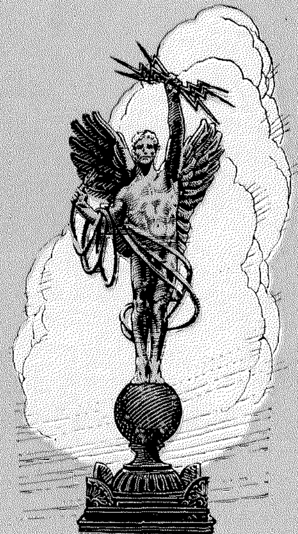
# ELECTRICAL COMMUNICATION



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# ELECTRICAL COMMUNICATION

**A Journal of Progress in the Telephone, Telegraph and Radio Art**



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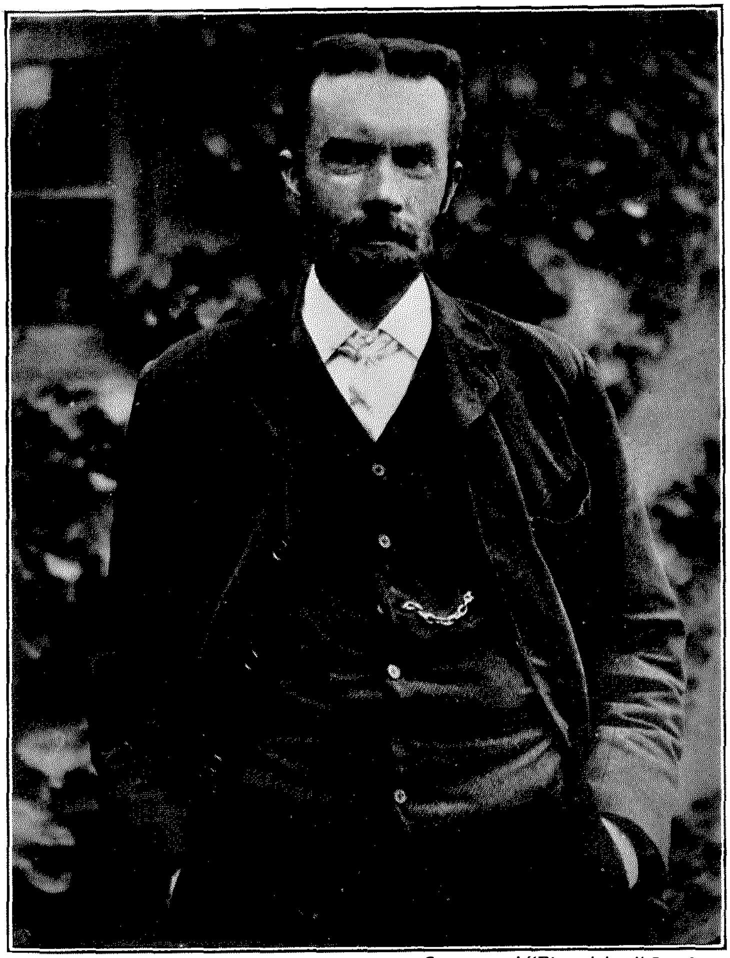

*Courtesy of "Electrician," London*

**The Late Oliver Heaviside, F.R.S.**

# Oliver Heaviside

By F. GILL

*European Chief Engineer, International Western Electric Company, Inc.*

ALTHOUGH abler pens[1] have expressed appreciation of the late Oliver Heaviside, it is perhaps permissible for an English telephone engineer to present a note regarding him. Of his life-history not very much is known; but he may have been influenced in his choice of a career by the fact that he was a nephew of the famous telegraph engineer, Sir Charles Wheatstone. Heaviside was born in London on May 13, 1850; he entered the service of the Great Northern Telegraph Company, operating submarine cables, and he remained in that service, at Newcastle-on-Tyne, until 1874. While he was with the Telegraph Company, he published in 1873, a paper showing the possibility of quadruplex telegraphy.

At the age of about 24, owing, it is suggested, to increasing deafness, he left the service of that Company and took up mathematical research work. How he acquired his mathematical training does not seem to be known;[2] perhaps he was self-taught,—in some of his Papers he implies it. By whatever means he mastered the principles, it is evident that he was an ardent student of Maxwell, for constantly in Heaviside's own writing runs a vein of appreciation of Maxwell. For some time he lived in London, then he moved to Paignton in Devonshire; his Electrical Papers are written from there, and he died at the neighboring town of Torquay on February 4, 1925, in his 75th year.

That is about all the personal history at present available, and yet it gives a clue to a dominant note in his character, viz., reluctance to come into prominence, originating, perhaps, in a kind of shyness, which ultimately led to the recluse state. It is strange that so remarkable an investigator should, in his earlier manhood, have convinced so few, notwithstanding the fact that his voluminous writings made his name well known. It must, however, be remembered that his articles were very difficult, even for advanced mathematicians to follow, for he used a system of mathematics which, at that time, was unusual. Whatever the cause, the fact remains that until about the year 1900 few engineers understood him.

Coming to his work, what was it that Heaviside did, and upon what does his fame rest? That is too large a subject for a telephone engineer to answer fully, but as regards communication engineering something may be said. His great achievement was the discovery of the laws governing the propagation of energy in circuits. He recognized the relationship between frequency and distortion; he illustrated it by numerical examples, and he showed what was required to make a "distortionless circuit." Further, he showed the effects of "attenuation" and the result of "inductance" (these words were his own coinage) in improving telephony. He also explained how the inductance of circuits could be increased; he suggested the use of continuous loading, of lumped inductance in the form of coils, and he pointed out the difficulty of obtaining sufficiently low resistance in such coils. He investigated the effect of sea and land and the upper atmosphere on the propagation of radio energy and how it was that this energy could be transmitted over the mountain of earth intervening between two distant places.

His activity in these matters can best be illustrated by extracts from his writings, as follows:

In his "Electrical Papers," Vol. II, written in 1887, p. 164, he gives numerical examples of frequency distortion and of its correction, and says:

> "It is the very essence of good long distance telephony that inductance should *not* be negligible."

In his "Electromagnetic Theory," Vol. I, published in 1893, he considers in Section 218, p. 441,

> "various ways, good and bad, of increasing the inductance of circuits"

[1] *The Electrician*, Vol. XCIV, p. 174, by Sir Oliver Lodge, F.R.S., O.M. *Nature*, Vol. 115, p. 237, by Dr. Alex. Russell, F.R.S.

[2] Was he the youth with the frown in the library? He says he "then died," but also says "he was eaten up by lions." (E.M.T., Vol. III, pp.1 & 135.)

He suggests, page 445, the use of

"... inductance in isolated lumps. This means the insertion of inductance coils at intervals in the main circuit. That is to say just as the effect of uniform leakage may be imitated by leakage concentrated at distinct points, so we should try to imitate the inertial effects of uniform inductance by concentrating the inductance at distinct points. The more points the better, of course. . . . The Electrical difficulty here is that inductance coils have resistance as well, and if this is too great the remedy is worse than the disease. . . . To get large inductance with small resistance, or, more generally, to make coils having large time constants, requires the use of plenty of copper to get the conductance, and plenty of iron to get the inductance, employing a properly closed magnetic circuit properly divided to prevent extra resistance and cancellation of the increased inductance. . . . This plan . . . is a straightforward way of increasing the $L$ largely without too much increasing the resistance and may be worth working out and development. But I should add that there is, so far, no direct evidence of the beneficial action of inductance brought about in this way."

In "Electrical Papers," Vol. II, p. 311, he deals with reflected waves, and on page 347 he says:

"... but the transmitter and the receiving telephone distort the proper signals themselves. The distortion due to the electrical part of the receiver may, however, be minimized by a suitable choice of its impedance."

"Electromagnetic Theory," Vol. I, p. 404:

"We have seen that there are four distinct quantities which fundamentally control the propagation of 'signals' or disturbances along a circuit, symbolized by $R$, $K$, $L$, and $S$, the resistance, external conductance, inductance, and permittance;"

"Electromagnetic Theory," Vol. I, p. 411:

"It is not merely enough that signals should arrive without being distorted too much; but they must also be big enough to be useful. . . . Nor can we fix any limiting distance by consideration of distortion alone. And even if we could magnify very weak currents, say a thousandfold, at the receiving end, we should simultaneously magnify the foreign interferences. In a normal state of things interferences should be only a small fraction of the principal or working current. But if the latter be too much attenuated, the interferences become relatively important, and a source of very serious distortion. We are, therefore, led to examine the influence of the different circuit constants on the attenuation, as compared with their influence on the distortion."

"Electrical Papers," Vol. II, p. 402:

"I was led to it (the distortionless circuit), by an examination of the effect of telephones bridged across a common circuit (the proper place for intermediate apparatus, removing their impedance) on waves transmitted along the circuit."

With regard to Radio Communication, one extract must suffice. Writing on The Electric Telegraph in June, 1902, for the Encyclopedia Britannica, he says,—"Electromagnetic Theory," Vol. III, p. 335:

"There is something similar in 'wireless' telegraphy. Sea water, though transparent to light, has quite enough conductivity to make it behave as a conductor for Hertzian waves, and the same is true in a more imperfect manner of the earth. Hence the waves accommodate themselves to the surface of the sea in the same way as waves follow wires. The irregularities make confusion, no doubt, but the main waves are pulled round by the curvature of the earth, and do not jump off. There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other. But obstructions, on land especially, may not be conducting enough to make waves go round them fairly. The waves will go partly through them."

Probably due to his long seclusion, his approach to certain subjects was rather critical. At one time I tried to get a portrait of him for the Institution of Electrical Engineers, but failed; he did not wish to have his photograph exhibited, he thought that "one of the worst results (of such exhibition) was that it makes the public characters think they really are very important people, and that it is therefore a principle of their lives to stand upon doorsteps to be photographed."

On another occasion when I sent him a copy of an article by a distinguished telephone engineer on "The Heaviside Operational Calculus," he replied that he had "looked through the paper . . . with much interest, to see what progress is being made with the academical lot, whom I have usually found to be very stubborn and sometimes wilfully blind."

Some have held that Heaviside was not recognized as he ought to have been. This was probably the case some time ago, but not in recent years. The same is true of many very great men who were much in advance of their time, for the English have the national characteristic that they do not make much fuss about their great men. So if Heaviside suffered, he shared this experience in common with other pioneers who deserved higher recognition. See, for example, what Heaviside himself said about one of these, in a footnote in "Electromagnetic Theory," Vol. III, p. 89:

> "George Francis Fitzgerald is dead. The premature loss of a man of such striking original genius and such wide sympathies will be considered by those who knew him and his work to be a national misfortune. Of course, the 'nation' knows nothing about it, or why it should be so."

During the last 20 years or more, the significance and luminous quality of the work of Heaviside has been increasingly acknowledged by mathematicians and by practical telephone, telegraph and radio engineers. To other electrical engineers, his treatment of wave-transmission has not yet appealed quite so strongly.

Probably his first recognition came from his contribution to the problem—"Electromagnetic Induction and its Propagation" in the *Electrician.* It appeared as a series of articles between January, 1885 and December, 1887. His "Electrical Papers" were written at various times and were published in two volumes in 1892. Then followed his three volumes on "Electromagnetic Theory"—on the basis of the *Electrician* articles, —published in 1893, 1899 and 1912. He also wrote, in 1902, the article on the "Theory of the Electric Telegraph" in the Encyclopedia Brittanica.

In 1891, the Royal Society made him a Fellow. In 1899, the American Academy of Arts and Sciences elected him an Honorary Member. In 1908 the Institution of Electrical Engineers did the same, followed by the American Institute of Electrical Engineers in 1917. The Literary and Philosophical Society of Manchester also elected him an Honorary Member. He was an Hon. Ph.D. of the University of Göttingen, and in 1921, the Institution of Electrical Engineers conferred upon him the highest award in their gift—the Faraday Medal. He was the first recipient of this Medal which was established to commemorate the 50th anniversary of the founding of the original Society of Telegraph Engineers and of Electricians, and since then the Medal has been bestowed upon Sir Charles Parsons, Dr. S. Z. de Ferranti, and Sir J. J. Thomson.

From time to time there were reports of his living in great poverty, and attempts were made to help him. These reports lacked proportion, but it is true he had not much money and perhaps still less comfort; he was a difficult man to help. Towards the end of his life he received from the British Government a Civil Pension. His independent character rendered it necessary that offers of assistance should be tactfully made, and apparently this was not always the case, as I believe help was sometimes refused; but there were those who succeeded. Another difficulty was his unconventional mode of living which caused him, in his last years, to live as a recluse, cooking and looking after his house alone.

Just what other work Heaviside did, in addition to his published writings, is not at present known to me. I believe he left a good deal of manuscript, but whether it is in such a state it could be completed by another, I do not know. Let me conclude this note by an extract from his last chapter of his last book, "Electromagnetic Theory," Vol. III, page 519:

> "As the universe is boundless one way, towards the great, so it is equally boundless

the other way, towards the small; and important events may arise from what is going on in the inside of atoms, and again, in the inside of electrons. There is no energetic difficulty. Large amounts of energy may be very condensed by reason of great forces at small distances. How electrons are made has not yet been discovered. From the atom to the electron is a great step, but is not finality.

"Living matter is sometimes, perhaps generally, left out of consideration when asserting the well-known proposition that the course of events in the physical world is determined by its present state, and by the laws followed. But I do not see how living matter can be fairly left out. For we do not know where life begins, if it has a beginning. There may be and probably is no ultimate distinction between the living and the dead."

# Transatlantic Radio Telephone Transmission*

By L. ESPENSCHIED, C. N. ANDERSON and A. BAILEY

*Department of Development and Research, American Telephone and Telegraph Company*

*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 strength 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 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.[1] 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 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.

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 kilocycle 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 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 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 tele-

* Presented before the Institute of Radio Engineers, May 6, 1925.

[1] "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.

phone 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

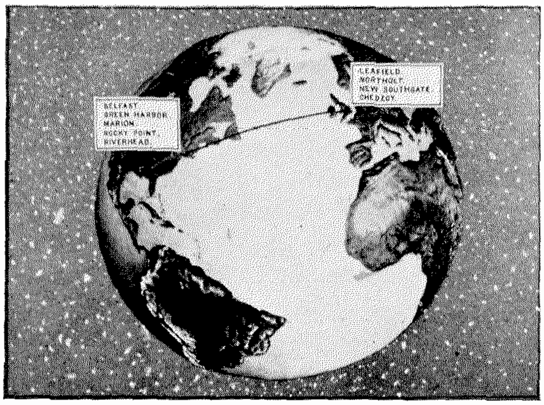


Figure 1

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

Figure 2

United States were initiated at Green Harbor, Mass., and continued at Belfast, Maine and Riverhead, L. I.

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. 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

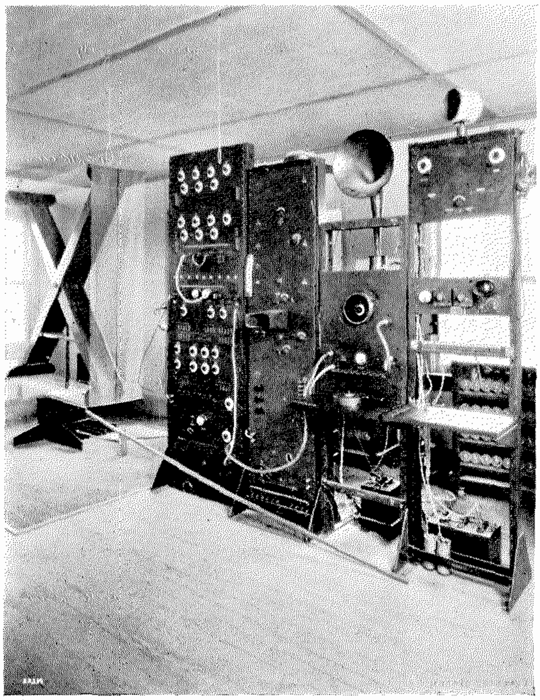

Figure 3

attenuating it, and the fourth bay contains means for monitoring the transmission from the nearby Rocky Point radio telephone transmitter.

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 Figure 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

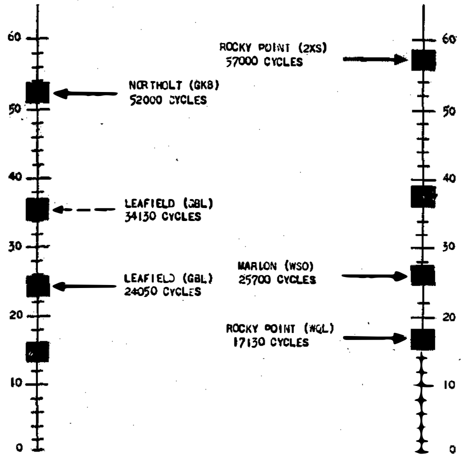


Figure 4—Frequency distribution of measurements denotes band in which noise measurement was taken

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.

## 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,[2] a brief review 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 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.

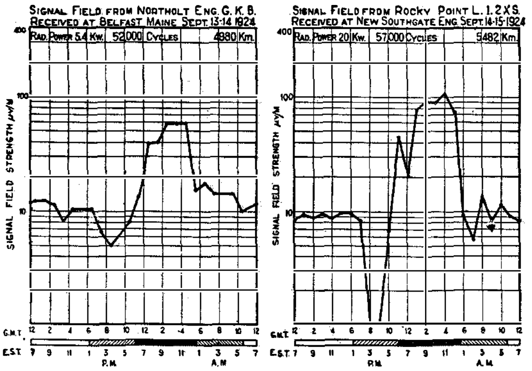


Figure 5—Diurnal variation in signal field

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

[2] Radio Transmission Measurements, Bown, Englund, and Friis. Proceedings I. R.E., April, 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 of the time during which daylight pervades the entire path.

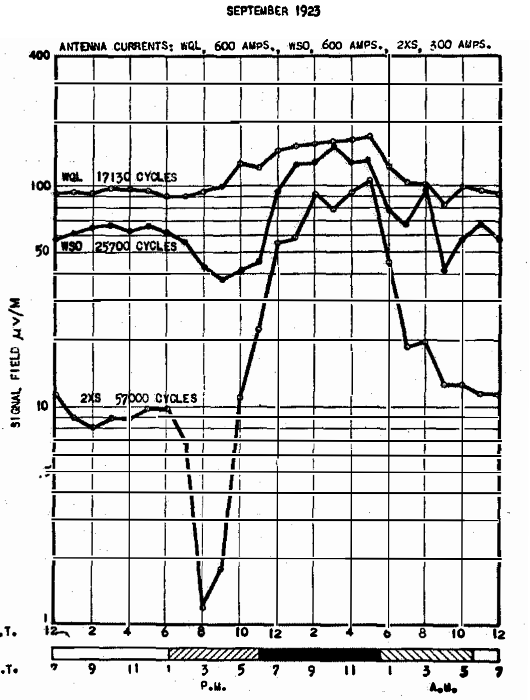


Figure 6—Monthly average of diurnal variation in signal field transmission from American stations on various frequencies received at New Southgate, England, September, 1923

The 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 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 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 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 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.

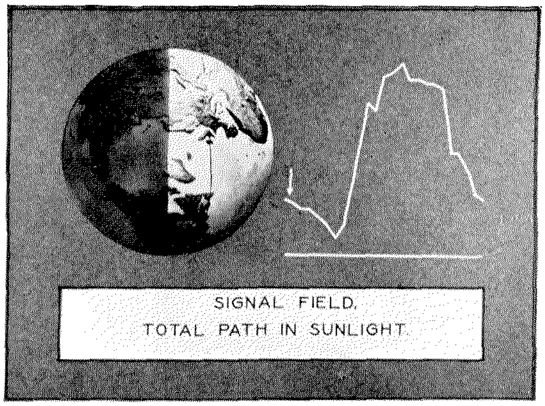


Figure 7a

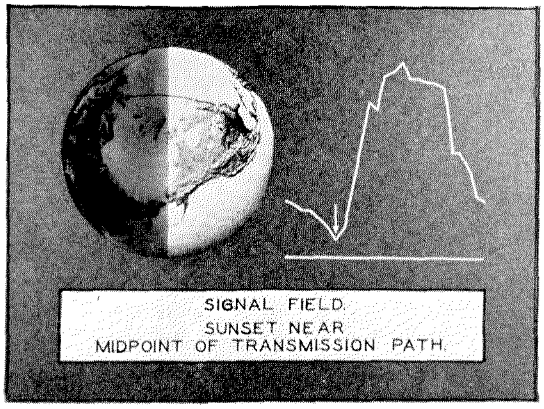


Figure 7b

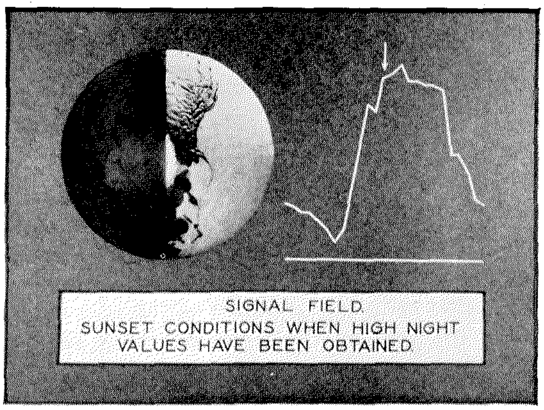


Figure 7c

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.

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

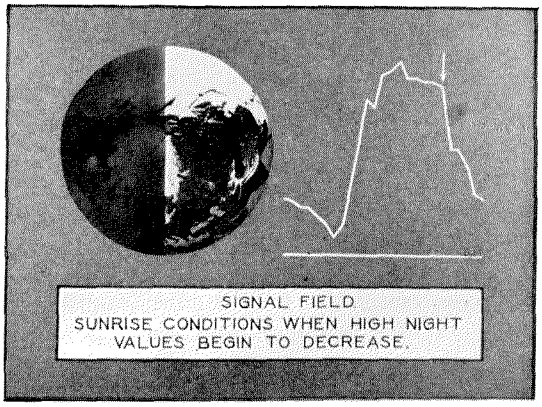


Figure 7d

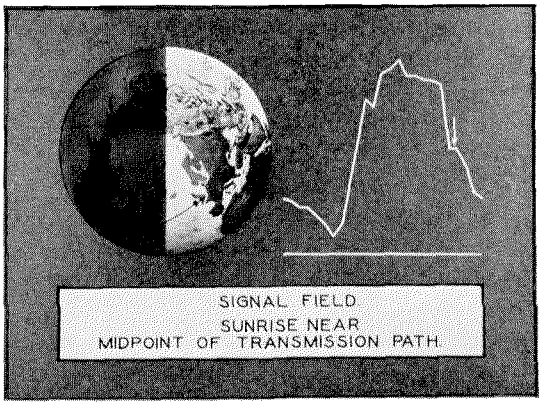


Figure 7e

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 about the sun, the sunlit hemisphere recedes southward until

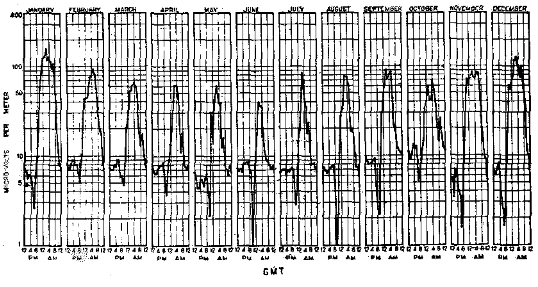


Figure 8—Monthly averages of diurnal variation in signal field, Rocky Point, L. I. (2 X S) to New Southgate, England, 57,000 cycles—Ant. Current, 300 Amps—5480 Km. 1923–1924

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

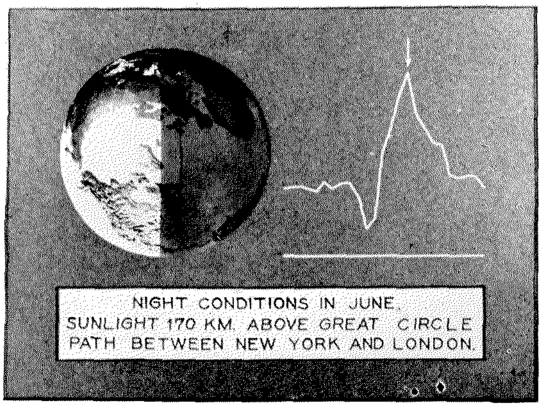


Figure 9

diurnal 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

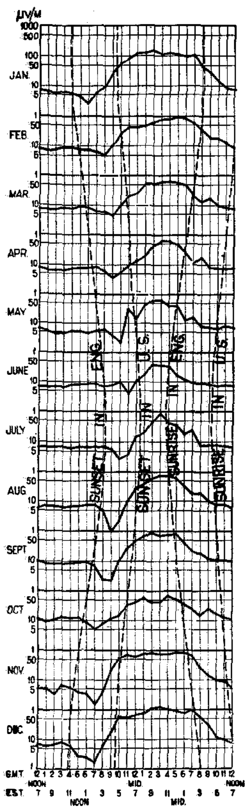


Figure 10—Monthly averages of diurnal variation of signal field, Rocky Point, L. I. (2XS) to New Southgate, England; 20.8 k.w. radiated power, 57,000 cycles, 1923-1924

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 Figure 9.

