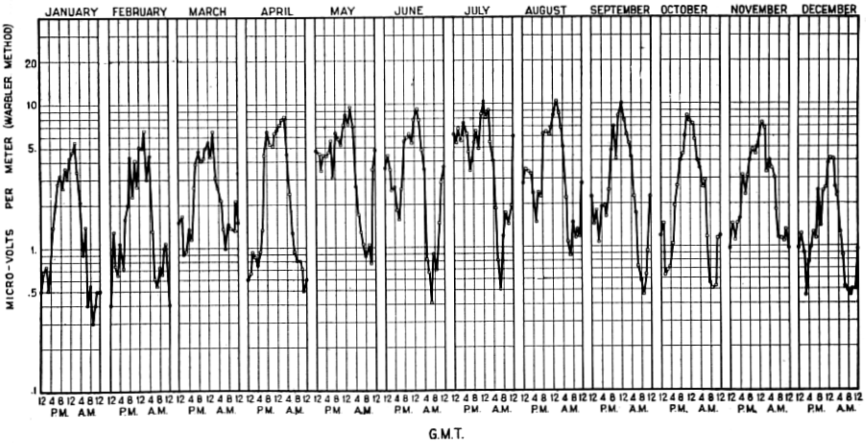
April, 1923—Feb., 1925



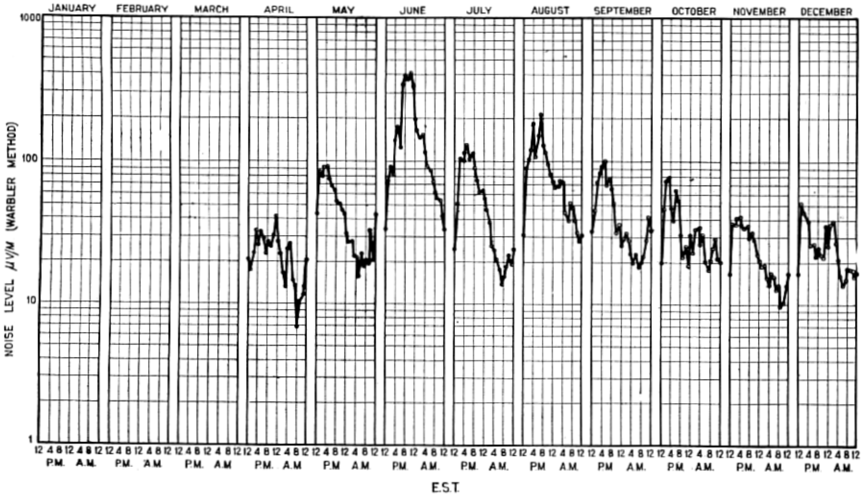
Monthly Averages of Diurnal Variation of Noise
New Southgate, England
25,000 Cycles
Aug., 1923—Feb., 1925



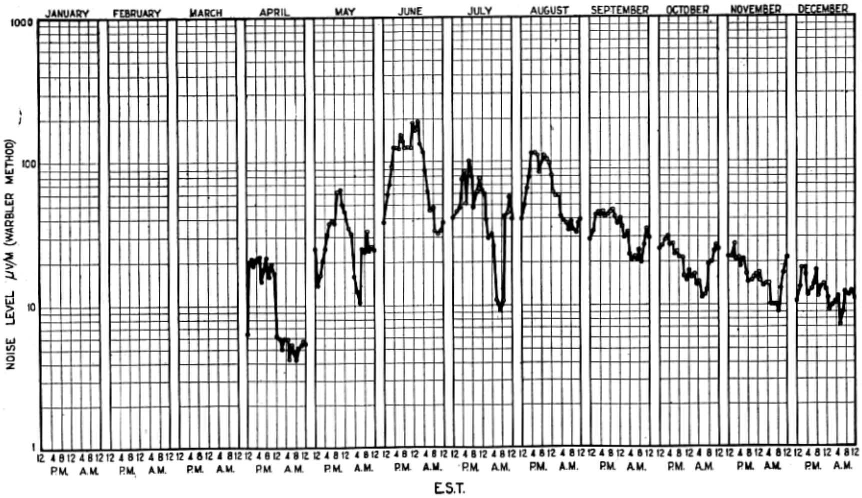
Monthly Averages of Diurnal Variation of Noise
New Southgate, England
37,000 Cycles
Oct., 1923—Feb., 1925