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 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 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 [3] that the high night-time values are merely the result of a reduction of the absorp-

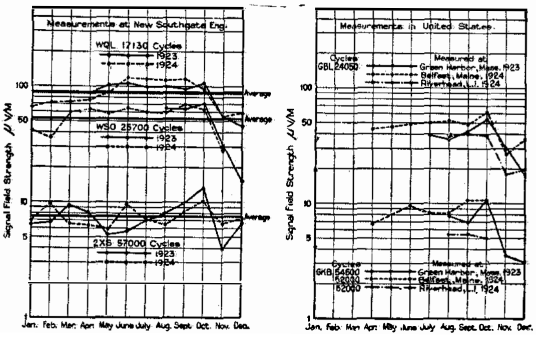


Figure 11—Monthly averages of daylight field strength

tion 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 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, Sommerfield (1909) gave $\alpha = .0019$ and $x = 1/3$. In the Austin-Cohen formula $\alpha$ 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 $\alpha$ from 25 selected observations from tests between San Francisco and Honolulu in 1914.

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

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 $\alpha = .005$ 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

$$E = \sqrt{P}\,\frac{298 \times 10^3}{D} e^{-\frac{.005D}{\lambda^{1.25}}}$$

where

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

The table above summarizes the data relative to daylight transmission.

TRANSATLANTIC RADIO TELEPHONE MEASUREMENTS

| Transmitting Terminal | Receiving Terminal | Freq. | Distance Km. | Power* Radiated Kw. | Daylight Field Strengths Observed 1923 | 1924 | Av. | Daylight Field Strengths Calculated 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.

## 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 in Figure 12 is represented in the upper curves. 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 was 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. Coincidence similar to those described above have been found for other

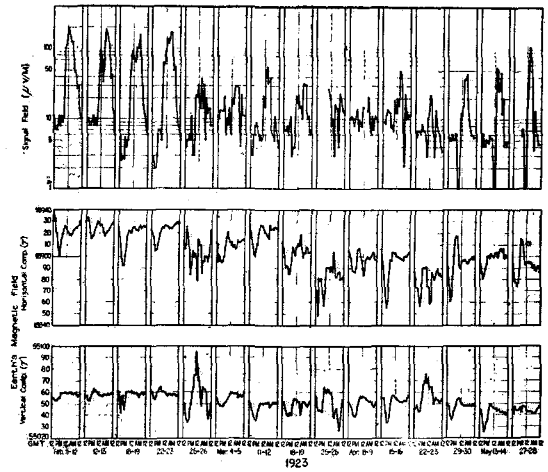


Figure 12—Correlation of radio transmission and earth's magnetic field—Transmission from Rocky Point, U. S. A. (57,000 cycles) to London, Eng.—Earth's magnetic field measured at Cheltenham, Md., U. S. A.

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 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 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 prevailed at the time of these disturbances.

## 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.

*Diurnal Variation.* An example of the diurnal characteristic of the noise for both ends of the

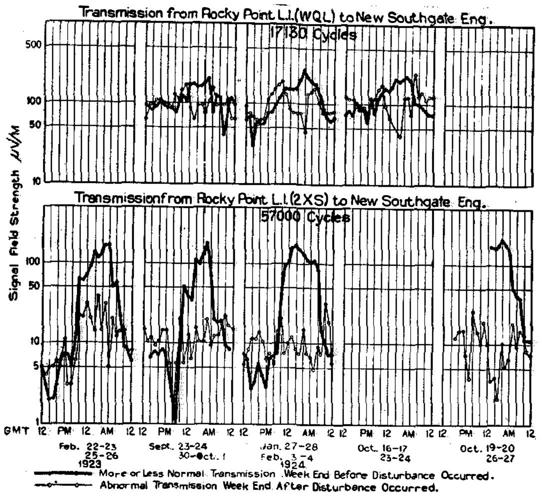


Figure 13—Correlation between radio transmission and variations in earth's magnetic field. Transmission from Rocky Point, L. I. (WQL) to New Southgate, England—17,130 cycles—Transmission from Rocky Point, L. I. (2 X S) to New Southgate, England—57,000 cycles

transatlantic path is given in Figure 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 unusual for all frequencies in this 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 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.

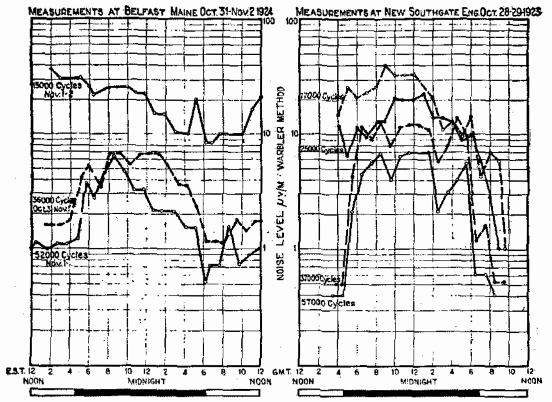


Figure 14—Diurnal variation in noise

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.

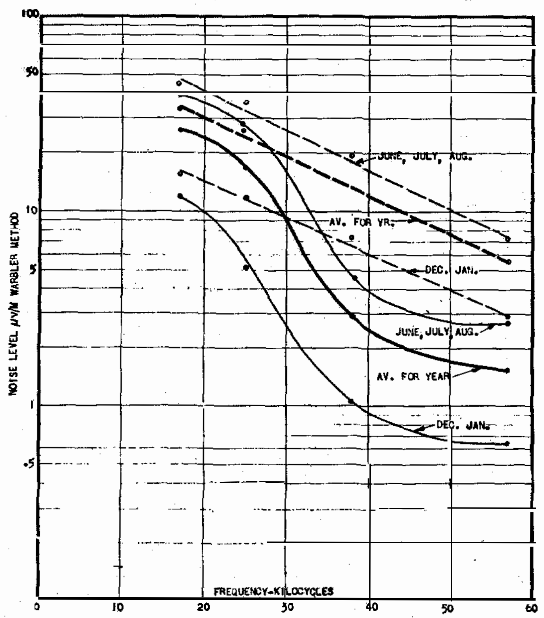


Figure 15—Frequency distribution of noise, New Southgate, England—Night time — — — Day time——— 1923-1924

The curves of Figure 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.

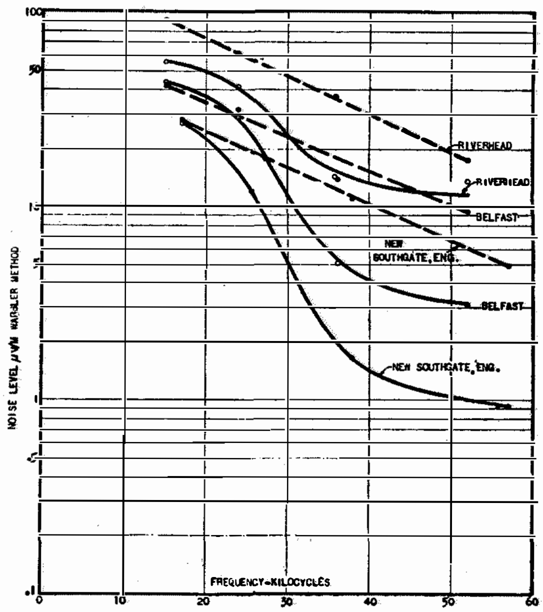


Figure 16—Frequency distribution of noise, New Southgate, Eng., Belfast, Maine, Riverhead, L. I. Night time — · — — Day time ——— Aug.-Dec., 1924

*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 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-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

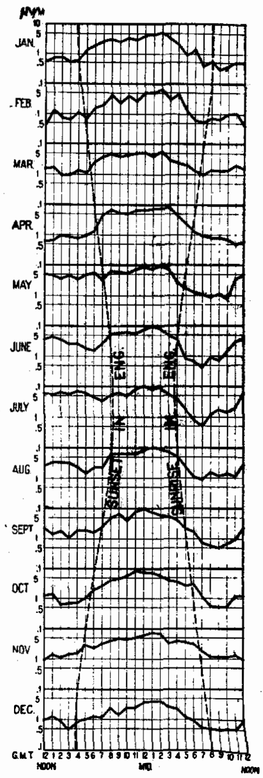


Figure 17—Monthly averages of diurnal variation of noise, New Southgate, England; 57,000 cycles; 1923-1924

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 increase 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 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 trans-

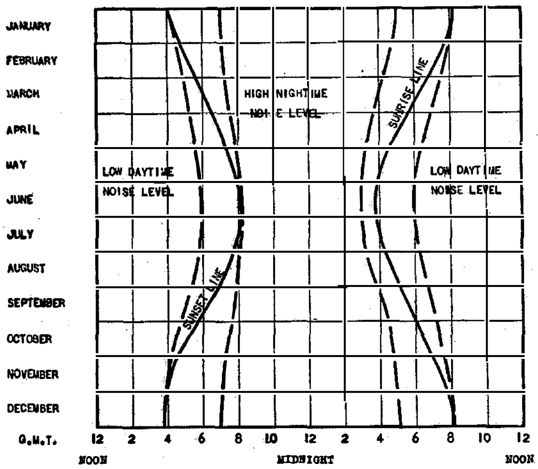


Figure 18—Seasonal variation in distribution of daytime and night-time noise with respect to sunset and sunrise, New Southgate, England—1923–1924

mission 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. Figure 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

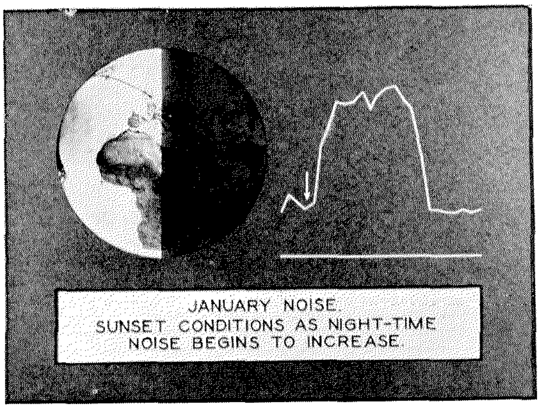


Figure 19a

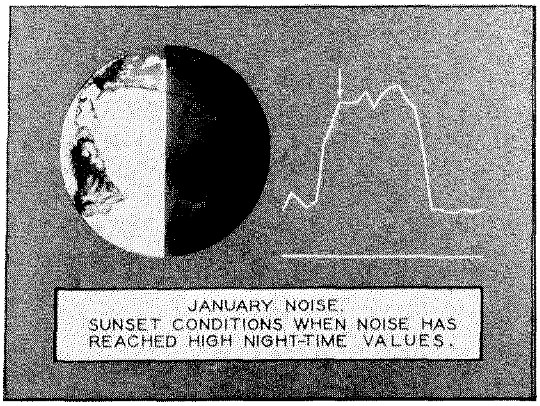


Figure 19b

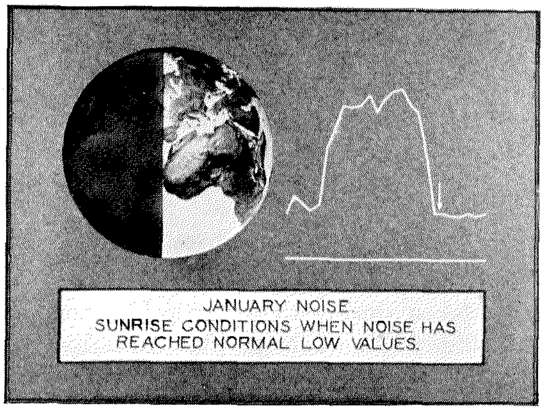


Figure 19c

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 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 daylight values.

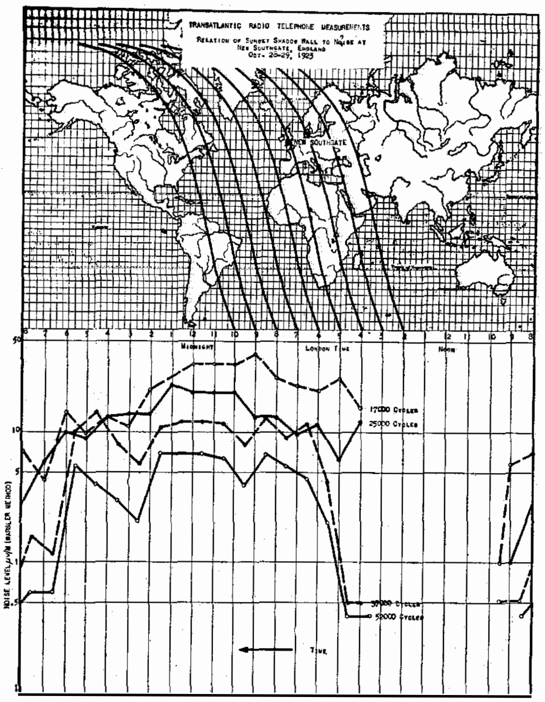

Figure 20—Relation of sunset shadow wall to noise at New Southgate, England—Oct. 28–29, 1923

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

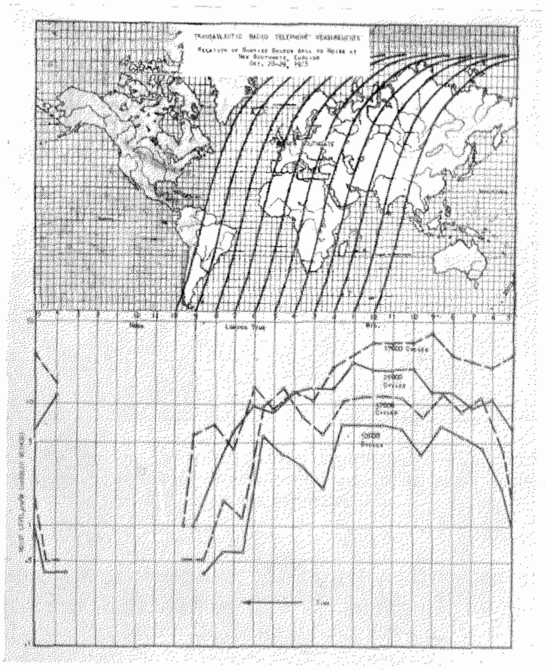

Figure 21—Relation of sunrise shadow wall to noise at New Southgate, England—Oct. 28–29, 1923

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.

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.

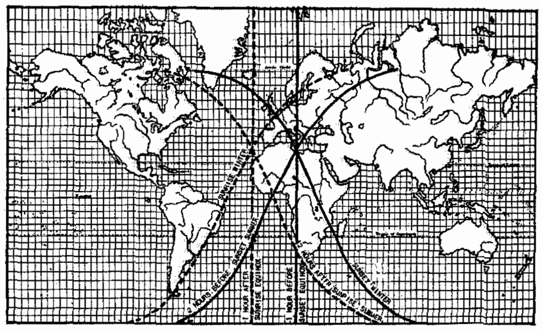

Figure 22—Position of sunset lines at sunset dip and sunrise lines at sunrise dip in noise level in England for various seasons

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 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 level 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. Although 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

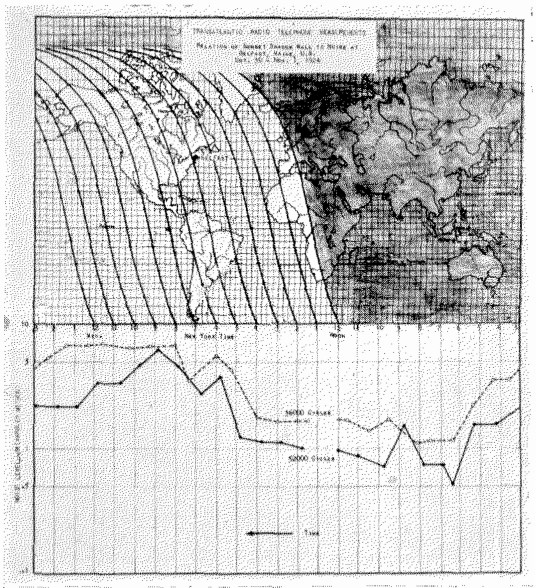

Figure 23—Relation of sunset shadow wall to noise at Belfast, Maine, U. S.—Oct. 30—Nov. 1, 1924

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.

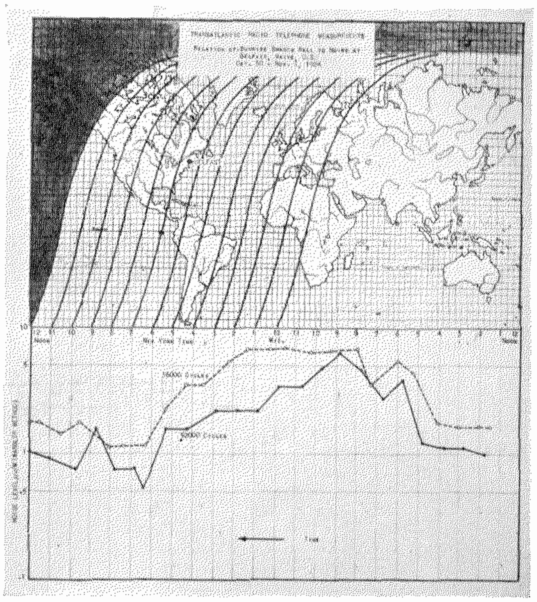

Figure 24—Relation of sunrise shadow wall to noise at Belfast, Maine, U. S.—Oct. 30—Nov. 1, 1924

## SIGNAL TO N●ISE 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 Figure 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 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 Figure 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

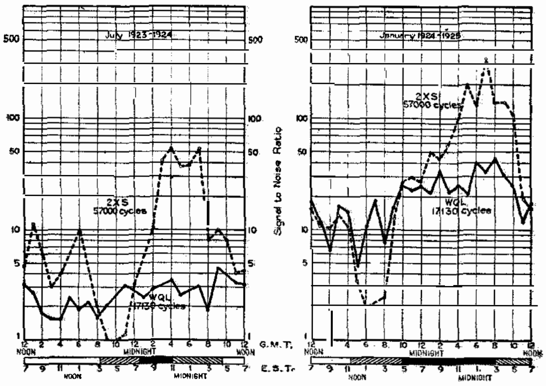


Figure 25—Variation of signal to noise ratio with frequency. Corrected to same antenna input power (68.5 KW) in Rocky Point antenna—Reception at New Southgate, England

rises earlier in the afternoon and declines earlier in the morning than do the corresponding variations in signal strength.

Figure 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

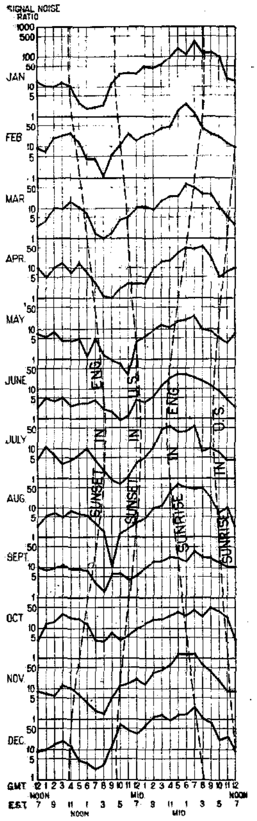


Figure 26—Monthly averages of diurnal variation of signal-to-noise ratio, Rocky Point, L. I. (2XS), received at New Southgate, England; 20.8 k.w. radiated power, 57,000 cycles, 5,480 km.—1923-1924

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 antenna built by the Radio Corporation of America for radio telegraph operation upon lower frequencies.

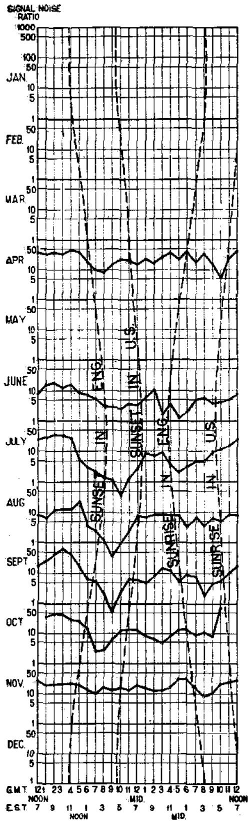


Figure 27—Monthly averages of diurnal variation of signal-to-noise ratio, Northolt, England. (GKB) Received at Belfast, Maine; 20.8 kw. radiated power; 4,980 km.; 52,000 cycles; 1924

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

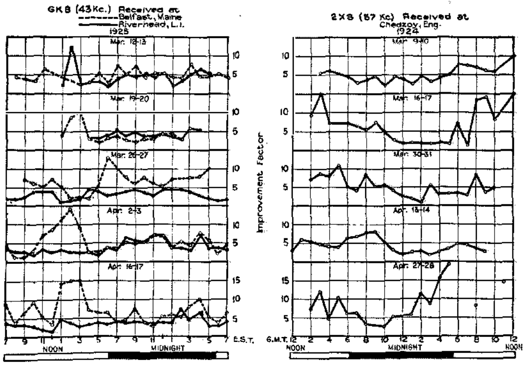


Figure 28—Improvement in signal noise ratio of wave antenna over loop reception

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.

*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. 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

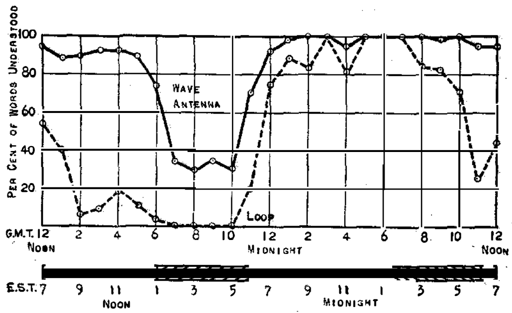


Figure 29—Comparison of reception on wave antenna and loop. Per cent of words understood—Reception of Rocky Point (2 X S) at Chedzoy, England, March, 1924

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.

# Commercial Loading of Telephone Cable

By WILLIAM FONDILLER

*Bell Telephone Laboratories, Incorporated*

THERE has been a world-wide increase in the use of the telephone, such that the increasing use of cable has been necessary in order to provide economically the required number of circuits in a limited space. This is particularly the case in metropolitan areas where, aside from the question of economy, it would be physically impossible to provide the space necessary to carry the exchange area or junction circuits if open wire pole line construction were used. In the case of toll circuits there is a great economy in cable construction over open wire lines when the traffic is such as to require a considerable number of channels. Some further advantages of toll cable are, its greater reliability and freedom from service interruptions. These factors have combined to lead to the general adoption of cable construction for important toll routes carrying heavy traffic.

The bringing together of the wires of a talking circuit in close proximity to each other with accompanying high capacity imposes difficulties due to high attenuation per unit length as well as a degree of distortion not experienced in open wire lines. This limitation was so serious that up to about 1900 there was a general avoidance of the use of cable in the toll plant so far as possible. The invention of the loading coil by Professor Pupin in 1900 marked an epoch in the evolution of the modern telephone plant. This invention, following the mathematical researches of Heaviside and others, disclosed a practical means of adding inductance to telephone circuits by the addition of inductance loads at periodic intervals. A more obvious method, first put into practice by the Danish engineer Krarup, is to add the inductance uniformly as by the winding of an iron wire over the copper conductor. Owing to the high cost and comparative inefficiency of continuous loading, its application has been limited practically to submarine cables. In such cables the mechanical difficulties encountered in connecting loading coils into the circuit and maintaining a watertight joint preclude the use of loading coils except for comparatively shallow water. The following discussion is confined to coil loading and treats of the development in design and application of loading coils for cable circuits.

In practice, the addition of loading to No. 8-BWG (4.2 mm.) open wire circuits has been discontinued in the United States. This is due to the development of a practically distortionless vacuum tube telephone repeater, and to the increasing use of carrier frequencies for multiplexing the lines. High efficiency repeaters in combination with non-loaded open wire circuits give results superior to those obtainable with such repeaters connected in a loaded open wire circuit. A considerable mileage of No. 12-NBSG (2.6 mm.) circuit is loaded at the present time though little new loading of open wire circuits is being done. There appears, however, to be a small field for the loading of No. 12-NBSG circuits under conditions where the installation of telephone repeaters would be uneconomical.

With the advent of telephone repeaters, and the development of corrective networks which serve to equalize the attenuation of the different frequencies, the question naturally arises whether the field for the loading even of cable circuits is not materially reduced. The fact is that although the attenuation and distortion can both be offset by correctly designed repeaters and equalizers, this can be accomplished far more economically by the use of loading or loading combined with repeaters. For example, a loaded No. 16 gauge (1.3 mm.) circuit 75 miles in length gives very satisfactory transmission without repeaters, whereas, to get the same volume and quality over a non-loaded cable would require at least 4 intermediate repeaters. The annual cost of the loaded circuit without repeaters would obviously be far lower than that of the repeatered cable without loading.

Cable circuits may be divided into two main classes as regards the requirements for the loading coils:

1. Exchange area cable.
2. Toll cable.

In addition to these two main classes, there are also short cables incidental to a long open wire line which are referred to as intermediate or toll entrance cables. These short lengths of cable serve to carry an open wire circuit through cities, or may serve to terminate such a circuit. In the usual case of cables connecting to open wire lines used only for audio frequency transmission, a special form of toll cable loading is employed designed primarily to avoid reflection losses and irregularity effects. Loading coils for this class of service must in general meet the same requirements as toll cable loading coils, the requirements for which are considered later in this article. In the event that the open wire toll circuit is multiplexed by means of carrier frequencies, a special design of air core loading coil is employed.

As the consideration of carrier frequency loading apparatus is beyond the scope of this paper, only the general requirements for the loading coils will be mentioned here. Owing to the multi-frequency transmission through the carrier circuit loading coils and the comparatively high frequencies used, viz., up to 30,000 cycles or higher, severe requirements are imposed as regards freedom from intermodulation between channels and the maintenance of low losses. Obviously, the most satisfactory solution as regards freedom from magnetic modulation is the avoidance of the use of ferro-magnetic core materials. In carrying out the design of air core loading coils it is necessary to use finely stranded copper conductors for the winding to limit the eddy current losses. In practice, a special type of compensated loading unit is employed at the junction points of the cable and open wire circuits and at the office terminals which affords an economical means of obtaining the desired matching of impedances with respect to the carrier frequencies to be transmitted. Audio frequency transmission can at the same time be carried out over the loaded phantom circuit, the sides of which may be loaded for carrier (and audio) frequency transmission.[1]

## 1. Loading for Exchange Area Cable

This class of cable includes switching trunks used to connect the central offices in a given exchange area. The requirements for this class of loading are comparatively simple. The coils should be stable in inductance, and of sufficiently low cost to be in equilibrium with the gauge of circuit for which they are used. The cost equilibrium just referred to implies that the loading for a given cable circuit has been so designed that any further improvement in transmission efficiency would require approximately equal expenditure whatever method were employed, i.e., whether the improvement were obtained by increasing the amount of copper in the cable, by improving the efficiency of the loading coils, or by other means.

As the gauge of the trunk cable will, in general, be No. 22-AWG, (.64 mm.) or No. 19-AWG (.91 mm.) — in short trunks No. 24-AWG (.51 mm.) is also used—the effective resistance of the coil may be considerably higher than that of the loading coils for the heavier gauge toll circuits. This follows from the comparatively high conductor resistance of these cables before loading. Small size is a primary requirement for trunk loading coils because of the very large number required, and the congested space generally available for their installation in cities.

As a general rule exchange area circuits are not sufficiently long to make it economical to use phantom circuits. Accordingly, non-quadded cables are used almost exclusively for this

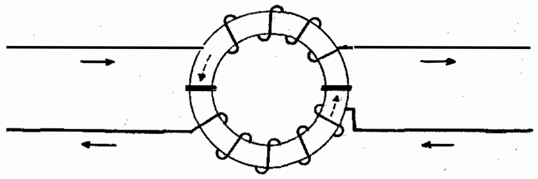


Figure 1—Diagram of Simple Two Winding Coil for Loading Non-Phantomed Circuits

grade of service and a simple two-winding coil as shown in Figure 1 will meet the requirements of the circuit. Figure 2 shows a photograph of a small coil designated No. 602 recently developed for use in loading exchange area cable circuits. A curve showing the effective resistance-frequency characteristic of this loading coil is given in Figure 3. In Table I some general data are given for various loading schemes now standard in the Bell System for different lengths of exchange area circuit.

[1] U. S. Patent 1501926, 1924, Thomas Shaw.

It is convenient to use certain abbreviations to designate the different grades of loading as listed in the first column of Table I. Here "M" signifies a spacing of 9,000 feet (2.74 km.) and "H" a spacing of 6,000 feet (1.83 km.). Accordingly, M-88 indicates a loading scheme in which coils having an inductance of 88 milhenrys are spaced 9,000 feet apart, H-135 coils having an inductance of 135 milhenrys, 6,000 feet apart, etc.

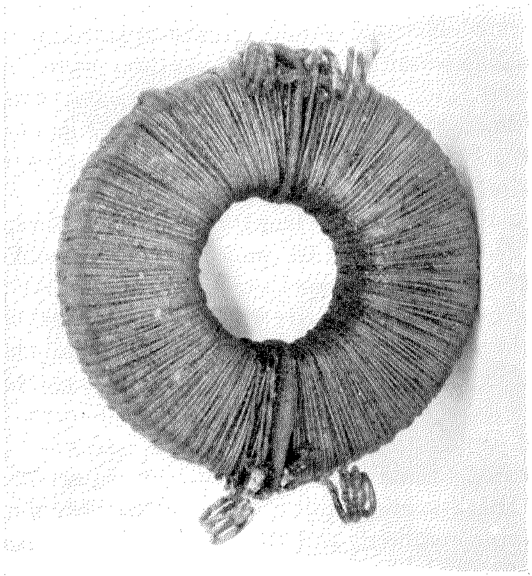

Figure 2—No. 602 Loading Coil for Exchange Area Circuits

In Table II are given transmission data for the more commonly used types of loaded trunk circuits.

The type of loading adopted in any given case will depend upon the length and gauge of the trunk and the allowable transmission loss in it. It will be observed that the loading systems listed in Table II give a minimum cut-off frequency of 2800 cycles. In determining the proper inductance and spacing of the loading coils, it should be recognized that a loaded circuit has a transmission-frequency characteristic similar to that of a low-pass filter. Thus, as the

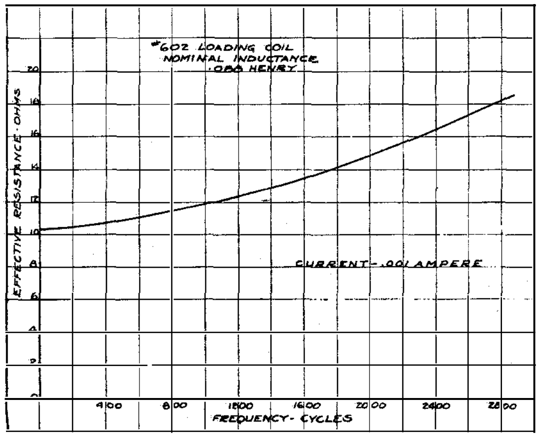


Figure 3—Effective Resistance-Frequency Characteristic of No. 602 Loading Coil

upper frequency limit is approached, the attenuation increases rapidly and the impedance departs widely from its value in the freely transmitted frequency range. In telephony that which it is desired to transmit is intelligence and not simply speech frequency power. Efficient telephone transmission requires, therefore, that the loading be so designed as to give a sufficiently high cut-off frequency. It will be understood that as regards the loading, this depends not alone on the coil inductance, but also on the spacing of the coils.

TABLE I

Loading for Exchange Area Cables

| Designation of Loading | Code No. of Coil | Spacing of Coils | Average Total D.C. Resist. Ohms | Average Eff. Resist. Ohms at 1,000 Cycles (1 milampere) | Nominal Inductance Milhenrys |
|---|---|---|---|---|---|
| M-88 | 602 | 9,000 ft. (2.74 Km.) | 10.3 | 11.9 | 88 |
| H-135 | 575 | 6,000 ft. (1.83 Km.) | 3.5 | 7.8 | 135 |
| H-175 | 574 | 6,000 ft. (1.83 Km.) | 4.6 | 10.6 | 175 |

Note: Resistance values apply at the end of the cable stub.

TABLE II
TRANSMISSION CHARACTERISTICS OF LOADED EXCHANGE AREA CABLE CIRCUITS

| Cable Conductor | | Capacity Mf/Km. | Loading | | | Cut-off Frequency | Attenuation TU/Km at 1,000 Cycles |
|---|---|---|---|---|---|---|---|
| Size—AWG | Diam. mm. | | Code No. | Inductance Milhenrys | Spacing | | |
| No. 16 | 1.3 | .041 | 602 | 88 | 9,000 ft. (2.74 Km.) | 3200 | .15 |
| No. 19 | .91 | .041 | 574 | 175 | 6,000 ft. (1.83 Km.) | 2800 | .18 |
| No. 19 | .91 | .041 | 575 | 135 | 6,000 ft. (1.83 Km.) | 3200 | .19 |
| No. 19 | .91 | .041 | 602 | 88 | 9,000 ft. (2.74 Km.) | 3200 | .28 |
| No. 22 | .64 | .052 | 575 | 135 | 6,000 ft. (1.83 Km.) | 2800 | .40 |
| No. 22 | .64 | .052 | 602 | 88 | 9,000 ft. (2.74 Km.) | 2900 | .60 |
| No. 24 | .51 | .049 | 602 | 88 | 9,000 ft. (2.74 Km.) | 2900 | .92 |

## 2. Loading of Toll Cable

In considering the requirements for toll cable loading, it will be worth while to review briefly the major steps in the development of long distance cables which have affected loading coil development.

1st—In the early days of loading in the United States, the desirability of compositing loaded circuits so as to permit the simultaneous transmission of telegraph and telephone currents was recognized. This brought in the necessity for limiting the detrimental reaction between telegraph and telephone currents, due to modulation effects in the loading coil cores known as "flutter."[2]

2nd—Another step in the evolution of the modern cable plant was the development of quadded cable which enabled phantoming loaded circuits. This development involved problems of considerable magnitude, owing to the fact that the unbalances tending to produce crosstalk were greatly emphasized by the loading of the circuit. Some of the development problems in loading quadded cable are discussed in a recent paper by Mr. W. E. Mougey.[3]

3rd—The application of telephone repeaters to loaded cable circuits involved new problems. Owing to the increased length of circuit and the low transmission equivalent made possible by the use of repeaters, crosstalk and flutter conditions are more severe. Much closer limits for inductance and stability are also imposed on the loading coils.

4th—The recent development of the four-wire system with one-way repeaters has brought in certain additional requirements owing to the large difference in energy level of the circuits transmitting in opposite directions.

In the following there are considered the developments in loading coil design and in magnetic materials which have made it possible to meet the exacting requirements of a modern toll cable plant such as that referred to above.

In order to analyze more completely the problem of loading phantomed circuits, the requirements for this class of loading are given below:

### A. *Loading Requirements*

1. The desired inductance must be introduced into the phantom and the side circuits.

2. The effective resistance must be low for the inductive connection of windings which provides the loading effect, and practically the same as the ohmic resistance for the non-inductive connection.

3. The inductance and resistance values should be stable over a wide range of magnetizing currents and temperatures.

[2] Hysteresis Effects with Varying Superposed Magnetizing Forces, W. Fondiller and W. H. Martin, Trans. A. I. E. E., 1921, Vol. XL, p. 553.

[3] The Testing of Long Distance Telephone Cable During Installation, *Electrical Communication*, January, 1925.

4. The effective resistance change with frequency should be small in order to avoid serious frequency distortion.

5. The inductance value must be uniform, from coil to coil, to satisfy the requirement of impedance regularity of the circuit.

In order to define the limiting conditions, there are given below the crosstalk and noise requirements for an ideal phantom loading system.

*B. Crosstalk and Noise Requirements*

1. The effective resistance and self-inductance of the two line windings of either side circuit shall be equal to prevent phantom to side crosstalk.

2. There shall be no mutual impedance unbalance or admittance unbalance between line windings not associated with the same side circuit, to prevent phantom to side and side to side crosstalk.

3. There shall be no admittance unbalance to core, to adjacent shields, or to ground, of the two line windings of either side circuit, to prevent phantom to side crosstalk.

4. There shall be a symmetrical distribution of the direct admittances between the line windings of either side circuit, to prevent phantom to side crosstalk.

5. There shall be no unbalanced coupling, either electrostatic or electromagnetic, between coils, to prevent crosstalk between coils mounted in close proximity.

6. All line windings of a phantom group shall be mutually balanced, both electromagnetically and electrostatically, to all adjacent circuits other than those of the phantom group, and to ground, to prevent crosstalk and noise disturbance between the circuits of the given phantom group and outside circuits.

7. The balance conditions defined in 1-6 inclusive shall be maintained over a wide range of magnetizing currents and frequencies.

It should be observed in connection with the unbalances mentioned in 1-5 inclusive that any unbalance which gives rise to crosstalk may also cause noise in the circuit. In practice it has been found possible by suitable choice of materials and by design to approach closely these ideal requirements. As illustrating the extent to which this object has been accomplished, data are given later in the paper of actual crosstalk values obtained on commercially manufactured loading units of the Campbell-Shaw type.

In addition to the requirements relating particularly to crosstalk and noise, as already noted the toll cable coil must have low distortion in terms of its transmission-frequency characteristics, low modulation or flutter effect, adequate dielectric strength, and freedom from magnetization effects. It will be seen that the design of a loading coil embodying the above requirements at a moderate cost presents a problem of more than average difficulty. As illustrative of the scope of the developments which had to be undertaken in order to properly solve the loading coil problem, it is interesting to refer to some of the collateral problems which had to be solved because of their direct bearing on the loading coil problem. Among these may be cited—the development of machine generators (later—vacuum tube oscillators) as a source of voice frequency currents free from harmonics, the shielded impedance bridge, new magnetic materials, machinery for winding toroids, special types of permeameter, etc. It will be evident from these few illustrations that many years of physical research work have been necessary in order to carry the loading coil development to the point where it would meet present day requirements.

*Phantom Loading Apparatus*

Various methods of loading phantom circuits have been developed comprising 2-coil, 3-coil and 4-coil schemes. The selection of the preferred system depends on satisfying the operating requirements of a toll cable system with the least cost. There will first be described the 3-coil system invented by G. A. Campbell and T. Shaw,[4] which is the system that has been most widely used, and most completely satisfies the conditions laid down for a satisfactory loading system. In a paper entitled "Commercial Loading of Telephone Circuits in the Bell System,"[5] Mr. Gherardi referred briefly to the Campbell-Shaw loading coils. It is

[4] U. S. Patents 980921, 1911, Campbell-Shaw; 981015, 1911, Shaw.

[5] Trans. A. I. E. E., 1911, Vol. XXX, p. 1743.

interesting to note that the first commercially successful loading of phantom cable circuits was carried out in the United States using the Campbell-Shaw design of loading. This was in 1910 when the Boston-Neponset cable was installed by the American Telephone and Telegraph Company.

The general winding arrangement of the Campbell-Shaw loading coils and their connection to the lines is shown in Figure 4. The group of two side circuit and one phantom coil associated as in this figure is referred to for convenience as a "loading unit," and the two side circuits and the derived phantom circuit will be referred to as a "phantom group."

Considering first the side circuit coils, it will be seen from Figure 4 that there are two inner and two outer windings on each core. The connection of an inner winding in series inductively with the outer winding on the opposite half of the core forms a "line winding." With the arrangement of windings shown the side circuit current would magnetize the core in the same direction throughout. Under these conditions the side circuit coil loads the circuit similarly to the simple non-phantom circuit coil shown in Figure 1. When the phantom current traverses the side circuit coil, however, the current flows through the two lines of a pair in parallel, and the two line windings are thus connected non-inductively in parallel. If the phantom current were to flow through the windings of the loading coil shown in Figure 1, it would magnetize the two sides of the core in opposite directions and produce consequent poles. This would not only bring in serious losses, but also large crosstalk. The current in the phantom circuit flowing through the windings of the side circuit coils shown in Figure 4, however, produces practically no magnetizing effect on the cores owing to the intermeshed arrangement of the windings. Such coils may be used to effectively load the side circuits of a phantom group and in so far as the phantom circuit is concerned they introduce practically only the non-inductive resistance of the windings.

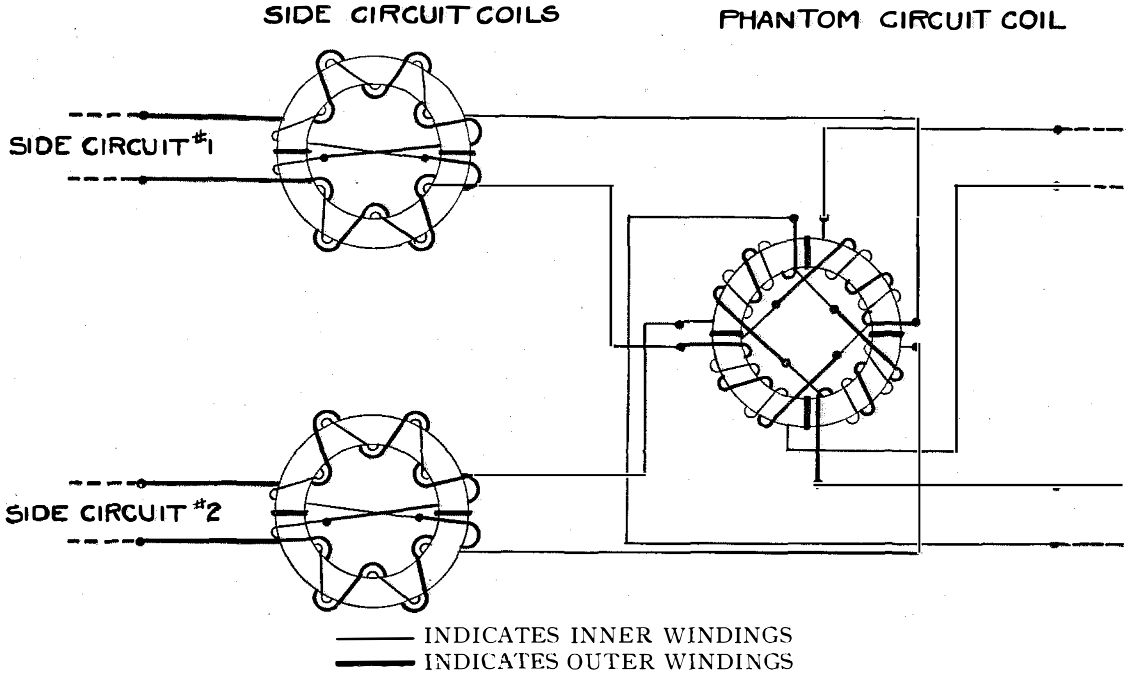


Figure 4—Campbell-Shaw Loading Unit Showing Arrangement of Windings

The loading of the phantom circuit itself is accomplished by means of an 8-winding coil as shown at the right in Figure 4. These windings are distributed uniformly over the core, there being an inner and outer winding on each quadrant. An inner winding on one quadrant is connected in series inductively with an outer winding on the opposite quadrant to form a line winding. It will be seen that with respect to the phantom current, the two line windings associated with one pair are connected in parallel inductively and the two pairs of line windings

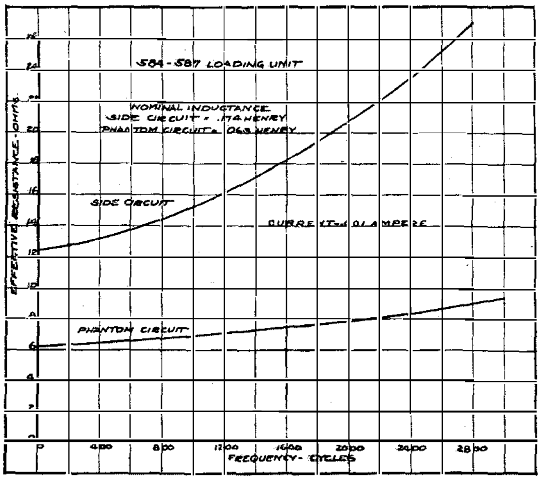


Figure 5—Effective Resistance-Frequency Characteristics of Nos. 584–587 Loading Unit

of the phantom group in series inductively, thus providing the desired loading in the phantom circuit. Currents flowing in either side circuit, however, produce very small magnetization in the core owing to the fact that the line windings of a pair are then connected in series non-inductively. The use of mutual inductance between the line windings of the loading coil for a given circuit leads to an efficient design, promotes an accurate winding balance, and at the same time makes for magnetic stability. On the other hand, the sub-division and intermeshing of the windings makes the side circuit loading independent of that of the phantom circuit, which is desirable from the standpoint of greater flexibility.