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



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

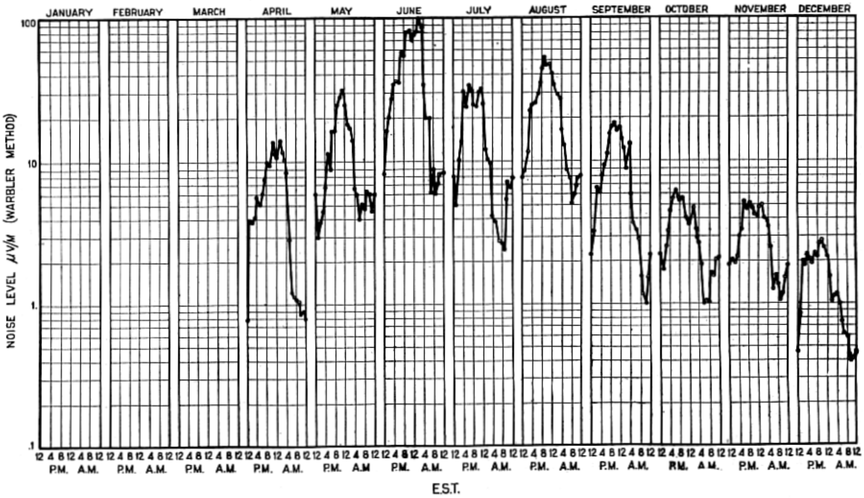


Monthly Average of Diurnal Variation of Noise

Belfast, Maine

24,000 Cycles

1924

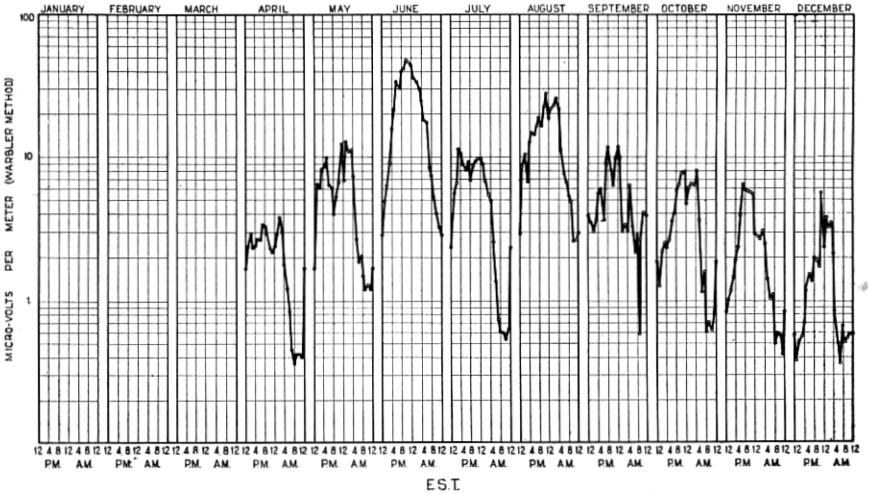