Table III shows some of the more important loading coils used for toll cable loading, and gives data regarding their characteristics. All of these coils have cores of compressed powdered iron.

The scheme of designation of the different loading systems is similar to that described in connection with Table I. Thus, the term H-44-25 designates a loading spacing of 6,000 feet using side circuit coils of 44 milhenry, and phantom coils of 25 milhenry inductance. The H-44-25 and H-174-63 loading systems are both used with 16-AWG and 19-AWG circuits.

Figure 5 shows the effective resistance-frequency characteristics for the loading unit consisting of the Nos. 584 and 587 coils.

In Table IV are given the important transmission characteristics of cable circuits loaded with the coils, the constants of which are given in Table III.

The choice as to the gauge of conductor and loading system is conditioned on a number of factors such as the character and volume of traffic involving switched or terminal connections, grade of service required, composition of circuits as to connection with open wire lines, etc. For instance, for circuits handling only terminal business, a single repeater could be used for handling connections 100 miles long on 19-AWG wires with H-174-63 loading. For a circuit 150 miles long, a 16-AWG pair with H-174-63 loading with a single repeater would be satisfactory. This grade of loading with other gauge is also suitable for longer circuits up to say 300 miles with an appropriate number

TABLE III

Loading for Toll Cable Circuits

| Designation of Loading | Code No. of Coils | Circuit | Electrical Characteristics of Loading Unit | | |
|---|---|---|---|---|---|
| | | | Average D.C. Res. Ohms | Average Eff. Res. Ohms at 1,000 Cycles | Nominal Induct. Milhenrys |
| H-44-25 | 590 | Side | 4.0 | 4.6 | 44 |
| | 591 | Phantom | 2.0 | 2.3 | 25 |
| H-174-63 | 584 | Side | 12.4 | 15.2 | 174 |
| | 587 | Phantom | 6.2 | 6.8 | 63 |

Note: Resistance values apply at the end of the cable stub.

of repeaters. For the longer connections, as has been pointed out by A. B. Clark,[6] high velocity circuits have been found advantageous in reducing echo effects and transients. Thus, for very long cables of the order of 1,000 miles (1600 km.) the H-44-25 loading is to be preferred. Circuits from about 300 to 700 miles in length could be handled to advantage by repeatered 16-AWG cable with H-44-25 loading. Still longer circuits up to 1,000 or 1,500 miles would be made up principally of 4 wire 19-AWG repeatered circuits with H-44-25 loading.

TABLE IV

TRANSMISSION CHARACTERISTICS OF LOADED TOLL CABLE CIRCUITS

| Cable Conductors | | Loading | | | | Cut-off Frequency Cycles | Attenuation TU/Km at 1,000 Cycles |
|---|---|---|---|---|---|---|---|
| Circuit | Gauge | Capacity per Km. | Code No. | Induc. Mil-henrys | Spacing | | |
| Side Circuit | No. 16 AWG (1.3 mm.) | .039 mf. | 584 | 174 | 6,000 ft. | 2800 | .10 |
| Phan. Circuit | No. 16 AWG (1.3 mm.) | .062 mf. | 587 | 63 | (1.83 Km.) | 3700 | .10 |
| Side Circuit | No. 16 AWG (1.3 mm.) | .039 mf. | 590 | 44 | 6,000 ft. | 5600 | .16 |
| Phan. Circuit | No. 16 AWG (1.3 mm.) | .062 mf. | 591 | 25 | (1.83 Km.) | 5900 | .13 |
| Side Circuit | No. 19 AWG (.91 mm.) | .039 mf. | 584 | 174 | 6,000 ft. | 2800 | .17 |
| Phan. Circuit | No. 19 AWG (.91 mm.) | .062 mf. | 587 | 63 | (1.83 Km.) | 3700 | .17 |
| Side Circuit | No. 19 AWG (.91 mm.) | .039 mf. | 590 | 44 | 6,000 ft. | 5600 | .30 |
| Phan. Circuit | No. 19 AWG (.91 mm.) | .062 mf. | 591 | 25 | (1.83 Km.) | 5900 | .25 |

*Crosstalk*

In considering the disturbing currents in the circuit, the term crosstalk or overhearing has been used to indicate a disturbing current induced by a speech current in the cable; noise refers to a disturbing current produced in the speech circuit due to induction from other than speech currents. In general, in a well designed loaded cable system the noise factor will be less important than the crosstalk, except in cases of unusually severe exposure.

In long toll cable circuits it is very essential that the crosstalk or overhearing between talking circuits be kept to a very low value in order to provide the requisite high grade of service. This necessitates the utmost refinement in manufacture of the loading coils in order to make it possible to meet these exacting requirements.

Two general methods of approach to this problem are possible. First, to design and manufacture the loading coils, cable, etc., to as narrow limits of crosstalk as is commercially practicable, and to depend on the further balancing at time of installation merely to secure added refinement in the final crosstalk characteristics of the circuit. Second, to design and manufacture the loading and cable equipment with only moderately good precision as regards crosstalk balance and depend on auxiliary balancing means applied at the time of installation to correct the large unbalances contributed by the coil and cable apparatus.

Both methods have been used to some extent by different manufacturers. It has been the experience of the Western Electric Company however, that more satisfactory final results are achieved by following the first method and it is now the standard practice of this Company to use the utmost refinement in the manufacture of the loading coils so that the coils when shipped from the factory will have satisfactory low crosstalk for service.

The results of factory adjustments for crosstalk are given in Table V. It will be seen from this table, that, due to the improvements in manufacture and in adjustment means, it is now commercially possible to produce phantom

[6] Telephone Transmission over Long Cable Circuits, Trans. A. I. E. E., Vol. XLII, 1923, p. 86, *Electrical Communication*, Vol. I, Feb., 1923.

loading units having average phantom to side crosstalk corresponding to 90 TU and maximum crosstalk corresponding to 76.5 TU. These crosstalk values are equivalent to $\beta l$ 10.3 average and $\beta l$ 8.8 maximum respectively, which meet the exacting requirements of even the longest repeatered cable circuits installed up to the present time.

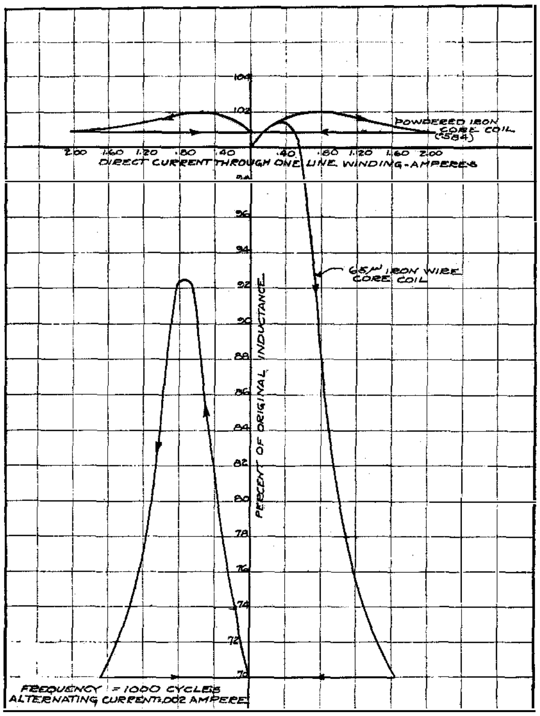


Figure 6—Magnetization Characteristics with Superposed D.C. of Powdered Iron Core and Iron Wire Core Coils

*Magnetic Stability*

Experience shows that induction from neighboring power circuits, electrical storms or other causes may impress on the cable conductors foreign currents of the order of magnitude of two amperes. It is very essential that the inductance depart only slightly from the nominal value when used on repeatered circuits, in order not to affect the balance between the line and the network with corresponding reaction on the allowable repeater amplification. Figure 6 illustrates the magnetization characteristic of the No. 584 coil with respect to superposed D. C. Figure 7 shows the residual effect of D. C. magnetization. These curves indicate the high stability of the loading coil with respect to magnetizing effects. For purposes of comparison these figures also illustrate the corresponding characteristics of the wire core loading coils which were standard before the advent of vacuum tube repeaters.

In order to secure the high magnetic stability illustrated by Figure 7, it was necessary to develop a radically new magnetic material for the loading coil cores. The general characteristics of this material have been described in a paper by Speed and Elmen[7] and further data on the magnetization and flutter characteristics are contained in a paper to which reference has already been made.[8] While consideration has been given to the use of finely divided iron for loading coil cores prior to the work of Speed and Elmen, no practical results had come from this early work. For instance, investigations made by Dolezalek in Germany, as disclosed by his U. S. Patent No. 716,206 12/16/02, considered the use of finely divided iron. No practical results ensued, however, until the invention of the compressed powdered iron core described in the Speed-Elmen paper which,

[7] Magnetic Properties of Compressed Powdered Iron, Trans. A. I. E. E., 1921, Vol. XL, p. 1321.

[8] Fondiller and Martin, *Loc. cit.*

TABLE V

CROSSTALK DATA ON TOLL CABLE LOADING UNITS

| Type of Loading | Code No. of Coils | Crosstalk—TU at 800 Cycles | | | |
|---|---|---|---|---|---|
| | | Phantom to Side | | Side to Side | |
| | | Average | Maximum | Average | Maximum |
| H-174-63 | 584–587 | 90 | 76.5 | 96 | 80 |
| H-44-25 | 590–591 | 90 | 76.5 | 96 | 80 |

as is clearly pointed out in a recent article by Dr. Walter Ehlers[9] gives the first comprehensive treatment of this subject published.

In the production of iron dust rings from which the cores are built up, extreme care is used in order to secure uniform properties. By

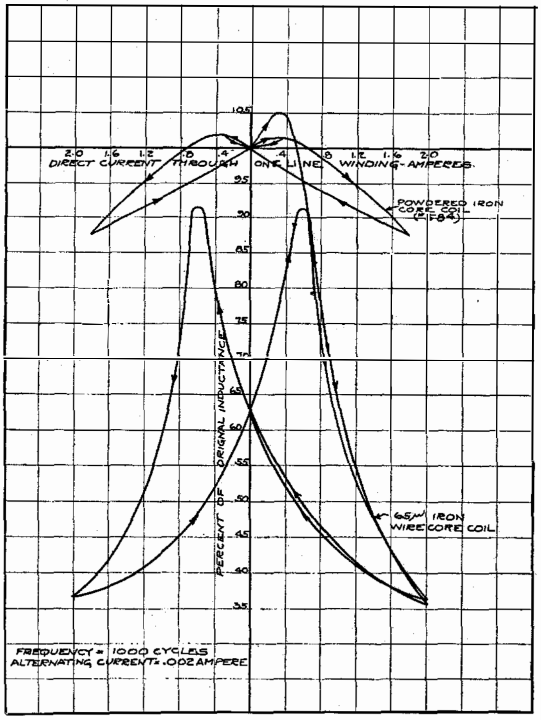


Figure 7—Residual D.C. Magnetization Characteristics of Powdered Iron Core and Iron Wire Core Coils

suitable control of the raw material and of the insulating processes applied to the powdered iron, the initial permeability is kept within narrow limits. Careful tests are made on the individual rings in a special testing device which enables the maintenance of a uniformly high quality by checking the permeability and loss characteristics of the core rings. A normalizing treatment is applied to the finished core in order to further reduce the small changes which would otherwise be liable to occur during the manufacturing operations or service life of the coil.

As a result of the scientific work carried on over a period of years by the Western Electric Company, it has thus been possible to produce a magnetic material which, while comparing favorably in cost with the older forms of fine wire or laminated core, far excels these materials as regards magnetic stability and low core losses.

*Olsson-Pleijel Loading System*

Having described the 3-coil Campbell and Shaw loading system, reference will be made to the 2-coil scheme of Olsson and Pleijel,[10] and the 4-coil scheme due to Ebeling.[11] Considering first the 2-coil scheme, the phantom loading effect is obtained by superposing two simple Pupin coils, one above the other, so poled that when the phantom current flows through their windings the leakage flux from one coil will have a return path through the core of the other coil. This is assisted by the use of magnetic yokes connecting the cores as shown schematically in Figure 8. The Olsson-Pleijel arrangement is a very interesting one and offhand would appear to have advantages in the direction of low cost, owing to the reduced number of coils. This expectation is, however, dissipated on more careful examination. It will be evident that owing to the fact that the yoke

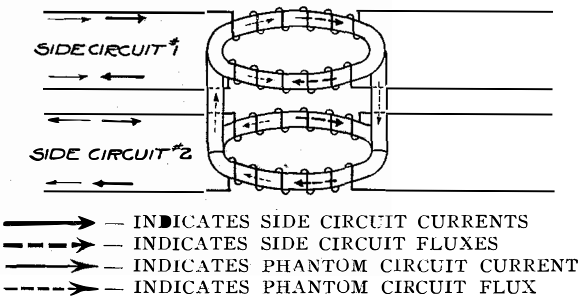


Figure 8—Diagram of Olssen-Pleijel Two Coil Loading Unit

has appreciable thickness, there will be a tendency to very high crosstalk from side circuit to side circuit. In addition, owing to the necessarily imperfect magnetic joints between the cores and yokes, considerable magnetic leakage takes place which has the two-fold disadvantage of increasing the effective resistance due to losses in the containing case and causing crosstalk between the loading of one quad and ad-

[9] "Verlust Freies und Magnetisch Stabiles Eisen Für Ton und Hochfrequenztechnik," Zeitschrift Für Technische Physik., 1924, Vol. 5, No. 12, page 589.

[10] U. S. Patents Nos. 1148792,1167654 and 1196277, 1916 and 215702, 1917.

[11] U. S. Patent No. 960856, 1910.

joining loading units connected in other circuits in the cable. In a recent article,[12] Mr. E. Schürer, Chief Engineer of Felten and Guilleaume, has described the steps taken to develop the Olsson and Pleijel loading unit in commercial form. It is evident from this description that it has been found necessary to resort to extreme precautions as regards shielding and to employ numerous auxiliary windings in order to reduce crosstalk.

Further, owing to the necessity of localizing each line winding over one part of the core instead of intermeshing the windings, the coil is liable to develop serious impedance unbalance in service due to the fact that the two line windings may carry widely different currents as may be produced by accidental grounds, crosses, etc., or when exposed to high voltage power circuit induction. Such unbalances would tend to produce excessive phantom to side crosstalk, as well as to aggravate side to side crosstalk. These unbalances due to residual magnetization effects, may be minimized by the use of powdered iron cores, but even in this case a different magnetic experience of the two halves of the core may produce serious crosstalk owing to the localization of the line windings. The seeming simplicity of the Olsson and Pleijel loading unit is, therefore, misleading in that this form of loading unit is inherently incapable of satisfactorily meeting all of the requirements imposed on loading coils for repeatered toll cables. In the United States, where the American Telephone and Telegraph Company carefully studied the relative merits of the Campbell-Shaw system and the Olsson-Pleijel system, it was decided after careful investigation that the Campbell-Shaw system had important features of superiority over the latter system. The consideration of the use of the Olsson-Pleijel system of the form shown in Figure 8 was therefore laid aside.

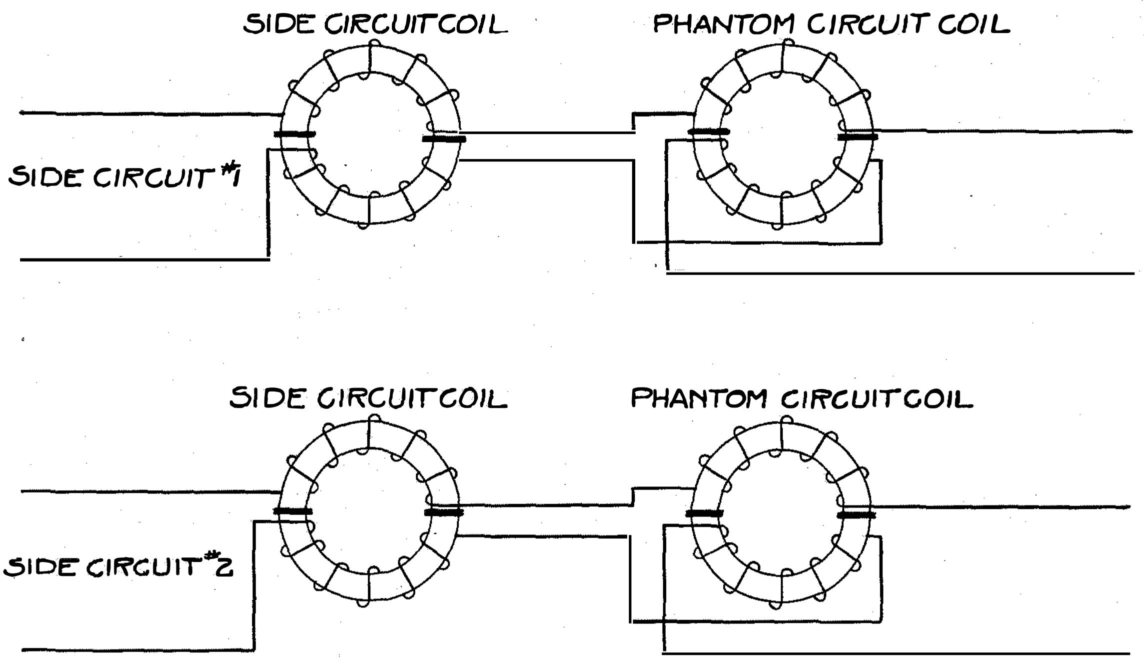


Figure 9—Diagram of Original Ebeling Four Coil Loading Unit

*Ebeling Loading System*

The Ebeling system of 4-coil loading as originally disclosed is illustrated in Figure 9. It will be noted that each coil had but two windings, one pair loading the side circuits in the usual manner and the other pair loading the phantom circuits by reversing the connection of one of the windings with respect to the line. Owing to the formation of magnetic poles and

[12] Aufbau und Praktische anwendungen der Pleijelspule Das Fernsprechen Im Weitverkehr Reichspostministerium, Berlin, 1923.

the consequent large leakage flux, the losses in the iron containing case for the non-inductive connection of the side circuit or phantom loading coils would tend to be excessive. It is understood that an intermeshed construction was later adopted similar to that shown for the side circuit coils of the Campbell-Shaw system in Figure 4. The side circuit loading under these conditions would be practically the same as in the Campbell-Shaw system. As regards the phantom circuit, however, there is an important difference in that there is no mutual inductance between the line windings in one side circuit and those in the other side circuit of the phantom loading coils. Thus, there is a liability to unbalance of the phantom circuit due to a difference in magnetic experience of the cores of loading coils in the two sides of the phantom. This would make the phantom circuit liable to noise troubles and to crosstalk from the circuits in other quads. The absence of mutual inductance also has the disadvantage of making the pair of coils used for loading the phantom circuit larger and more expensive than the single 4-winding coil used in the Campbell-Shaw system. The attempt to apply the Ebeling loading system with wire cores in the Swiss cable between Bellinzona and Chiasso proved a failure.[13] So far as the side circuits are concerned, the use of the improved powdered iron core makes the side circuit loading satisfactory. As regards the phantom circuit, however, the liability to crosstalk and noise unbalance to circuits in other quads is even greater than that pointed out for the side circuit in the Olsson-Pleijel loading system.

*Loading Coil Cases*

Considerable study has been devoted to the casing of loading coils, as in many instances the cases are installed in manholes that are occasionally flooded, and it is of the utmost importance to protect the loading coils from the entrance of moisture. Cast iron cases with special seals have been developed, many of which have been in service for 15 to 20 years under the most severe conditions, demonstrating the efficacy of the design. The loading coils before being placed in the containing case are thoroughly

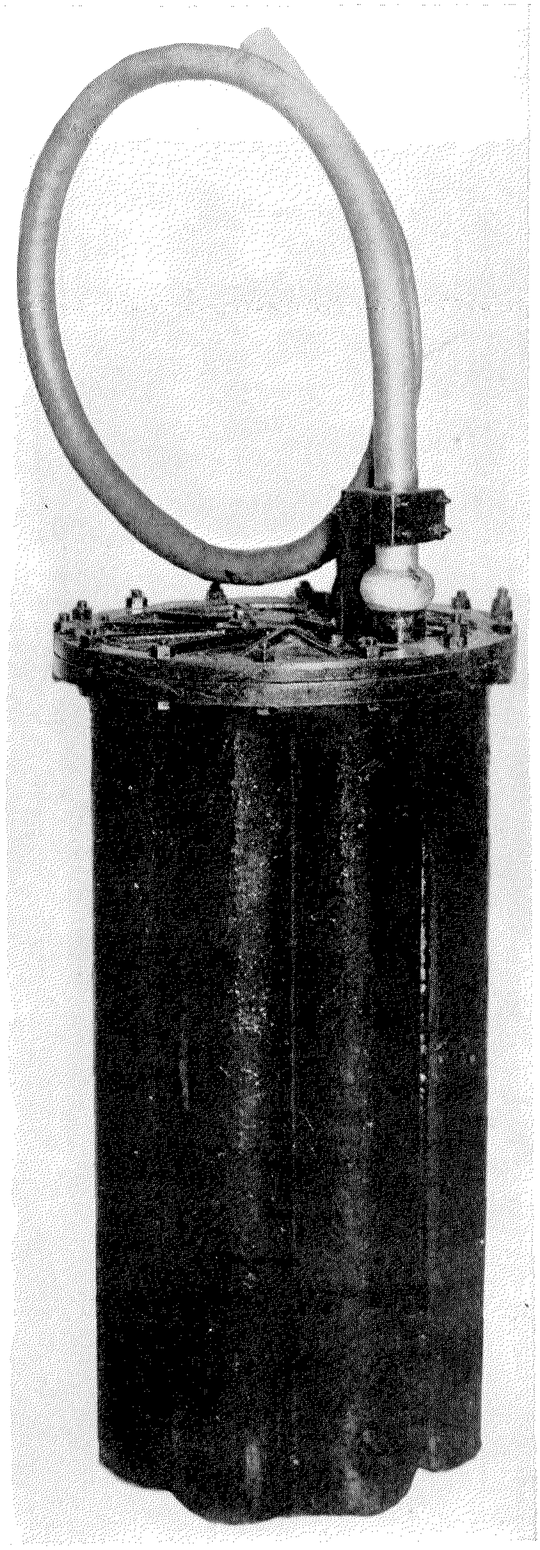

Figure 10—Loading Coil Case Containing 300 Coils

[13] Das Fernkabel, Heft 7, p. 42, Nov., 1924. Amerikanische und Deutsche Technik des Fernsprechweitverkehrs. K. Höpfner and K. Dohmen.

dried, impregnated under vacuum with a moisture-proofing compound and carefully adjusted to meet the electrical requirements. They are then assembled on wooden dowels and connected to conductors leading out through a lead sheath. This short length of lead covered

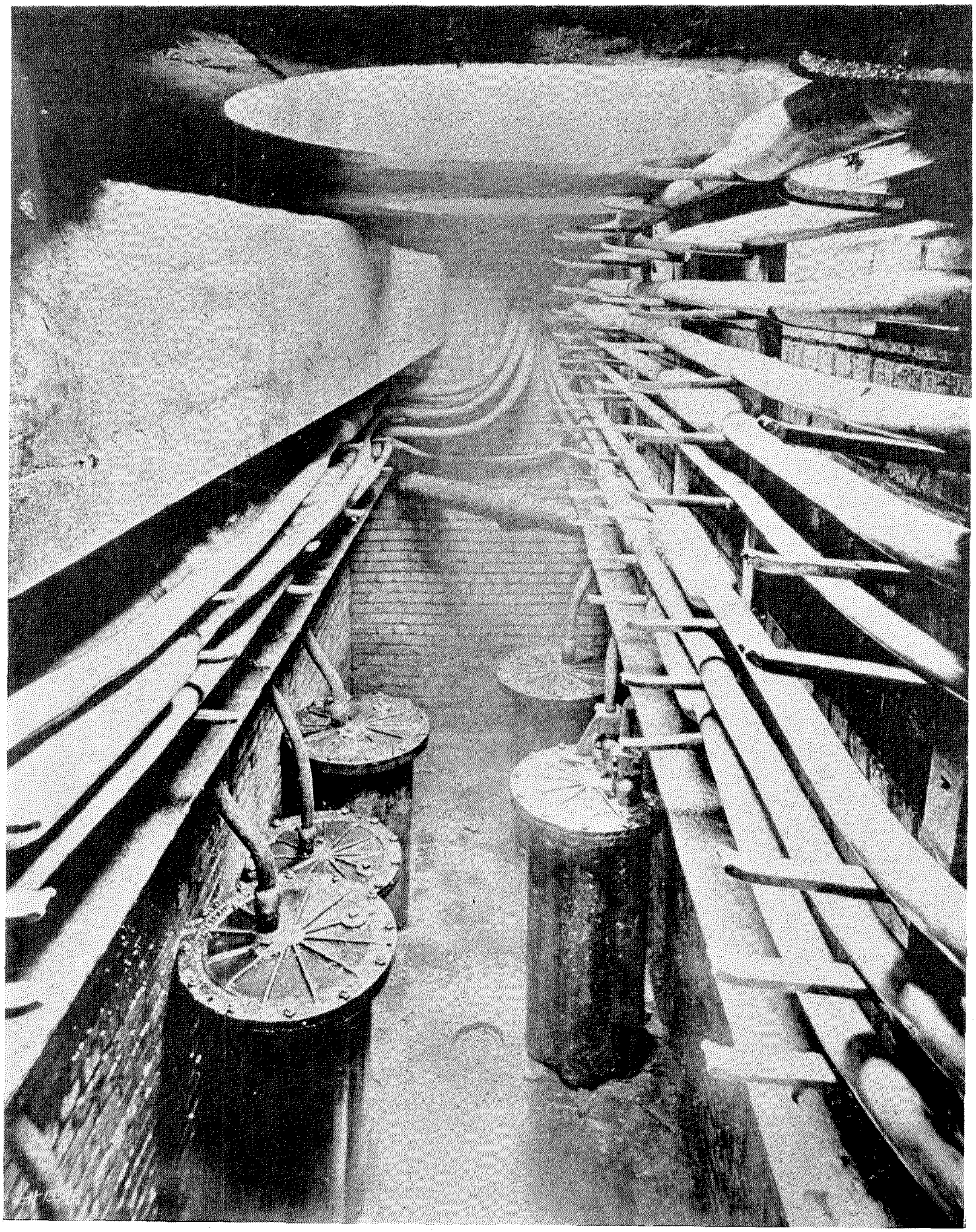

Figure 11—Loading Coil Cases Installed in Underground Vault

conductors will be referred to as the "stub cable." The coil dowels are assembled in the case, each in a separate crosstalk-proof partition, and the case is then filled with a moisture-proofing compound.

In the case of loading coils for quadded cable, the cross connections between the side circuit and the phantom coils are made in the loading pot and the stub cable contains only the conductors to be spliced to the east-bound and west-bound conductors in the line cable. The lead-sheathed stub cable is brought through the cast iron cover of the loading coil case through a brass nipple, and the cover bolted to the case. A double seal is provided between the cover and the wall of the case for the purpose of preventing the entrance of moisture at this vulnerable point. A wiped joint is made between the lead sheath of the cable and the brass nipple. A final complete filling of the case with moisture-proof compound is made through pipe plug holes in the cover. Special care is taken to protect the joint between the nipple and the stub cable from undue strains in shipment by a protecting bracket. This is shown in Figure 10, which illustrates a case containing 300 No. 602 loading coils. The east and west conductors in the stub cable are suitably designated by special colored binders, thus facilitating the selection of the conductors in splicing the loading coils into the cable. Owing to the simplicity of the design the connection between the line cable and the stub cable is readily made by the cable splicer. Figure 11 shows a typical loading vault in the New York metropolitan district, and gives an indication of the number of loading coils necessary to meet the conditions. At the present

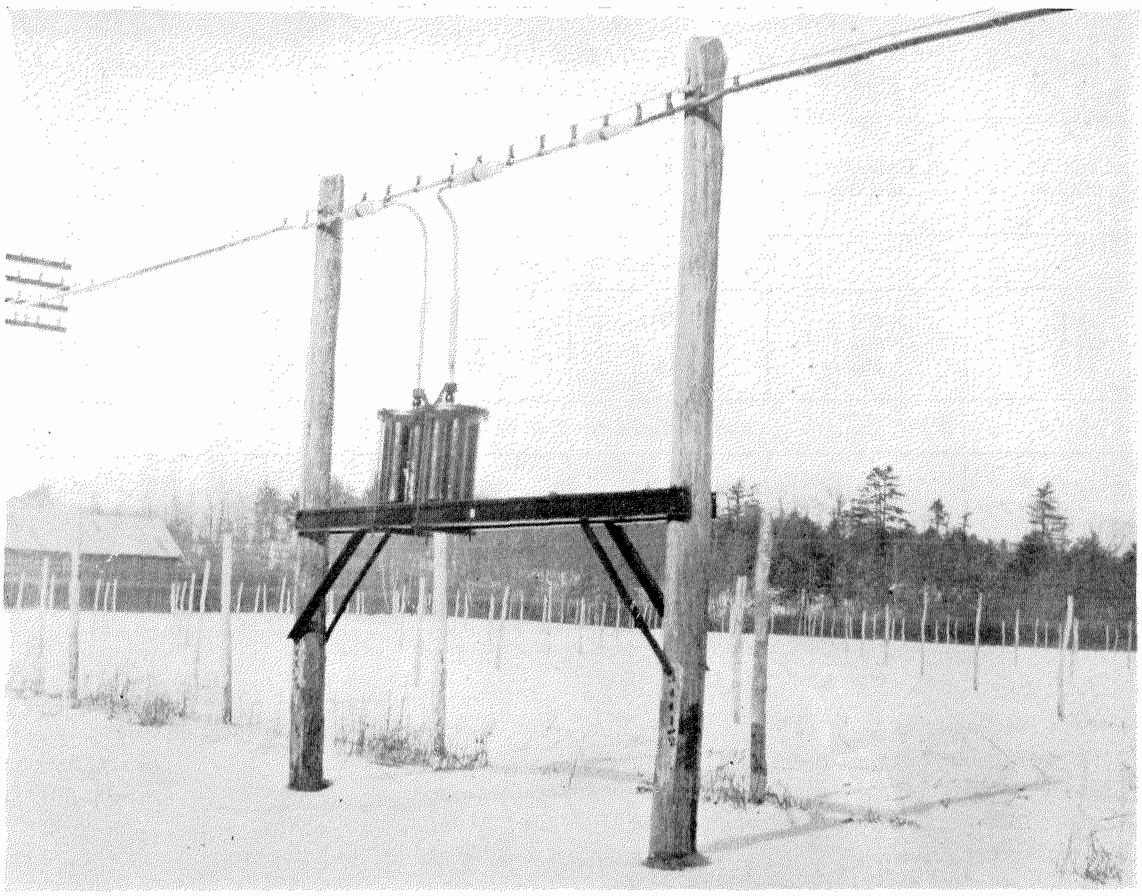

Figure 12—Loading Coil Cases Installed on Pole Fixture and Spliced to Aerial Cable

time there are 5 cases in the vault containing an aggregate of 490 coils. Ultimately, a total of 3,600 loading coils will be installed in this manhole, though some of the larger vaults in this district are built to accommodate a total of 30 large cases containing a total of 9,000 coils.

With the increasing installation of aerial cables, owing to the lower cost of construction, it has been necessary to develop methods of mounting loading coil pots on the pole. For this purpose, pole fixtures have been designed capable of supporting the desired number of coil cases. A typical installation of aerial cable loading is shown in Figure 12. Experience in the United States and in Great Britain has indicated that loading coils installed in cases of the general design exhibited by the illustrations have given very satisfactory service.

Table VI lists some typical loading coil cases, and gives data regarding their size, weight, etc.

Of the three systems of phantom loading considered above, the Campbell-Shaw system has been employed to the greatest extent as it meets the exacting requirements of long repeatered toll cables most satisfactorily. As an indication of the large scale on which the Campbell-Shaw loading system has gone into use the following approximate figures are cited. Up to January 1, 1925 about 570,000 Campbell-Shaw loading coils were installed in the United States and 348,000 in the various countries of Europe. According to the best information available this is about ten times the combined total of all other phantom loading coil designs which have gone into commercial use. To illustrate some of the important cables using the Campbell-Shaw coils having compressed powdered iron cores developed by the Western Electric Company, there may be cited the New York-Chicago cable, the Stockholm-Goteberg cable, the Milan-Turin-Genoa cable, the London-Glasgow cable, and the Paris-Strasbourg cable, the latter two being still under construction.

TABLE VI

LOADING COIL CASES

| Code No. of Case | Code No. of Coils | Quantity per Case | Overall Dimensions—Inches | | Approx. Weight in Pounds |
|---|---|---|---|---|---|
| | | | Diameter | Height* | |
| *Cases Designed for Local Cable Loading* | | | | | |
| 23-U | 602 | 100 | 25¾ | 31½ | 1180 |
| 23-W | 602 | 200 | 25¾ | 50½ | 1800 |
| 43-B | 602 | 300 | 29½ | 52¼ | 3100 |
| *Cases Designed for Toll Cable Loading* | | | | | |
| 40-C | 584, 587 or 590, 591 | 42<br>21 | 25¾ | 38 | 1565 |
| 40-A | 584, 587 or 590, 591 | 70<br>35 | 25¾ | 56 | 2335 |
| 41-A | 584, 587 or 590, 591 | 90<br>45 | 29½ | 56 | 2905 |

* This dimension does not include the height of the clamping bracket.

The researches of scientific workers in many lands have brought out far reaching improvements in long distance telephony. The great progress already made foreshadows new improvements, not only in the design of loading coils, but also in the cable and the telephone repeaters. New improvements in magnetic materials may be expected to improve the efficiency as well as to reduce the size and cost of loading coils. The development of a practical form of echo suppressor[14] gives further

[14] Echo Suppressors for Long Telephone Circuits by A. B. Clark and R. C. Mathes, *Jour. A. I. E. E.*, June, 1925, *Electrical Communication*, Vol. IV, No. 1, July, 1925.

impetus to the extension of the length of repeatered and loaded cable circuits. A probable reaction will be in the direction of using, for very long circuits, a heavier weight of loading than that now in use as the reduction of the increased echo effects in the lower velocity circuits will enable a greater reduction in line attenuation by means of loading. This will, in turn, impose more severe requirements on the loading coils as regards power losses and crosstalk characteristics. There is, indeed, a broad field for further research when one considers the manifold aspects of the long distance telephone transmission problem.

# Echo Suppressors for Long Telephone Circuits*

By A. B. CLARK

*Department of Development and Research, American Telephone and Telegraph Company*

R. C. MATHES

*Bell Telephone Laboratories, Incorporated*

*Synopsis:* A device has been developed by the Bell System for suppressing "echo" effects which may be encountered under certain conditions in telephone circuits which are electrically very long. This device has been given the name "echo suppressor" and consists of relays in combination with vacuum tubes, which are operated by the voice currents so as to block the echoes without disturbing the main transmission.

This paper gives a brief description of this device, together with a discussion of its possibilities and limitations. A number of echo suppressors have been operated on commercial telephone circuits for a considerable period so that their practicability has been demonstrated.

## INTRODUCTION

IN designing telephone circuits which are electrically very long, an important problem is presented by the necessity of avoiding serious "echo" effects. Echo effects are caused by reflections of voice waves which take place whenever electrical irregularities are encountered in telephone circuits. The effects produced are very similar to echoes of sound waves. Some of the reflected waves return to the receiver of the talker's telephone so that if the effects are severe, he may hear an echo of his own words. Other reflected waves enter the receiver of the listener's telephone and, if severe, cause the listener to hear an echo following the directly received transmission.

Reflections of voice waves occur in all practical telephone circuits. It is only in telephone circuits of such length as to require a number of repeaters, however, that echo effects become serious. The fact that the circuits are electrically very long makes the time lag of the echoes appreciable. At the same time, the telephone repeaters overcome the high attenuation of these long circuits and, consequently, make the echoes louder. The seriousness of the effect is a function both of the time lag and the volume of the echoes relative to the direct transmission.

A brief discussion of these echo effects was given in a paper[1] presented before this Institute about two years ago, and in a later paper[2] some examples of their relative effects in practical telephone circuits were given. In these papers the importance of keeping electrical irregularities within proper limits was pointed out as was also the advantage gained by using circuits having a high velocity of propagation so that the lag of the echoes is reduced.

As a supplement to these methods, a device to which has been given the name "echo suppressor" was developed by the Bell System, along lines suggested by John Mills.[3] In all practical telephone circuits involving more than a single repeater there are points where the transmission in the two directions passes through two separate paths. At these points the direct transmission passes through one path while only reflected currents or echoes pass through the other. The echo suppressor is located at one of these points. In this device, the voice currents, with the help of vacuum tubes, are caused to actuate relays which cut off the echoes in the return path without disturbing the other path through which passes the main transmission.

This paper, after briefly reviewing the nature of echo effects in four-wire circuits, explains, in a general way, how an echo suppressor functions on such a circuit. The four-wire echo suppressor is then described together with some variations in its design for use under special conditions and with other circuits. This is followed by a discussion of the possibilities and limitations of echo suppressors, both on four-wire and other types of telephone circuits.

## REVIEW OF NATURE OF ECHO EFFECTS IN FOUR-WIRE CIRCUIT

Figure 1 illustrates the way echo currents may be set up and circulate in a four-wire circuit. In this figure, *a* shows a four-wire circuit in dia-

* Presented at the Spring Convention of the A. I. E. E., St. Louis, Mo., April 13-17, 1925.

[1] "Telephone Transmission over Long Cable Circuits" by A. B. Clark, Transactions A. I. E. E., Vol. XLII, page 86; and *Electrical Communication,* Vol. I, February, 1923.

[2] "Telephone Transmission over Long Distances" by H. S. Osborne, Transactions A. I. E. E., Vol. XLII, page 984; and *Electrical Communication*, Vol. II, October, 1923.

[3] U. S. Patent No. 1,434,790, John Mills, "Two-Way Transmission with Repeaters." Issued Nov. 7, 1922.

grammatic form. The squares at the extreme right and left are intended to represent the telephone sets used by two subscribers at the terminals *W* and *E*. The squares marked *N* represent electrical networks which simulate or balance, more or less perfectly, the impedances of the two telephone lines terminating in the

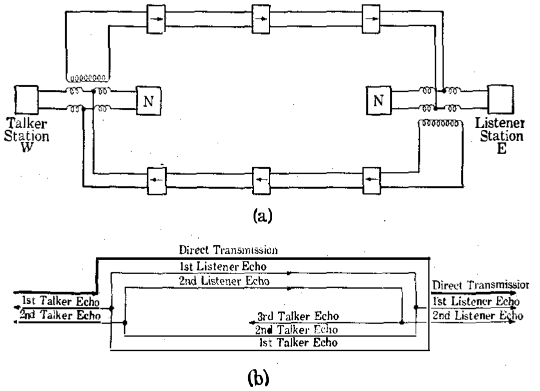


Figure 1—Echoes in Four-Wire Circuit

instruments at *W* and *E*. In the four-wire circuit, the squares with arrows represent one-way repeaters. At each terminal the two separate one-way circuits comprising the four-wire circuit are joined together by means of the familiar balanced transformers. When *W* talks, the transmission passes directly to *E* over the upper pair of wires in the four-wire circuit, while, when *E* talks, the direct transmission passes over the lower pair of wires.

Below the diagram of the four-wire circuit is given another diagram *b* showing the path of the direct transmission as well as the paths of the echoes which are set up when *W* talks to *E*. The heavy line in the diagram represents the path of the direct transmission through the upper pair of wires in the four-wire circuit. In a practical four-wire circuit it might require, say, 0.05 second for the voice currents to make this journey. This would be the case if the four-wire circuit were 1000 miles (1600 km.) long in cable with extra-light loading—coils of 0.044 henry spaced 6000 feet (1.8 km.) apart. Cable circuits loaded in this way have a velocity of propagation of about 20,000 miles (32,000 km.) per second.

When the voice currents reach the distant end of the four-wire circuit, the larger part goes to the listener at *E*. If the balance between the line and network at the distant terminal is not perfect, however, a portion of the currents will travel back over the lower pair of wires toward *W* as an echo. This echo will, in the case assumed, reach the receiver of the telephone at station *W* 0.1 second after the original voice wave is impressed on the line at that station. The path of this echo is labeled "1st Talker Echo." It is evident that if this echo is loud enough that it may seriously distract the talker.

If the balance between the line and the network at Station *W* is also not perfect, part of this first echo will travel back over the upper pair of wires to Station *E*, the path of this echo being labeled "1st Listener Echo." The listener at *E* will hear this echo, if strong enough to be audible, 0.1 second after he hears the direct transmission. Evidently, if this echo is sufficiently loud as compared to the direct transmission, it will cause difficulty in understanding.

When the "1st Listener Echo" arrives at the end of the four-wire circuit, there is still another reflection of part of the current which occurs producing the "2nd Talker Echo."

This process is repeated, producing successive echoes which are received at both terminals *W* and *E* as indicated, the successive echoes getting weaker and weaker.

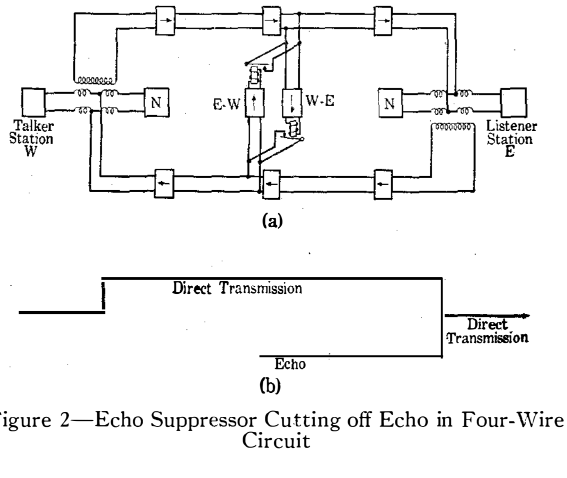


Figure 2—Echo Suppressor Cutting off Echo in Four-Wire Circuit

## Action of Echo Suppressor on Four-Wire Circuit

An echo suppressor will now be applied to the four-wire circuit and consideration given to its action and to its effect on the echoes. Figure 2 shows a four-wire circuit which it will be assumed is exactly like the one shown in Figure 1, with the exception that an echo suppressor has been applied to it. As before, the diagram *a* shows the four-wire circuit, while, below this, another diagram *b* shows the paths of the direct transmission and of the echo.

In Figure 2*a* the echo suppressor is shown in very simple diagrammatic form. It will be described later in detail. For the present it is sufficient to explain that the echo suppressor consists of two similar high-impedance vacuum tube amplifier-detectors bridged across the two sides of the four-wire circuit, each amplifier-detector having associated with it a relay which operates whenever alternating voltage of sufficient strength is impressed across the input. The operation of either relay places a short circuit across the side of the four-wire circuit opposite to the one to which the input of its particular amplifier-detector is connected. This short circuit blocks the transmission flowing in one side of the four-wire circuit and, at the same time, renders the other amplifier-detector inoperative.

Normally, the contacts of the two relays are open, so that talking may be done in either direction over the circuit. When *W* begins to talk, the condition illustrated in the figure is produced. *W*'s voice currents, when they reach the middle of the circuit, cause the relay associated with amplifier-detector *W-E* to operate, thus placing a short circuit across the lower pair of wires in the four-wire circuit. The direct transmission from *W* to *E* is not affected at all in passing on to Station *E* where it is heard by the listener. The echo, which starts back from Station *E*, travels toward Station *W* as far as the point where the echo suppressor is connected to the circuit. It is stopped there, however, by the short circuit which the echo suppressor has applied.

In the same way, when *E* talks, his voice currents actuate the amplifier-detector marked *E-W* and apply a short circuit to the upper pair of wires, thus preventing the passage of the echo current around the circuit.

The circuit shown in Figure 2*a* is one of the more convenient for satisfying the fundamental operating conditions of an echo suppressor. These may be stated as follows: When no one is talking, free paths should exist for transmission in either direction and each suppressing relay should be ready to act at the passage of speech over the side of the circuit with which it is associated. When speech passes in one direction over the circuit the resulting operation of the corresponding half of the suppressor should not only interrupt the continuity of the opposite side of the circuit, but at the same time prevent the other half of the suppressor from functioning. The latter condition is desirable as otherwise the returning echo might have enough energy at times to operate the opposite part of the suppressor circuit and so interrupt the direct transmission. Outside of this restriction the selection of the points from which the echo suppressor input currents are derived and the points at which the relay control functions are applied is governed only by such considerations as economy of apparatus and convenience. In general, it is the more economical arrangement to have a single relay, which interrupts the path through which the echoes return, also remove the speech input from the suppressor by such a relative association of parts as shown in Figure 2*a*.

It will be noticed that, as a finite time is needed for the switching operation, there is a possibility, if the two subscribers begin talking simultaneously, of both halves of the suppressor being operated together and remaining operated, with both sides of the circuit cut off, for a time equal to the release time of the relays. However, for the times of operation and release, which are found desirable from other considerations, it has been found that no apparent difficulty has been caused by this effect.

Because of the fact that an appreciable time is required for the voice currents to travel, it will be seen that exceedingly fast operation of the relays is not necessary. In the example given, if it is assumed that the echo suppressor is connected to the circuit at its midpoint, the echo requires 0.05 second to reach the point where the short circuit is applied, after the voice currents reach the input of the amplifier-detector. The echoes will be cut off by the relays, therefore, even if the latter require as long as 0.05 second for operation. If the echo suppressor is nearer to the end of the four-wire circuit this operating time would need to be somewhat shorter. In practical four-wire circuits it is seldom that an operating time shorter than about 0.02 second is required. It is an easy matter to secure this speed of operation with standard telephone relays.

The diagram also shows that, in order to completely cut off the echo, the echo suppressor relay must not open, after talk ceases, until the complete train of echoes has reached the point where the short circuit is applied. In the example given, the length of time required to reach the point where this relay applied the short circuit after the voice currents pass the input of the amplifier-detector is 0.05 second. It is seldom that this lag is greater than 0.1 second in practical four-wire circuits.

It is seen from the above two paragraphs that it is desirable for a four-wire echo suppressor to possess a moderately short operating time and a longer releasing time. How this is accomplished will be described in what follows.