Monthly Average of Diurnal Variation of Noise

Belfast, Maine

36,000 Cycles

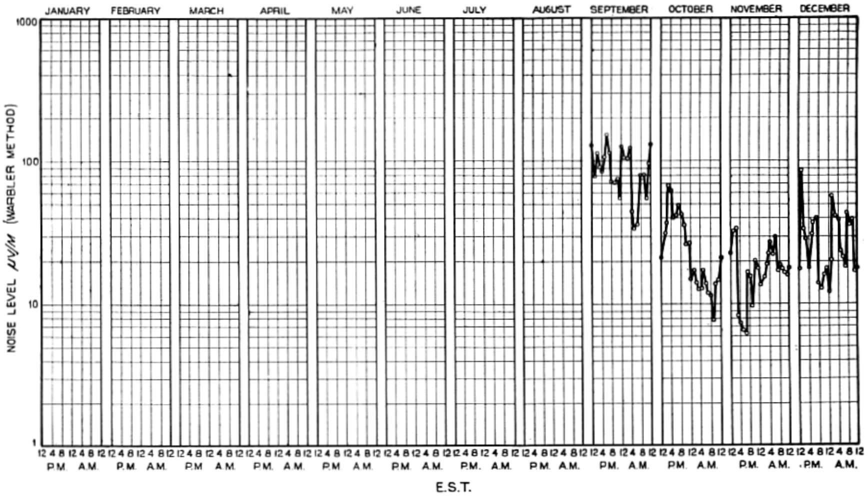
1924



Monthly Average of Diurnal Variation of Noise

Belfast, Maine 52,000 Cycles

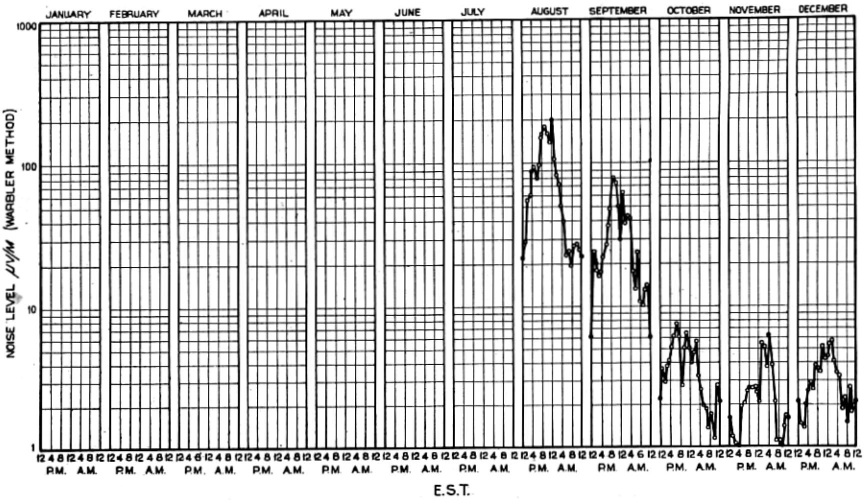
1924



Monthly Average of Diurnal Variation of Noise