## Description of Four-Wire Echo Suppressor

In Figure 3 is shown a circuit diagram of one-half of the echo suppressor, which is shown complete but in less detail in Figure 2*a*. It consists of two vacuum tubes operating in tandem, the first functioning as an amplifier and the second

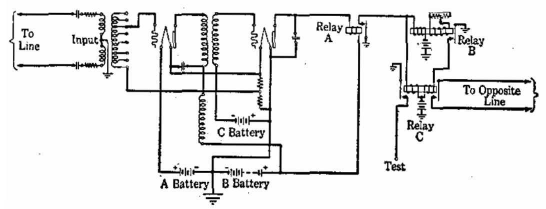


Figure 3—Circuit Diagram of One-Half of a Four-Wire Echo Suppressor

as a combined amplifier and detector. As was shown in Figure 2*a* the voltage impressed on this amplifier-detector combination is derived from speech currents passing over one side of the circuit while the relay controlled by this combination short-circuits the other half of the circuit.

The voltage input to the amplifier tube is supplied through a transformer which is broadly tuned by series condensers to produce a circuit efficient at the more important voice frequencies but inefficient at other frequencies, particularly below 500 cycles per second. The circuit thus functions to minimize the effect of noise currents on the operation of the relays. Likewise, in the interstage transformer coupling, emphasis has been placed on securing the maximum voltage step-up to the detector grid in this same frequency region. To avoid any harmful reaction upon the transmission characteristics of the main circuit which might result from bridging on an input circuit whose impedance varies so greatly over the speech frequency range, this circuit is arranged to have a high impedance. The input transformer is also provided with a series of taps on one of the windings, thus affording a simple means of varying the sensitivity of the device.

The detector tube is operated with a sufficiently large negative grid potential to reduce its space current to zero, or nearly so, when no input is applied to the circuit. Accordingly, relay *A* which is connected in the plate circuit is normally in a released condition. When speech currents are applied to the circuit the voltage on the grid of this tube fluctuates. Those variations which make the grid more negative produce no effect but those which make it more positive allow pulses of current to pass through relay *A* tending to operate it. A condenser is bridged from plate to filament of this tube, the purpose of which is to average these rectified half waves of applied speech so as to insure smooth and positive operation of the relay.

When speech is applied to the circuit the resulting operation of relay *A* does two things. It causes the operation of relay *C* by connecting a ground to one of its windings, and it likewise operates relay *B*. The operation of relay *C* short circuits the opposite line. The time required for the operation of relay *C*, in response to a sustained alternating e. m. f. suddenly applied to the input of the amplifier detector, is about 0.02 second. As was pointed out above, operation in this length of time takes care of conditions in the large majority of cases encountered on four-wire circuits.

The function of relay *B* is to provide a delay in the release of relay *C* after speech has ceased to be applied to the suppressor circuit input and relay *A* has released. Its operation in response to that of *A*, it will be noticed, connects ground to a second winding on relay *C* which will then in turn remain operated as long as the relay *B* maintains this auxiliary current after the relay *A* has released. Relay *B* is made slow releasing by an auxiliary winding closed through a low resistance, and its time of release can be adjusted over a considerable range to meet different operating conditions by changing the value of this resistance. Differing adjustments are rarely called for in practise and these relays are normally set for a releasing time of 0.1 second.

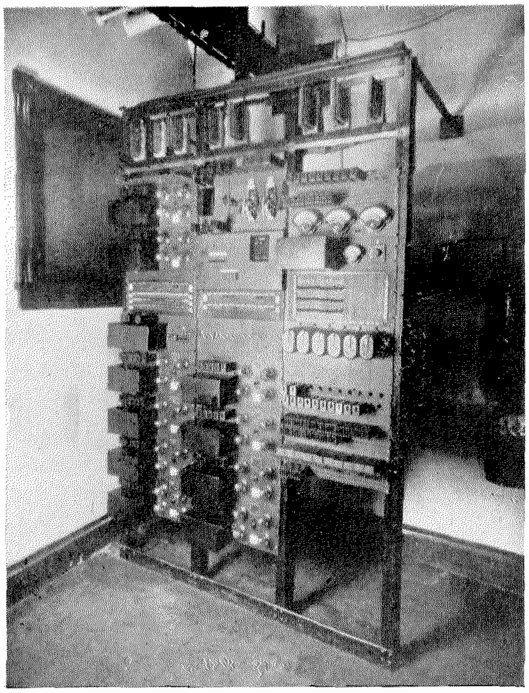

Figure 4—Installation at Harrisburg, Pa.

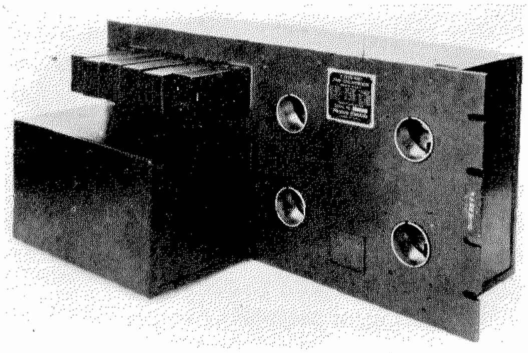

Figure 5—Front View of Echo Suppressor Panel

A number of echo suppressors have been installed at Harrisburg, Pa., where they are now in service on a group of four-wire circuits. Figure 4 is an illustration of this installation of four wire echo suppressors. Figure 5 shows a close-up view of an individual panel from the front. Both halves of the suppressor working on a single circuit are mounted together on one panel. The method of mounting and the type of equipment in the echo suppressors are in general quite like the standard for the four-wire circuits with which they operate. Although in Figure 3 the battery supply circuits are shown individual to this set, in the actual installation common batteries are used. The four filaments of the tubes on one panel are operated in series from the 24-volt battery.

The operation and maintenance of these devices involve little that is different from standard repeater equipment. There is one test, however, which is employed in checking the times of functioning which perhaps deserves special mention. This test involves observing the time needed for the suppressor to go through any number of complete cycles of operation and release. To make this test, the short-circuiting contacts of relay *C* and the input of the suppressor circuit are connected together and to an oscillator as shown in Figure 6. As soon as the

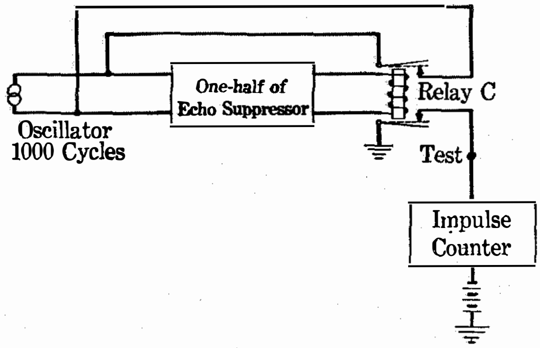


Figure 6—Circuit for Testing Time of Operation and Release

oscillator is connected to the input, the relay train begins operating and the shorting contacts of relay *C* in turn cut off the applied voltage. This short circuit is maintained across the input for a time by the slowness of release of relay *B* as previously explained. When it finally releases and in turn releases relay *C*, the suppressor again operates and the process is repeated over and over. At each repetition of the cycle the auxiliary contacts of relay *C* apply a ground to the test terminal which is connected to a counting device. With the aid of a stopwatch the number of cycles in any given time is readily determined and thus the time of a single cycle of operation. This time is the sum of the time needed for relays *A* and *C* to make and the time needed for relays *A*, *B* and *C* to release. By observing the uniformity and smoothness of operation with which this cycle is carried out the tester can check the adjustment of all the relays. If relays *A* and *C* are properly adjusted so that their operation is positive and uniform, the operating time will vary but slightly from the proper value of about 0.02 second. The test, therefore, gives a good measure of the longer release time which would normally be about 0.1 second.

## Some General Considerations

As was pointed out above, when an echo suppressor is applied to a telephone circuit, the telephone circuit remains operative in both directions when it is in the normal condition, *i. e.*, when no one is talking. It is only when talking is done over the circuit that the path for transmitting in the reverse direction, which is then useless so far as talking is concerned but which is harmful because it furnishes a path for the echoes, is blocked. The advantages gained by this arrangement are: (1) there is no possibility of cutting off the first part of words owing to the fact that the transmission path actually carrying the speech is unaffected by the switching operations; and (2) if the relays should fail to operate because the voice currents happen to be very weak, the listener at the distant end would still hear the speaker although both he and the talker might also hear some echoes. Weak speech does not, in general, give rise to such serious echoes as does strong speech. Therefore, when the voice currents happen to be so weak that they fail to operate the suppressor, the echoes produced may not be serious.

Now, in order to obtain these advantages it is necessary to face the possibility of "singing," since when no one is talking the paths for transmission in both directions remain in their normal operative condition. It is evident that if the repeater gains are raised high enough, singing will begin exactly as it would if the circuit contained no echo suppressor. If singing starts in a circuit containing an echo suppressor, the circulating currents will build up until they become strong enough to cause operation of the relay associated with one half or the other of the echo suppressor so that one of the transmission paths will be blocked. This will temporarily stop the singing. It will commence again, however, as soon as the relay falls back to its normal condition. Thus, a chattering condition is produced which, in general, would not be tolerated.

In order to overcome the limitations which may be set on a circuit by the possibility of singing, it is necessary to go back to the old idea of a voice-controlled system in which the transmission is blocked when no one is talking. It is not necessary, however, to block both of the transmission paths since if one path only is blocked, singing evidently cannot occur.

Figure 7 shows one of the possible arrangements of a voice-operated system in which singing is prevented. It will be seen that this arrangement includes an echo suppressor to which an additional relay *D* has been added, which keeps the upper transmission path blocked when the circuit is normal, *i. e.*, when no one is talking. Singing is, therefore, not possible when the circuit is normal.

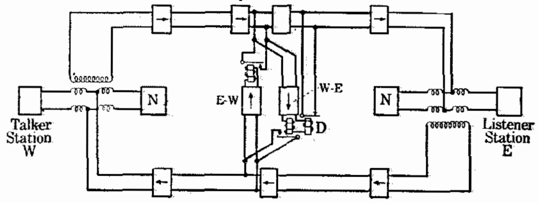

Figure 7—Four-Wire Circuit with Voice-Operated Device Arranged to Suppress Echoes and Singing

Now, when talking is done at Station *W* the voice current waves, on arrival at the middle of the circuit, cause operation of the two relays associated with the amplifier-detector *W-E*. An appreciable length of time is required, of course, to operate relay *D*. To avoid the possibility of cutting off the initial parts of words during the time before relay *D* operates, it is desirable to delay the main transmission. What has been called a "delay network" has, therefore, been included as shown in the figure. This delay network may, of course, assume various forms, one of which might be an artificial loaded line or low pass filter. By including such a delay network, the voice currents can be retarded long enough to give the contacts of relay $D$ time to clear the path before the voice currents reach the point in the circuit where the transmission has been blocked.

In addition to clearing a path for the main transmission in the direction from $W$ to $E$, the transmission path from $E$ to $W$ is blocked by the operation of the other relay associated with amplifier-detector $W$-$E$. The circuit, therefore, has no chance to sing when in the condition for talking from $W$ to $E$.

When talking is done at Station $E$, the relay associated with amplifier-detector $E$-$W$ is operated. This prevents the echo returning from Station $W$ from operating the relays associated with amplifier-detector $W$-$E$. For talking in this direction, therefore, the upper transmission path remains blocked. There is, therefore, no chance for singing, as was also the case for the other conditions.

By adding the delay network, one of the disadvantages of voice-controlled relay systems which keep transmission normally blocked is overcome in large part. This is the clipping off of the first parts of words, the possibility of which was mentioned above.

There remains, however, an important disadvantage in the fact that it is necessary that the voice currents never fail to operate relay $D$. If they did fail to operate this relay, the listener at Station $E$ would hear nothing. It is necessary, therefore, that the amplifier-detector-relay system $W$-$E$ be sensitive enough so that the voice currents which traverse the upper path in the four-wire circuit will never fail to cause operation of its relays.

On the other hand, noise currents which traverse the upper path in the four-wire circuit must never cause operation of the relays associated with the amplifier-detector $W$-$E$. Such false operation would, of course, prevent transmission over the lower pair of wires from Station $E$ to $W$ and would, therefore, render the four-wire circuit inoperative.

To overcome the singing limitation, it is thus seen that it has been necessary to produce a device which requires greater sensitivity and is, therefore, more seriously affected by noise currents than is a simple echo suppressor. This is in addition to the further complications involved.

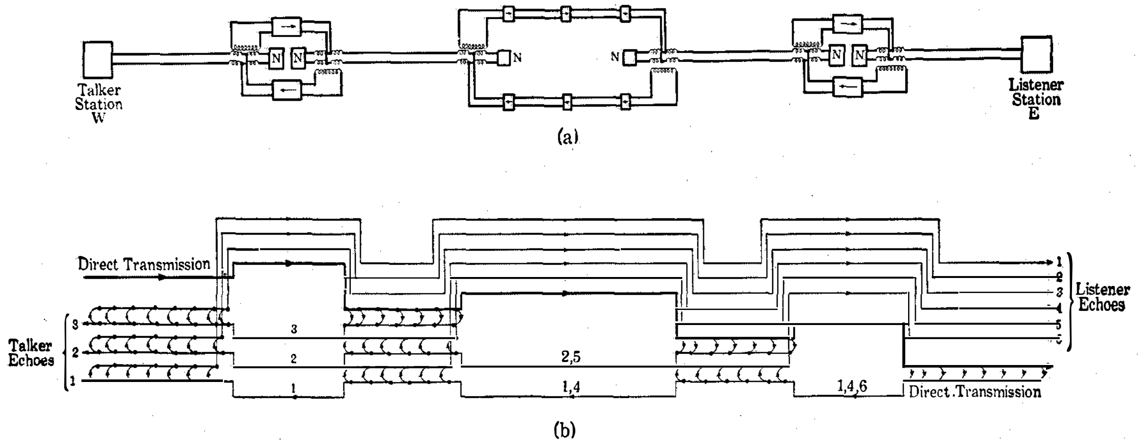

Figure 8—Echoes in Combination Two-Wire and Four-Wire Circuit

Now, in applying simple echo suppressors to long telephone circuits, it is in general not the possibility of singing, but rather, the necessity of avoiding false operation of the relays by noise currents that constitutes the most serious limitation. This is discussed in more detail in what follows. For the present, it is sufficient to note that in the case of most long-distance telephone circuits the method of avoiding singing, which has been described, appears to offer possibilities of limited application only.

## Echo Suppressors Applied to Other Types of Telephone Circuits

It will, of course, be understood that in practise a normal commercial telephone circuit is always two-wire at the two ends where connection is made to the subscriber's instrument. The rest of the circuit may be entirely four-wire or it may be all two-wire, or a combination of both. The application of echo suppressors to circuits which are not all four-wire will now be considered.

One important practical case is that where a four-wire circuit is sandwiched in between two two-wire circuits. Such a case is illustrated in Figures 8 and 9. Figure 8 shows conditions without an echo suppressor while Figure 9 shows conditions with an echo suppressor. In both figures, a diagram of the circuit itself is shown in the upper part *a*, while in the lower part *b* are shown the paths of the direct transmission and echoes. These transmission paths illustrate the condition when talking is being done from Station *W* to Station *E*. In both figures, for simplicity, the first echoes affecting the talker and listener only are shown, echoes of these echoes being ordinarily of little importance.

It will be observed in Figure 8*b*, which represents the condition of affairs when no echo suppressor is used, that the listener hears echoes coming from as many as six different paths. The talker hears echoes from three paths. Now compare this with Figure 9*b* which represents the condition of affairs when an echo suppressor is employed. It will be observed that all of the echoes which return through the four-wire circuit have been suppressed. Echoes from only two paths now reach the listener, while echoes from only one path now reach the talker. Furthermore, the echoes affecting both talker and listener, which remain when the echo suppressor is employed, are those whose paths are comparatively short. The echoes whose paths are the longest have been cut off by the action of the echo suppressor. These echoes which travel over the long paths have the greatest lag and are usually most serious. Consequently, cutting these echoes off makes a material improvement possible even though the echoes whose paths are short remain.

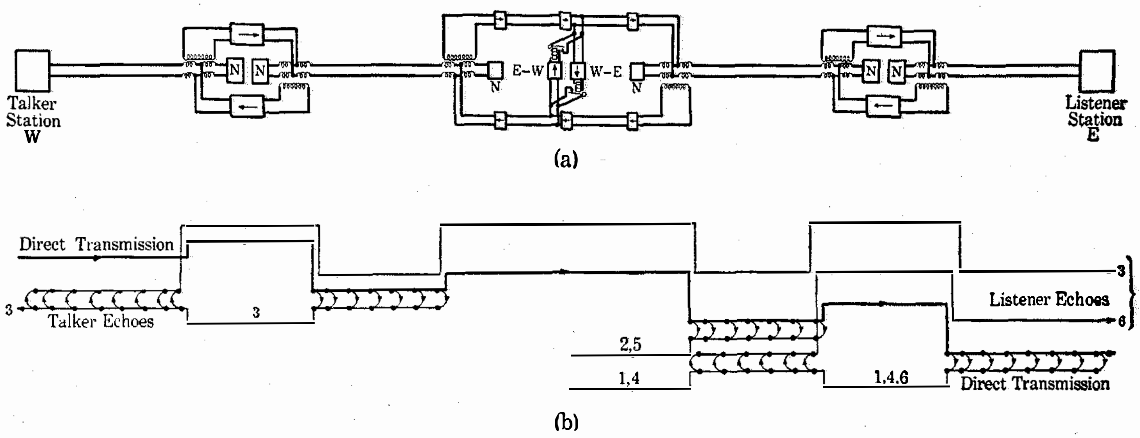


Figure 9—Echo Suppressor Cutting off Echoes in Combination Two-Wire and Four-Wire Circuit
(a) Combination two-wire and four-wire circuit with echo suppressors
(b) Paths of direct transmission and echoes

In order that an echo suppressor may operate satisfactorily on a circuit, such as the one shown in Figure 9*a*, it is necessary that the time required for operation of the relays be short enough so that, if there are any serious echoes returning over short paths, the relays will operate before these reach the suppressor. After operation, the suppressor relays must remain operated until the echoes whose paths are the longest have been suppressed.

In the case of telephone circuits worked entirely on a two-wire basis, echoes may also constitute an important limitation when the circuits are electrically long. On such circuits it is also generally true that the most serious echoes are those whose paths are the longest, namely, those which travel back and forth between points at or near the ends of the circuit. The application of an echo suppressor to one of the repeaters in a two-wire circuit, therefore, offers possible advantages.

If it is imagined that the four-wire circuit shown in Figure 9*a* is shortened so that the whole four-wire circuit is located at one point, the two-wire condition would be represented. The time lags which were introduced by the lines comprising the four-wire circuit are now absent. It is possible, however, to introduce delay networks into the two sides of the two-wire repeater to which the echo suppressor has been applied, so as to make it effectively a four-wire circuit, although the two ends are not geographically separated. This would evidently allow the four-wire echo suppressor which has already been described to be applied without modification.

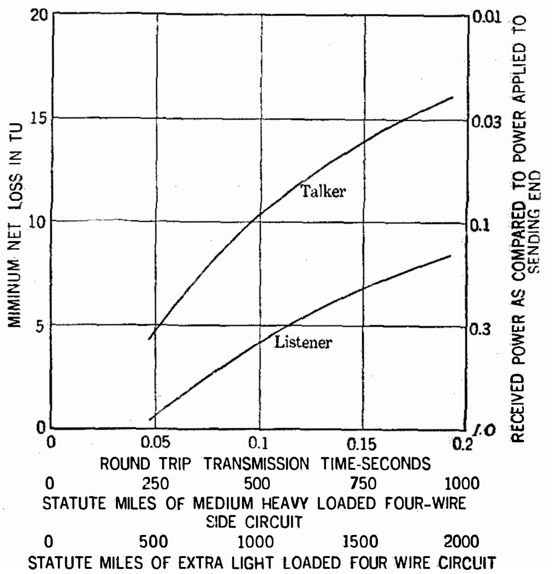


Figure 10—Echo Limitations on Loss of a Four-Wire Circuit

By using somewhat higher speed relays and switching systems, however, it has been found possible in tests which have been made, to obtain satisfactory operation on an all two-wire circuit without introducing devices to produce time lags. This is possible because the important echoes in a two-wire circuit generally lag enough to allow time for relays to operate. Only a few of the echoes return to the suppressor with very small time lags. Some of these can be allowed to pass without causing appreciable impairment, provided they are not strong enough to cause false operation of the relays which block the main transmission path.

## Possibilities and Limitations of Echo Suppressors

The curves in Figure 10 show how, when no echo suppressors are employed, the echo effects limit the extent to which the overall loss of a circuit may be lowered by the application of repeaters.[4] The curves in this figure apply to four-wire circuits of various lengths (without echo suppressors) used to handle terminal business, *i. e.*, connections to subscribers not involving the use of other toll lines in tandem with the four-wire circuit. It is assumed that simple compromise networks giving only a rough degree of simulation of the impedances of the terminal circuits are used. The curves, which are based on experimental data, indicate roughly how the overall volume efficiency must be limited to keep echo effects small enough so that they are not considered disturbing when ordinary telephone conversations are carried on.

Consider, for example, what are the limitations for a circuit 1500 miles (2400 km.) long, with extra light loading. One of the curves which is marked "Talker" shows that in order to keep the echoes which affect the talker sufficiently low, requires that the overall loss in the circuit be made no lower than about 14 TU.[5] The other curve marked "Listener" shows that keeping the echoes which affect the listener within proper limits is a less severe limitation, requiring only that the net loss be made no less

[4] The ordinates on this figure are in terms of the new "transmission unit" abbreviated "TU," which is defined in a paper entitled "The Transmission Unit, etc." by W. H. Martin, *Journal* of the A. I. E. E., June 1924. Also in the article entitled "The Transmission Unit" by R. V. L. Hartley, *Electrical Communication*, Vol. III, July 1924.

[5] Due to transmission variations of the different parts comprising long telephone circuits such as these, the overall loss varies to a certain extent with time. In practice, adjustments of circuits in the Bell System Plant are made often enough to keep the variations within about ± 2 or 3 TU. The working net loss must, of course, be made high enough so that echo difficulties will not be encountered when the variations combine in such a way as to give the overall, or net loss, its minimum value. For example, in the case of the 1500-mile (2400 km.) circuit above, if it is assumed that the circuit is limited by echoes to a 14 TU minimum net loss and that it is maintained within limits of variation of ± 3 TU, the working net loss would be 17 ± 3 TU.

than about 7 TU. Singing of a circuit such as this would not ordinarily begin until the loss was reduced to zero or even, perhaps, made less than zero, *i. e.*, an overall gain.

If an echo suppressor were applied to a circuit such as the above, a maximum improvement of the order of 14 TU might be looked for. As a matter of fact, results as good as this have been obtained in tests.

In order to obtain a result as good as this requires, of course, that the echo suppressor be given a sensitive enough adjustment so as to cut off substantially all of the echoes, even when the voice currents are weak. When given such a sensitive adjustment, there will, of course, be a tendency for noise currents to produce false operation. In certain cases, avoiding such false operation may require that the sensitivity of the echo suppressor be reduced to the point where weak voice currents fail to operate the relays. In such cases, results as good as the above will not be obtainable.

In practise, little or no trouble from false operation due to noise within the cable facilities comprising a four-wire circuit is experienced. When the connections to the terminals of the four-wire circuit are short, therefore, so that, on these terminal connections, the noise currents are comparatively weak and the voice currents large, it is possible to realize in practise the full theoretical possibilities from an echo suppressor. In other words, it is possible to work a four-wire circuit under these conditions at a very low loss, or even an overall gain.