Riverhead, L. I. 15,000 Cycles

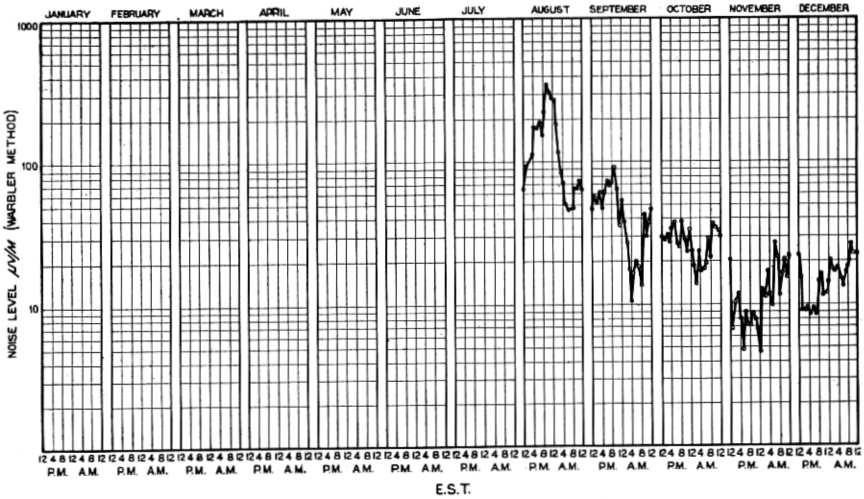
1924



Monthly Average of Diurnal Variation of Noise

Riverhead, L. I. 36,000 Cycles

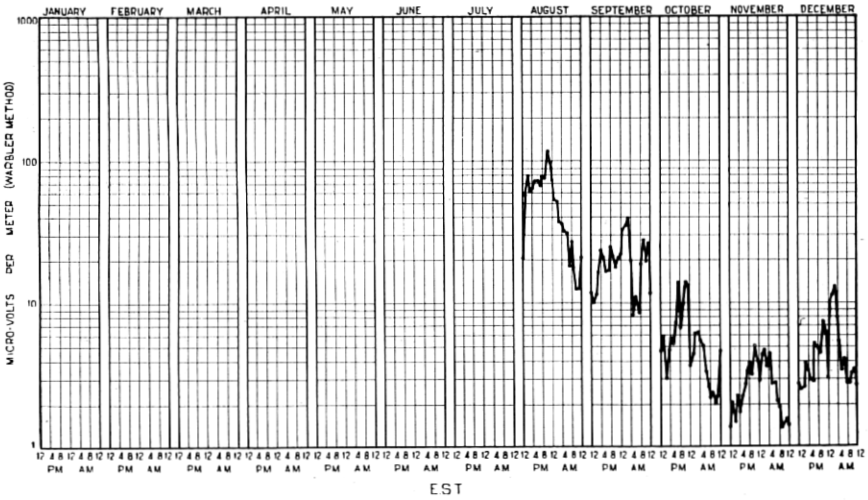
1924



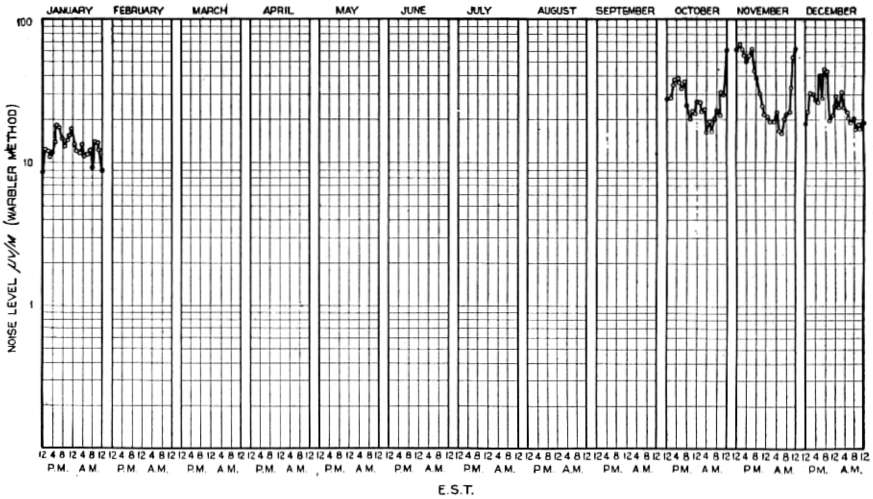
Monthly Average of Diurnal Variation of Noise