When the lines connecting the subscribers with the terminals of the four-wire circuit are long, so that the voice currents may be weaker and, perhaps, the noise currents may also be stronger, results as good as this may not be obtainable. However, even in this case, a material improvement can usually be effected by the echo suppressor.

For the condition in which a four-wire circuit is switched to a variety of different circuits at the terminals, it was shown in Figure 10 that the requirement that echoes should not disturb the talker is more severe, so far as limiting the minimum loss is concerned, than the requirement that echoes should not affect the listener's transmission. It will, of course, be obvious that talkers connected to either terminal of the four-wire circuit through connections involving small transmission losses will hear louder echoes than will talkers connected through circuits having larger losses. In other words, the minimum net loss of a four-wire circuit used in this way is limited by the requirement that the talkers connected through low losses should not receive too much echo. Now, of course, the relays in the echo suppressor will respond most readily to these talkers. Satisfactory operation of the relays for these talkers will, therefore, be secured even though the echo suppressors be given such an adjustment that the relays will not respond to the voice currents from talkers connected to the circuit through a higher loss. Cutting off the talker echoes in the case of the connections involving low losses, therefore, makes it possible to materially lower the loss introduced by the four-wire circuit even though other echoes are not cut off.

In the curves of Figure 10 it is seen that for a 1500-mile (2400 km.) extra light loaded circuit the possible improvement which may be secured by cutting off the talker echoes from low loss connections may be as much as 7 TU even though echoes from other connections are not cut off.

In general, for combinations of four-wire and two-wire circuits and for circuits which are all two-wire as well, talker echoes are also more serious than listener echoes provided that the impedance irregularities at intermediate points in the circuit are small, as is usually the case with high grade circuits. Consequently, echo suppressors make it possible to effect improvement in many cases even if the line noise which is present requires reduction of the sensitivity of the echo suppressors to the point where weak voice currents fail to operate the relays. If the line noise requirement does not enter as a limitation, a greater improvement is, of course, possible, as is also the case with all four-wire circuits.

## Conclusion

The echo suppressor, which has been described, offers attractive possibilities in supplementing other methods for obtaining satisfactory transmission over long two-way telephone circuits.

The application of an echo suppressor to a telephone circuit requires no changes in the circuit itself, the echo suppressor being merely attached to the circuit at some convenient point.

For any particular type of circuit, the advantages to be gained by using echo suppressors increase with length. For a given circuit length the advantages to be gained are greater with low-speed than with higher-speed circuits.

Echo suppressors offer the greatest possibility of usefulness on cable circuits, owing to the inherent low-speed and quietness of such circuits. Generally speaking, the application of echo suppressors to cable circuits offers possibilities of effecting savings by allowing the use of heavier weight, lower-speed loadings in place of lighter weight, higher-speed loadings, as well as the imposition of less severe requirements as to impedance uniformity of the circuits.

# Communication in Railroad Operation*

**By I. C. FORSHEE**

*Pennsylvania Railroad System, Philadelphia, Pa.*

*Synopsis:* The object of this paper is to show the part played by the different means of electrical communication in operating a large railroad system. The telegraph, which was the original and sole means of handling communications requiring immediate attention, has given way largely to the telephone and the printer. The development of the selector was essential to the general use of the telephone for train operation and message work, the train wire being considered the most important circuit in railroad operation.

Extensive and special facilities are required in some instances to provide necessary telephone communication with the public. This includes telephones on certain limited trains in terminals.

The telautograph is important but limited to local service in terminals and junction points.

Same problems in engineering, construction, maintenance and operation as with the commercial telegraph and telephone companies, except that smoke conditions are worse along the railroad and continuity of service is possibly more important.

Radio has possibilities as a means of providing information and entertainment to passengers on trains and in the operation of freight trains and tug boats.

In handling train orders the train conductor must verify the instructions or orders he receives. The quality and accuracy of radio reception when a train runs through rock cuts, over or under certain types of steel bridges, through tunnels and during certain weather conditions prevents this means of communication from being used at this time for handling train orders.

The volume of communication traffic is affected by the seasons, holidays and emergencies.

The size of the communication system on some railroads compares favorably with that of some of the large commercial telegraph and telephone companies.

An ideal communication system would provide accurate information between any two points on a railroad system or between the public and the railroad company without delay and under all operating conditions.

THE means of communication which will be referred to in this paper includes the telegraph, telephone, telautograph, telegraph printers and radio.

The signal system used in connection with the movement of trains, which includes the various hand operated or manual signals, and automatic signals of the different types such as semaphores, colored lights and position lights as well as train control systems, in reality form an important part of a railroad communication system, as they convey information to the enginemen or trainmen regarding the condition of the track ahead. This will not be included in the present paper.

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## TELEGRAPH

*Train Operation.* The handling of train orders by telegraph was started in 1850 and was used more or less extensively on all the railroads throughout the country until the advent of the telephone.

*Telegraph Development.* The earliest installations of the telegraph made use of the simple Morse circuit; the later developments provided duplex and quadruplex operation which were quite generally used for message service, especially between terminal or relay points. It might be said that the development of the telegraph as a means of communication progressed in step with the development of the railroads themselves. The importance of rapid and accurate communication was greatly increased by the increase in mileage of the railroads the efficient management of which required prompt, accurate and complete information regarding many matters pertaining to operation and management. The telegraph is still used by some roads for dispatching their trains and handling the regular message business, although the telephone has rapidly replaced it for this class of service in many sections.

*Telegraph as By-Product.* Although on some railroads and some divisions of the railroads the telegraph has given way almost completely to the telephone for all classes of local service yet it is probable that for many years to come the telegraph will still be used as a by-product of the wire plant for message service between the general office and division headquarters; also between the different relay points on the systems. This telegraph service will not be handled over direct Morse wires, but rather be a by-product obtained by compositing the telephone trunk circuits between these same points. This would mean that two pairs of telephone wires which are properly transposed can be phantomed and composited and thus furnish three telephone and four duplex telegraph circuits, all of which may be operated simultaneously without interference of one with the other. These composited circuits may be equipped with telegraph repeaters for through telegraph message business over the long circuits of, say, 300 miles or more.

*Commercial Telegraph Service.* For the benefit of the public, commercial telegraph offices are provided at the terminals and larger stations, and messages are handled by the railroad operators at other points.

Arrangements are in effect at many important points on some railroads for the uniformed messengers of the commercial telegraph companies to pass through the trains and collect telegrams from the passengers. Messages are delivered to passengers enroute by sending them in care of the conductor of the train (indicating by train number) on which the passenger is traveling. They are then delivered at the next point at which the train stops.

### Telegraph Printers

The telegraph printer has been developed to the point where it is being used very largely between division headquarters or relay points or where there is a sufficient volume of traffic to warrant their installation, and these same composite circuits referred to above, can be used for duplex operation of these machines.

*Reports.* For the efficient handling of freight and passenger business on a large system, it is necessary for those in charge to have current reports on the supply and demand of cars and the movement of the different classes of freight and engines; also on shop conditions where the different classes of repairs are made. This necessitates the use of many different report forms, for years handled by the Morse operators. An intelligent study of this condition would make it possible to redesign many of these forms so that they might be used in printer operation.

*Type of Printer.* It is believed that the page printer using tape transmission is, in general, most satisfactory for railroad message work between the more important points. Several carbon copies of the messages or reports can be made when this is necessary and very little instruction is required to teach one to manipulate a printer if the employe is able to operate a typewriter accurately. When line interruptions occur, the perforator operator can continue to punch the transmitting tape, and as soon as the line is restored the tape can be run through the transmitter at maximum line speed with minimum of delay.

*Maintenance.* The maintenance of printers requires the services of a skilled mechanic, so that the more printers there are in service at a given point the less the cost of maintenance per unit, as one mechanician can take care of a number of printers.

### Telegraph Replaced Largely by Telephone

The disadvantage in using the telephone in train dispatching in the early stages of its development was caused by the difficulty in signaling the desired party, as it was necessary to use code calls and this was very objectionable on heavy lines. There were many misgivings and doubts regarding the ability of the dispatcher and operators to handle train orders accurately by the telephone, and it was only after quite extensive use on certain limited installations that the telephone proved to be quite equal to the telegraph so far as accuracy and speed were concerned.

The more general use of the telephone for train dispatching was dependent upon the development and perfection of a selective calling device, which would enable the dispatcher to signal any one of the many stations connected to his telephone circuit. There were a number of types and makes of selectors in the early development, but the law of the survival of the fittest worked here as well as elsewhere and the selectors at present available for this service are both rugged and accurate with relatively little maintenance trouble. They are available for circuits having as many as seventy-five or more stations any of which can be called independently; but on a busy section of railroad they seldom exceed half this number. The approximate time required for the bell to start to ring after the dispatcher makes the call is four to six seconds.

*Time Service.* One important service which was formerly handled exclusively by telegraph and which is now quite generally transmitted over the telephone lines equipped with selectors is the time service from the U. S. Observatory. This transmission takes place twice a day, at noon and midnight in the Eastern time belt, and is an important service, as all the time pieces on the railroad used in connection with train operation for reasons which are obvious must be as nearly accurate as it is possible to have them.

## Telephone

So far as the public is concerned, they are interested primarily in telephone service with the railroad company to obtain information regarding such matters as arrival and departure of trains, Pullman reservations, cost of transportation, arrival and departure of freight, freight rates, etc.

When it is realized that the railroads are the largest users of almost every commodity, it will be evident that there are many other classes of information in which the public are very much interested at times and in which the telephone system forms an important link.

*Intercommunicating System.* In some of the larger cities, the different departments of the railroad are quite widely separated on account of the quarters required and those available; but the intercommunicating telephone systems, which may be automatic, manual or semi-mechanical, make it possible to secure those best adapted for the business by the telephone service which is as prompt as if all the parties were in adjacent offices.

*Private Intercommunication System.* In some places where the calling rate for strictly intercommunicating service is unusually high between the different subscribers it has been found economical to purchase, maintain and operate a private system of the automatic type, but this means duplication of the outside plant, wiring and maintenance, and requires a second telephone where there is occasion to have service with the commercial companies. Only a careful study, considering all items involved, will give the true answer as to the economies of this.

The long-distance or trunk-line circuits of the railroad company represent an appreciable investment which should be operated as efficiently as possible to secure the best returns. This means that a relatively small number of lines are given to each toll operator who is selected because of efficiency, and knowledge of the railroad organization and can be depended upon to handle the circuits to the best advantage.

*Directory Listing.* It is impracticable and undesirable to list in the public telephone directory all the different departments, much less all of the individuals, of a railroad organization, so that the burden of remembering each and all of the hundreds or thousands of individuals within reach of the telephones connected to such a switchboard becomes a problem of long and careful training.

The aim of the railroads, generally, is to simplify as much as possible the directory listings, so that by calling one telephone number, connections may be established with any department or individual in that vicinity.

*PBX Consolidation.* This is one argument in favor of the consolidation of the private branch exchanges of a railroad where there are several exchanges in a given vicinity. The cost of service through such a consolidated exchange is the deciding factor sometimes, as it might be necessary to lease a considerable mileage of cable circuits from the outlying points to the consolidated exchange; and if that rental and the rental of the additional facilities required at the consolidated board exceed the cost of the service through the individual exchanges, then the only remaining arguments are the twenty-four hour service and the greater convenience to the public from the simplified listing.

The advent of the automatic or machine-switching system it is believed will solve many of these problems, as the small automatic unit, called a satellite, can be used for the intercommunicating service at the points separated from the main exchange and connected with the railroad main *PBX* by automatic trunks. The calls to and from the city central offices then would be routed through the main *PBX*. The railroad operator would complete the incoming calls either by dialing the party, if on a satellite exchange, or by a cord and plug in the multiple if connected on the same switchboard. The outgoing calls would either be dialed direct by the different railroad subscribers or handled by the operator as desired by the railroad company.

*PBX Traffic.* During the busy hour it is not uncommon for an operator handling calls incoming from city to make 200 connections, and a considerably higher number of intercommunicating calls when made by number. The former class of calls probably will continue on a manual basis even after the central office and the private branch exchange are operating on a machine-switching basis. Through some of the larger private branch exchanges they handle as many as 18,000 to 20,000 or more calls per day.

*Train Dispatcher's Equipment.* There may be several dispatchers' circuits on a busy division, each dispatcher handling the movements over a given section with possibly a Chief Dispatcher's circuit operating over the entire length of the division and connecting to certain transfer points and with the dispatcher's office on one or more of the adjoining divisions. On these circuits equipped with selectors the dispatcher has control of the entire circuit; that is, the different way stations are signaled only by the dispatcher who is, in general, connected across the circuit continuously with his receiver, which may be of the head band type or a loud speaker.

For a long time the head-band receiver, used by the dispatcher, was the only type of reliable receiver available. It was very objectionable however, especially in warm weather, during lightning storms, or where the circuit was exposed to the effects of induction from power circuits. This trouble has been largely overcome by the development of the loud speaker which, at present, is very satisfactory for this service. The loud speaker can be so adjusted that, even though there are several of them in an office, a very satisfactory operation is obtained. This is convenient also for the supervisory forces in case of emergency, as they can get all details first-hand without disturbing the dispatcher.

*Selector Message Circuits.* Telephone circuits equipped with selectors also are used quite extensively for handling telegraph messages, especially between local division points.

To prevent errors in the transmission of words and numbers that might be misunderstood, a special code has been developed and is in very general use. The service is faster than the Morse and very little special training is required for such operation.

The installation of telephone selector equipment for train dispatching and message service generally has been objected to by those who are accustomed to handling this business by Morse, but it also has been quite general that these same objectors are the most enthusiastic proponents of the telephone system after they have become accustomed to this operation.

*Block Circuits.* Interlocking plants are located at regular intervals along the railroad, permitting the crossing over of trains from one track to another on a system having two or more tracks, and also allowing the trains to take a passing siding on single track operation. These points are known as interlocking stations.

Where interlocking stations are several miles apart, intermediate stations are often established for the purpose of shortening the block between the interlocking stations. They are known as block stations.

The attendant in charge of the interlocking or block stations may be a telegraph or telephone operator and must manipulate the levers controlling the signals or switches. He is now quite generally known as a "signalman."

A "block," as used in this paper, is the length of track between block or interlocking stations where the movement over the track is governed by fixed signals.

Telephone circuits between these block and interlocking stations are known as block circuits and are used for spacing trains and for transmitting intelligence regarding arrival and departure of trains in the different blocks. They are considered next in importance to the dispatcher's circuit so far as train operation is concerned.

Telephones in shelter boxes or booths are usually located at the different sidings and signal bridges and connected to the adjacent block or interlocking stations, or, in some cases, to the dispatcher's line.

These block circuits are often simplexed and the simplex carried through for a division telegraph circuit.

*Work and Wreck Train Equipment.* The work trains and wreck trains are quite generally equipped with portable telephones which may be connected to the adjacent block and interlocking stations or to the dispatcher's telephone circuit, to keep him advised of their whereabouts; also as to condition of track or equipment on which they may be working. Before the advent of the telephone for this service, it was necessary to establish a local telegraph office and an operator was required with the work-train or wreck-train crew to transmit the necessary information to and from the dispatcher.

First-hand information can now be obtained direct from the one in charge of the train crew in less time and more satisfactorily than was possible with the telegraph.

*Siding and Signal Bridge Telephones.* On some roads it is the practice to establish telephone service at each signal bridge and siding. This telephone is connected to the adjacent interlocking or block station. In some cases provision is made for connection to an adjacent private branch exchange in case of emergency, so that the calling party may be connected either directly to the signal man, to the dispatcher or other individual depending upon conditions. These telephones are usually installed in shelter boxes or booths to protect them and the user from the weather. Automatic switches are used to disconnect the telephone from the line when the telephone is not in use. These shelter boxes or booths usually are provided with regular switch locks to prevent the use of the telephone by unauthorized persons.

This general scheme of installing telephones along the railroad right-of-way, especially on a busy section, is considered more favorably than the use of portable telephones as they are available for all the different employees of the railroad system in that district, and less apt to develop trouble than the portable sets. They are also inspected more regularly by the maintainers.

*Emergency Circuits.* In some cases an extra circuit is provided in the shelter box or booths. This is termed an emergency circuit and is available for service with an emergency or portable telephone carried by the work- or wreck-train crews, so that it does not interfere with the operation of the regular signal bridge or way-station telephone circuit. The emergency circuit is associated with the adjacent block and interlocking stations and so arranged that it could be connected to the dispatcher or to a private branch exchange in the event of an emergency.

*Portable Telephones.* The renewing of ties and rails, together with other work on the track incident to track maintenance, requires that a track gang should be in constant communication with the train dispatcher, so that there will be as little delay to train movement as possible. The use of the portable telephone is essential in this operation and it also improves the efficiency of the track forces by a reduction in their lost time.

*Loud Speakers at Terminals.* In a busy terminal where there are crossovers, interlocking equipment, etc., it is desirable for each of the signalmen at different stations to know of all of the train movements arranged by the dispatcher in that district. This was handled by Morse for many years, but when the train and engine movements increased so much it became a great strain on the signalman. The head telephone with a long cord required to permit the signalman to handle the different switch levers, is impracticable so that more recently the loud speaking telephone has been used quite generally to solve this problem, and it is working very satisfactorily.

*Observation Cars.* Observation cars on certain limited trains are provided with desk telephones which are in turn connected to the railroad private branch exchanges thence to the city central offices when the trains are at the different terminals. This service, connected through to any point in the Bell System, is available for the passengers on the train up to the leaving time. The stenographer on these trains arranges for this service as desired.

*Crew Calling.* At some of the important division points the homes of the conductors, brakemen, engineers and firemen are quite widely separated from the division office. Due to different emergencies which may arise, the variation in the amount of traffic requiring different numbers of crews, sickness and other causes, it is quite a problem to make available the necessary men qualified to handle the different freight and passenger trains without delay. This requires either special messenger service or special telephone service. It has been found in some instances that special crew-calling telephone service (normally used for one-way operation but in emergencies employed for two-way service), is the most efficient and economical. With this system the Crew Caller gives the Telephone Operator the list of members to be called indicating time and place to report for duty.

*Public Telephones at Stations.* For the convenience of the traveling public, and not directly associated with railroad operation, a relatively large number of telephones is required at many of the important terminals to enable the patrons to make local and long distance calls through the commercial telephone systems. This convenience is provided for by the attended and unattended telephone stations, the latter being the usual coin in the slot or pay station telephones.

*Train Bulletins.* On many roads a regular bulletin service is also in effect giving information of general interest to the traveling public on through limited trains. This includes stock market quotations on the principal issues, baseball scores, and any other items of major interest. These bulletins are generally posted in the club or observation cars and are received at the principal points enroute.

### Telautograph

The telautograph has been used quite generally for recording information regarding the make-up of trains, track assignment for trains also the time of arrival and departure of different trains in the terminals and other important division points. This is a service which is of vital importance to the baggage department and in handling mail as arrangements must be made to load baggage and mail on the trains the latest possible before train departure, also for the necessary trucks to unload promptly incoming baggage and mail from the trains just arriving. This service is of a local nature. The circuits may have one or more transmitters and several receivers, all of which are operated simultaneously.

### Radio

*Passenger Trains.* Radio on passenger trains has been an interesting theme for many of the Sunday newspaper writers for some time; and they have not overlooked many of its possibilities.

The developments that have taken place in the broadcasting and receiving equipment within a few years and the results obtained from some of the experimental installations indicate that if there were a real demand for such service on our trains it could probably be met now in a more satisfactory manner than at any time in the past. There are many factors that affect the results obtained on a train installation including: the curvature of the track, causing changes in position of the car antenna with respect to the transmitting station; varying sub-surface conditions which apparently cause fading or varying intensity of received signals or sounds; shielding effect of tunnels and bridges, causing a reduction in intensity or complete loss of reception; noise from axle generator lighting equipment; in addition to the atmospherics that affect the fixed station.

There are certain events that are of general interest which might be received over a radio loud speaker in a club or observation car without much adverse criticism; but that would not hold good with the ordinary broadcasting.

*Freight Trains.* There is a real need for a sturdy, reliable, simple set for two-way communication between the front and rear end of long freight trains, which is reasonable in cost. This should have some scheme for visual or preferably audible signaling. The rails have been suggested as a conductor for a carrier system. These have insulated joints at certain intervals which might affect the operation, and on account of the connections between the different tracks at the interlocking points, there might be some complications or objections to such use.

The importance of this will be appreciated when one considers that some trains are nearly a mile long, with a hundred or more cars, the engine crew at the head end, the conductor and flagman in the caboose at the other end and the brakemen out over the train. Something goes wrong and the conductor wants to communicate with the engineer. It is a dark, rainy or foggy night, and in a place where the track winds around the hills with no opportunity for lantern signals. There is nothing to do but stop the train and walk the length of it. This takes a long time.

*Train Operation.* It is believed that the radio cannot yet be depended upon for issuing train orders, especially to moving trains, as accuracy is of prime importance, as well as continuity of service, and there must be a check on all orders issued by the dispatcher.

*Emergency and Tug Boat Service.* It has a real field, however, for emergency service between the different important points such as the general offices, division headquarters and certain important points on a system, when the wire lines fail because of storms, floods, fire, etc.; also for tug-boat operation in the harbors. The code signals are more reliable than the telephone for such service.

Small, efficient, portable transmitting and receiving sets which could be depended upon for distances up to two or three miles for service during floods and storm breaks would find favor with the railroad Superintendents of Telegraph.

## Line Construction

*Location.* The telegraph and telephone line construction is invariably along the railroad right-of-way, which means that, in general, it is not far from the running tracks and is subjected to the smoke and corrosive gases from the locomotives where steam operation is used.

*Types of Line Construction.* The different types of line construction used in various sections, dependent upon local conditions, include open wire, aerial cable and underground cable. The construction used in any particular section depends upon several things such as the number of circuits involved, the importance of the service, space available and hazards from electrical or mechanical interference. The appearance of the line, also, is an item in some sections. Each class of construction mentioned has certain merits as well as objections, for which reason the conditions in any given location have to be carefully considered before deciding upon just what should be used.

*Preservation of Poles.* The railroads have been active in the development and use of preservative treatment of pole timbers for years. Because of their use of forest products, amounting to about fifteen per cent of the total consumption in this country, they realize that this is a good and wise investment and in line with the policy of forest conservation.

*Insulator Pins.* If it were possible to obtain a satisfactory enameled pin which would preserve the metal pin from deterioration and also provide the necessary strength and insulating qualities at a reasonable price, it might be an improvement over the present practice.

*Wire.* Galvanized wire is used very little along a busy railroad on account of its short life before corrosion takes place. Practically all wire now placed is hard drawn bare copper No. 9 A.w.g., except that No. 8 B.w.g. is used for some important long distance trunk circuits.

*Insulation.* On a busy section of railroad the locomotive smoke is responsible for insulators soon becoming coated with a black deposit which covers not only their outer surface but underneath the petticoats as well, and is responsible for lowered insulation under unfavorable weather conditions. This causes leakage of current from the wires to ground and between wires, which affects both the telegraph and telephone service, probably the telegraph more than the telephone. This has been the subject of quite exhaustive studies to determine the best type of construction.