Riverhead, L. I. 24,000 Cycles

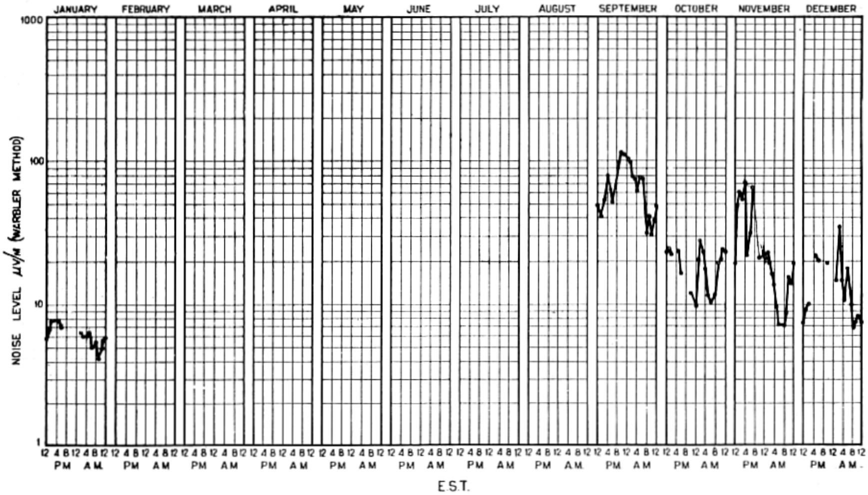
1924



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



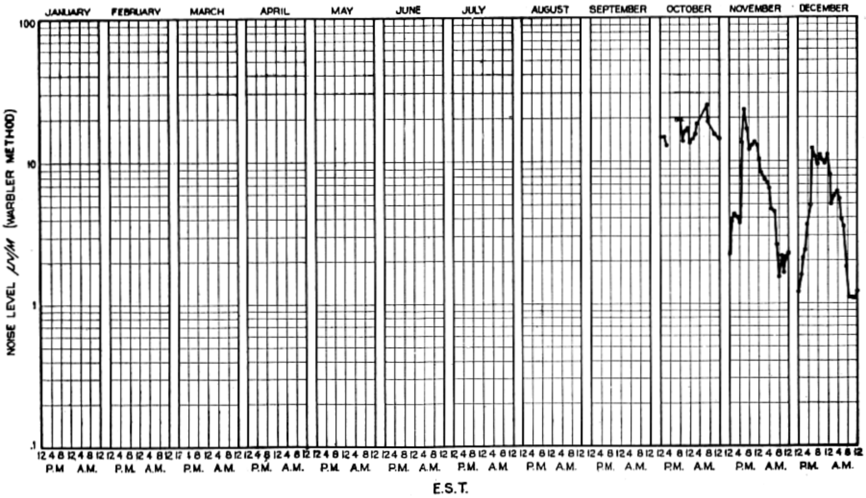
Monthly Average of Diurnal Variation of Noise
Green Harbor, Mass. 15,000 Cycles
Oct., 1923—Jan., 1924



Monthly Average of Diurnal Variation of Noise

Green Harbor, Mass. 24,000 Cycles

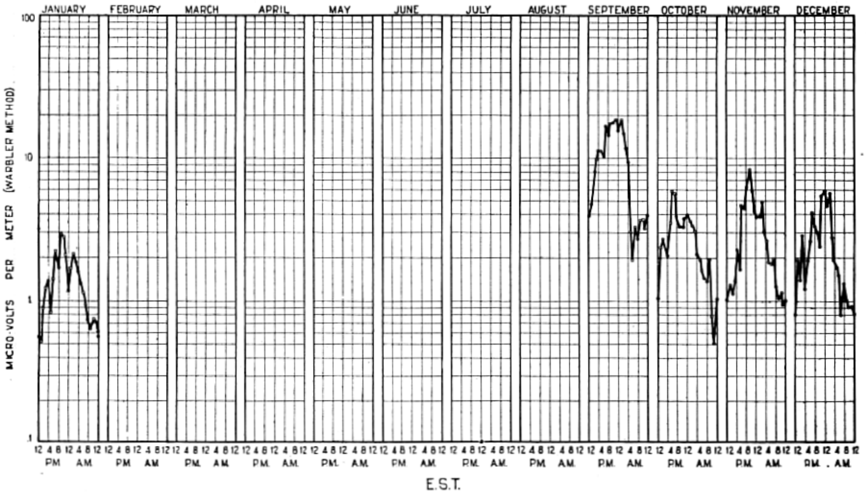
Sept., 1923—Jan., 1924



Monthly Average of Diurnal Variation of Noise

Green Harbor, Mass. 34,000 Cycles

1923



Monthly Average of Diurnal Variation of Noise

Green Harbor, Mass. 55,000 Cycles

Sept., 1923—Jan., 1924