It has been found uneconomical to attempt to clean the insulators after they have once become coated; so the remedy for this condition is to replace with new glass, unless some means is developed for preventing this accumulation or for economically and efficiently cleaning them in place.

*Importance of Continuous Service.* It is believed that the importance of continuous and efficient communication service in railroad operation is greater than with the regular commercial telegraph or telephone service. It is under the most unfavorable weather conditions that irregularities are apt to occur in train operation and that, too, is the time when open wire lines are most likely to fail, and when they are most needed.

*Alternate Routes.* Alternate routes for circuits between some of the more important places are usually available over the Railroad Companies' lines, and, in the event of line prostration over a normal route, it is many times possible to reroute some of the circuits to provide for the emergency service while repairs are under way.

*Cable Construction.* Where cable circuits are in service, there is generally less likelihood of line failure due to storms; but they might fail from other causes, such as electrolytic action, if underground, or from bullet holes or crystallization if in aerial construction. In either case duplicate cables provide certain insurance against complete failure, but with adequate testing facilities and a force of cable splicers available together with proper maintenance of the cable plant, there is little likelihood of these causes occasioning the loss of all service.

*Wire Patching Facilities.* All wires on the pole line look alike to the layman, but from a railroad operating point of view, some wires are vastly more important than others. The dispatcher's line is considered of the greatest importance in train operation and for this reason it is always restored first in the event of line prostration. If trouble develops on it while other circuits are intact, the circuit which can be spared with least inconvenience to the service is used to patch out the dispatcher's circuit in the defective section. This means that the patching facilities, which include test panels in which all wires terminate and the necessary patching cords and plugs, must be available for this purpose at certain points on the Division. However, it is undesirable to have these located too close together, as they introduce certain transmission losses on the longer circuits due to the necessity of using cable and protectors to connect between the line and the test panel, which usually is located in an interlocking or block station. Thus the additional protectors are added places for trouble to occur.

*Emergency Service.* With the open wire construction it is possible to make connections for local emergency service by means of the pole used for this purpose, with portable telephones, but where aerial or underground cable only are used, these emergency connections can be made only where cable conductors are brought out to terminals, as at signal bridge or siding telephones or special terminals provided for that purpose.

*Use of Commercial Lines.* It is sometimes possible to establish emergency service between the different important points by connection over the commercial telegraph or telephone companies' lines, routed either as direct circuits between the points involved or by circuitous routes to avoid the section in trouble. For the purpose of quickly establishing such services, it is the usual practise to have available certain tie lines between the railroad companies' important terminal or relay offices and the commercial offices of the telegraph or telephone companies.

### Operating Conditions

*Variation in Telephone Traffic.* There are quite wide variations in the traffic over the railroad companies' communication system, dependent upon the seasons. The increased travel during the holidays and vacation periods is also responsible for wide fluctuations in this communication traffic. The presence of any emergencies or conditions which are likely to cause delays in the train schedules are often reflected in the increased calls made from the public to the Information Bureau inquiring as to the probable arrival or departure of the different trains, the cause and results of accidents, etc. In the event that these emergencies develop at a time when the telephone operating force is greatly reduced, there is apt to be complaint as to the inadequacy of the service unless extra operators are summoned immediately, as is usually the case. It is doubtful if the machine switching service will remedy this particular condition, as it is quite probable that all incoming calls from the city central office will be handled by the manual operators as at present, but intercommunicating calls within the system itself could well be handled on a mechanical basis so that the increased load on the operators would not be so great as with the manual system.

*Engineering Problems.* The different problems met in the planning, operation and maintenance of a communication system for a large railroad are practically the same as with the large commercial telegraph and telephone companies, except that there are a few added special requirements. However, this phase of a railroad system is seldom given any consideration by one unfamiliar with the magnitude or importance of the railroad telegraph and telephone plant.

*Interest in Legislation.* When it is considered that some of the larger railroad systems operate in a number of States, it will be seen that the railroads are vitally interested in such matters as State regulations governing electrical construction, inductive coordination, etc., and in the revision of the National Electrical Safety Code which doubtless will have a far reaching influence on the State regulations now in effect, or which may be revised or formulated later.

*Magnitude of Some Systems.* The communication plant of one of the larger railroads includes, in round numbers, over 10,250 miles of pole line; 530 miles of underground duct; 125,000 miles of wire; 2,420 telegraph and telephone message offices; the average number of messages per month, not including train orders, through 86 relay and terminal offices is over 3,716,000; more than 11,700 telephones, privately owned, are used for dispatching trains, message service and private line operation; over 180 leased telephone exchanges, ranging from simple one position boards to a 23 position board at the General Office, are employed with over 18,800 leased telephones. This is called a private communication plant.

*Ideal System.* The ideal communication system would be such that, from any point on a railroad, any information wanted from any other point on that system could be obtained accurately and without delay. This would require more plant than could reasonably be expected and of such a quality that only the highest grade of construction could be used; the lines would have to be equipped with loading coils and telephone and telegraph repeaters, and the terminal equipment would have to be such that minimum losses would obtain. Some of the railroads have already gone a long way toward realizing this ideal.

# The Loaded Submarine Telegraph Cable

By OLIVER E. BUCKLEY

*Bell Telephone Laboratories, Inc.*

THE announcement on September 24, 1924, that an operating speed of over 1,500 letters per minute had been obtained with the new 2,300 mile New York-Azores permalloy-loaded cable of the Western Union Telegraph Company brought to the attention of the public a development which promises to revolutionize the art of submarine cable telegraphy. This announcement was based on the result of the first test of the operation of the new cable. A few weeks later, with an improved adjustment of the terminal apparatus, a speed of over 1,900 letters per minute was obtained. Since this speed represents about four times the traffic capacity of an ordinary cable of the same size and length, it is clear that the permalloy-loaded cable marks a new era in transoceanic communication.

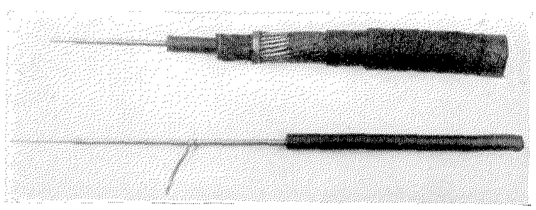

Figure 1—Permalloy Loaded Cable. Above, section of deep sea type, showing construction. Below, section of core, showing permalloy tape partly unwound

The New York-Azores cable represents the first practical attempt to secure increased speed of a long submarine telegraph cable by inductive loading and it is the large distributed inductance of this cable which is principally responsible for its remarkable performance. This inductance is secured by surrounding the conductor of the cable with a thin layer of permalloy. Figure 1 shows the construction of the deep sea section of the cable. In appearance it differs from the ordinary type of cable principally in having a permalloy tape 0.006 inch thick and 0.125 inch wide, wrapped in a close helix around the stranded copper conductor.

Permalloy, which has been described by Arnold and Elmen,[1] is an alloy consisting principally of nickel and iron, characterized by very high permeability at low magnetizing forces. The relative proportion of nickel and iron in permalloy may be varied through a wide range of additional elements as, for example, chromium may be added to secure high resistivity or other desirable properties. On account of its extremely high initial permeability a thin layer of permalloy wrapped around the copper conductor of a cable greatly increases its inductance even for the smallest currents.

In the case of the New York-Azores cable the permalloy tape is composed of approximately 78½% nickel and 21½% iron and gives the cable an inductance of about 54 millihenries per nautical mile. An approximate value of the initial permeability of the permalloy in that cable may be got by assuming the helical tape replaced by a continuous cylinder of magnetic material of the same thickness. This material would have to have a permeability of about 2,300[2] to give the observed inductance. A better appreciation of the extraordinary properties of the new loading material may be obtained by comparing this permeability with that which has previously been obtained with iron as the loading material. The Key West-Havana telephone cables are loaded with 0.008 inch diameter soft iron wire. The permeability of this wire, which was the best which could be

[1] *Jour. Franklin Inst.*, Vol. 195, pp. 621–632, May, 1923; *B. S. T. J.*, Vol. II, No. 3, p. 101; *Electrical Communication*, Vol. II, No. 4.

[2] The true initial permeability is slightly higher. To compute it, account must be taken of the fact that, contrary to what has been sometimes assumed, the magnetic lines of induction in the tape do not form closed loops around the wire but tend to follow the tape in a helical path. The pitch of the helical path of the lines of induction is slightly less than that of the permalloy tape with the result that a line of induction takes a number of turns around the conductor, then crosses an airgap between two adjacent turns of tape and continues along the tape to a point where it again slips back across an airgap. O. E. Buckley, British Patent No. 206,104, March 27, 1924, also K. W. Wagner, E.N.T., Vol. I, No. 5, p. 157, 1924.

obtained commercially when that cable was made, is only about 115, or approximately one-twentieth that of the permalloy tape of the New York-Azores cable.

The proposal to use permalloy loading to increase the speed of long telegraph cables was one outcome of an investigation undertaken by the author soon after the war to determine whether some of the new methods and materials developed primarily for telephony might not find important application to submarine telegraphy. In the subsequent development of the permalloy-loaded cable a large number of new problems, both theoretical and practical, had to be solved before the manufacture of a cable for a commercial project could be undertaken with reasonable assurance of success. The problems encountered were of three principal kinds. First was that of the transmission of signals over a cable having the characteristics of the trial conductors made in the laboratory. Although the theory of transmission over a loaded cable had been previously treated by others, the problem considered had been that of an ideal loaded cable with simple assumptions as to its electrical constants and without regard to the practical limitations of a real cable. The second class of problems had to do with the practical aspects of design, manufacture and installation. In this connection an extensive series of experiments was conducted to determine the means required to secure at the ocean bottom the characteristics of the laboratory samples on which the transmission studies were based. Among the numerous problems which arose in this connection were those concerned with protecting the copper conductor from any possible damage in the heat treating operation which was necessary to secure the desired magnetic characteristics, and those concerned with protecting the strain-sensitive permalloy tape from being damaged by submerging the cable to a great depth. The third class of problem had to do with terminal apparatus and methods of operation. The prospective speed of the new cable was quite beyond the capabilities of standard cable equipment and accordingly new apparatus and operating methods suited to the loaded cable had to be worked out. In particular it was necessary to develop and construct instruments which could be used to demonstrate that the speed which had been predicted could actually be secured. The success of the investigations along all three lines is attested by the results which were obtained with the New York-Azores cable. Figure 2 shows a section of cable recorder slip, the easily legible message of which was sent from Horta, Fayal, and received at New York at a speed of 1,920 letters per minute.

It is principally with regard to the first of these classes of problems, that of the transmission of signals, that the following discussion is concerned. No attempt will be made here to discuss the details of design and development

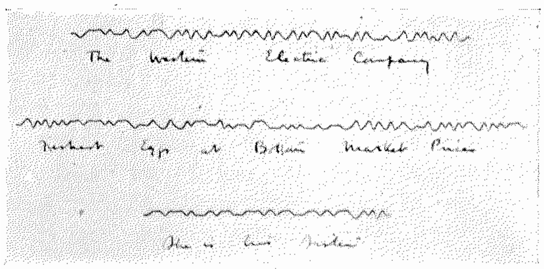

Figure 2—Test Message. Western Union New York-Azores Permalloy-Loaded Cable. Sent from Horta (Azores) and received at New York, November 14, 1924. Speed—1,920 letters per minute. Recorded with special high speed siphon recorder

of the physical structure of the cable nor will there be given a detailed description of the operating results or how they were obtained. These subjects must be reserved for later publication. It is desired in what follows to explain how inductive loading improves the operation of a submarine cable and to point out some of the problems concerned with the transmission of signals which had to be considered in engineering the first long loaded cable.

In order to understand the part played by loading in the transmission of signals, it is desirable first to review briefly the status of the cable art prior to the introduction of loading and to consider the factors then limiting cable speed and the possible means of overcoming them. A cable of the ordinary type, without loading, is essentially, so far as its electrical properties are concerned, a resistance with a capacity to earth distributed along its length. Although it does have some inductance, this is too small to affect transmission at ordinary speeds of operation except on cables with extremely heavy conductors. The operating speed of a non-loaded cable is approximately inversely proportioned to the product of the total resistance by the total capacity; that is,

$$S = \frac{k}{CRl^2},$$

where $C$ is capacity and $R$ resistance per unit length, and $l$ is the length of the cable. The coefficient $k$ is generally referred to as the speed constant. It is, of course, not a constant since it depends on such factors as terminal interference and method of operation, but is a convenient basis for comparing the efficiency of operation of cables of different electrical dimensions. As the technique of operating cables has improved the accepted value of $k$ has increased, its value at any time being dependent on the factor then limiting the maximum speed obtainable. This factor has at times been the sensitiveness of the receiving apparatus, at other times the distortion of signals and in recent years interference. During a great part of the history of submarine cable telegraphy distortion was considered the factor which limited the speed of operation of long cables and on this account most of the previous discussions of submarine cable transmission have been concerned principally with distortion and means for correcting it. As terminal apparatus was gradually improved means of correcting distortion were developed which practically eliminated distortion as an important factor in the operation of long cables. With distortion thus eliminated the speed was found to be limited principally by the sensitiveness of the receiving apparatus. This limit was, however, eliminated in turn by the development of signal magnifiers. During recent years in which numerous cable signal magnifiers have been available and methods of correcting distortion have been understood, the only factor limiting cable speed has been the mutilation of the feeble received signals by interference. Most cables are operated duplex, and in these the speed is usually limited by interference between the outgoing and incoming signals. In cables operated simplex and also in cables operated duplex, where terminal conditions are unfavorable, speed is limited by extraneous interference which may be from natural or man-made sources and which varies greatly in different locations. The strength of the received current must in either case be great enough to make the signals legible through the superposed interference current. Owing to the rapidity with which the received signal amplitude is decreased as the speed of sending is increased, the limiting speed is quite sharply defined by the interference to which the cable is subject.

With the speed of operation thus limited there were two ways in which the limiting speed could be increased: the interference could be reduced, or the strength of signals made greater. No great reduction in interference due to lack of perfect duplex balance could be expected, as balancing networks had already been greatly refined. Extraneous interference in certain cases could be reduced by the use of long, properly terminated sea-earths. The signal strength could be increased either by increasing the sending voltage or by decreasing the attenuation of the cable. However, with duplex operation nothing at all is gained by increasing the voltage in cases where lack of perfect duplex balance limits the speed, and with simplex operation any gain from raising the voltage is obtained at the cost of increased risk to the cable, the sending voltage being usually limited to about 50 volts by considerations of safety. The attenuation of the cable could be reduced and the strength of the signal increased by use of a larger copper conductor or by using thicker or better insulating material. None of these possible improvements, however, seemed to offer prospect of very radical advance in the art.

In telephony, both on land and submarine lines, an advantage has been obtained by adding inductance [3] in either of two ways, by

[3] The idea of improving the transmission of signals over a line by adding distributed inductance to it originated with Oliver Heaviside in 1887 (Electrician, Vol. XIX, p. 79, and Electromagnetic Theory, Vol. I, p. 441, 1893), who was the first to call attention to the part played by inductance in the transmission of current impulses over the cable. He suggested as a means for obtaining increased inductance the use of iron as a part of the conductor or of iron dust embedded in the gutta percha insulation. He also proposed inserting inductance coils at intervals in a long line. Other types of coil loading were proposed by S. P. Thompson (British Patent 22,304—1891, and U. S. Patents 571,706 and 571,707—1896), and by C. J. Reed (U. S. Patents 510,612 and 510,613—1893). M. I. Pupin (A. I. E. E. Trans., Vol. XVI, p. 93, 1899, and Vol. XVII, p. 445, 1900) was the first to formulate the criterion on the basis of which coil loaded telephone cables could be designed. Continuous loading by means of a longitudinally discontinuous layer of iron covering the conductor was proposed by J. S. Stone in 1897 (U. S. Patent 578,275). Breisig (E. T. Z., Nov. 30, 1899) suggested the use of an open helix of iron wire wound around the conductor and

coils inserted in series with the line or by wrapping the conductor with a layer of iron. The insertion of coils in a long deep-sea cable was practically prohibited by difficulties of installation and maintenance. Accordingly, only the second method of adding inductance, commonly known as continuous loading, could be considered for a transoceanic telegraph cable and it is primarily with regard to continuous loading that the following discussion is concerned.

Most of the proposals to load telegraph cables have had the object of reducing or eliminating distortion, and accordingly most of the mathematical treatments of loading have been from that point of view. The reduction of distortion is, however, not the only benefit to be obtained from loading and, in fact, may not always be secured in the high speed operation of a loaded cable. The principal benefit of loading from the practical standpoint is to decrease the attenuation of the signals so that for a given frequency more current will be received or so that the minimum permissible current may be received with a greater speed of signalling. From the mathematical standpoint there are two ways of treating the problem of the loaded cable, first with regard to the transmission of a transient impulse, and second with regard to setting up steady alternating currents of definite frequency. In the ultimate analysis the solution of either problem can be got from the other. However, for practical purposes they are two distinct means of attack. Which should be used depends on the object to be secured. If one is concerned primarily with the effect of the cable on the wave shape of the signal transmitted over it, it is fairly obvious that the transient treatment has advantages. If, however, one is concerned only with the strength of the received signal, as is the case if there is assurance that the signal shape can in any event be corrected by terminal networks, then the steady state treatment is sufficient and much more convenient to apply. In the case of the real loaded cable the complete transient solution is extremely complex and the steady state treatment relatively simple. The solution of the transient problem of an ideal loaded cable is, however, very valuable to give a physical picture of how inductive loading aids the high speed transmission of signals.

The transient solution of the problem of an ideal heavily loaded cable has been worked out by Malcolm [4] and more rigorously by Carson [5],

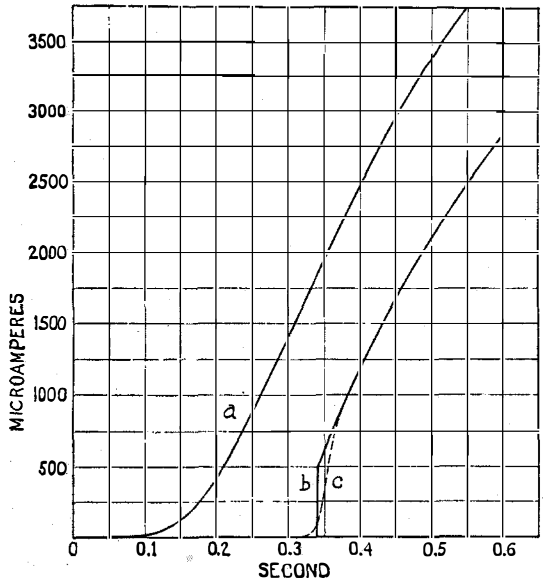


Figure 3—Arrival Curves. a. Non-loaded cable. b. Ideal loaded cable. c. Real loaded cable (approximate)

who have determined the curve showing the change of current with time at one end of the cable if a steady e.m.f. is applied at zero time between the cable and earth at the distant end. Such a curve is called an "arrival curve" and for an ideal loaded cable comprising only constant distributed resistance, capacity and inductance may have a form like that shown in Curve b of Figure 3, which is to be compared with Curve a, which is the arrival curve of a non-loaded cable. The straight vertical part of Curve b represents the "head" of the signal wave which has travelled over the cable at a definite speed and with diminishing amplitude. The definite head of the arrival curve is the most striking characteristic difference between

Krarup (E. T. Z., April 17, 1902) proposed using a closed spiral so that the adjacent turns were in contact. J. H. Cuntz (U. S. Patent 977,713 filed March 29, 1901) proposed another form of continuous loading. Recent general discussion of loaded telegraph cable problems have been given by Malcolm (Theory of Submarine Telegraph and Telephone Cable, London, 1917) and by K. W. Wagner (Elektr. Nachtr. Tech., Oct., 1924).

[4] Theory of the Submarine Telegraph and Telephone Cable, London, 1917.

[5] Trans. A. I. E. E., Vol. 38, p. 345, 1919.

the ideal loaded and the non-loaded cable. In the latter, as is evident from Figure 3, the current at the receiving end starts to rise slowly almost as soon as the key is closed at the transmitting end. When an e.m.f. is applied to the sending end of the non-loaded cable a charge spreads out rapidly over the whole length, the receiving end charging up much more slowly than the sending end on account of the resistance of the intervening conductor. Hence, if a signal train consisting of rapidly alternating positive and negative impulses is applied to the sending end the effect at the receiving end of charging the cable positively is wiped out by the succeeding negative charge before there has been time to build up a considerable positive potential and the successive alternating impulses thus tend to annul each other. In the loaded cable the effect of inductance is to oppose the setting up of a current and to maintain it once it has been established, and thus to maintain a definite wave front as the signal impulse travels over the cable. Hence, with inductive loading the strength and individuality of the signal impulses are retained and a much higher speed of signalling is possible. It should be noted that by speed of signalling is meant the rapidity with which successive impulses are sent and not the rate at which they travel over the cable. This speed of travel is actually decreased by the addition of inductance, about one-third of a second being required for an impulse to traverse the New York-Azores cable from end to end.

It should be noted that Curve b of Figure 3 is for an ideal loaded cable in which the factors of resistance, capacity and inductance are constant. In a real loaded cable none of these factors are constant and the arrival curve cannot be simply and accurately computed. Even the capacity which is usually assumed as constant for real cables varies appreciably with frequencies in the telegraph range, and owing to the fact that gutta percha is not a perfect dielectric material, its conductance, which is also variable with frequency, must be taken into account. Although the inductance of the cable is substantially constant for small currents of low frequency it is greater for the high currents at the sending end of the cable on account of the increase of magnetic permeability of the loading material with field strength and is less at high frequencies than at low on account of the shielding effect due to eddy currents. The resistance is highly variable since it comprises, in addition to the resistance of the copper conductor, effective resistance due to eddy currents and hysteresis in the loading material both of which vary with frequency and current amplitude. Furthermore, there is variable inductance and resistance in the return circuit outside the insulated conductor which must be taken into account. Although it is very difficult to compute the exact arrival curve of a cable subject to all of these variable factors, an approximate calculation in a specific case like that of the New York-Azores cable shows that the arrival curve has the general shape of Curve c of Figure 3. It will be noticed that although this arrival curve lacks the sharp definite head, characteristic of the ideal loaded cable, it still has a relatively sharp rise and that the time required for the impulse to traverse the cable is not greatly different from that of the ideal loaded cable.

Although it is difficult to take exact account of the variable characteristics of the loaded cable in the solution of the transient problem, it is easy to take account of them in the steady state or periodic analysis by means of well-known methods. If a steady sinusoidal voltage, $V_s$, is applied at one end of the cable the resulting voltage, $V_r$, at the distant end will be given by the equation

$$V_r = k V_s \epsilon^{-Pl},$$

where $l$ is the length, $P$, the propagation constant of the cable and $k$, a constant which depends on the terminal impedance and which is unity in case the cable is terminated at the receiving end in its so-called characteristic impedance. The propagation constant is given by the formula,

$$P = \sqrt{(R+ipL)(G+ipC)} = \alpha + i\beta,$$

where $R$ is the resistance, $L$, the inductance, $G$, the leakance, and $C$, the capacity per unit length and $p$ is $2\pi$ times the frequency. The real part of the propagation constant, $\alpha$, is called the attenuation constant and the imaginary part, $\beta$, the wave length constant. By separating $\alpha$ and $\beta$ the amplitude and phase displacement of the received voltage relative to the sent voltage may be computed for any particular frequency and the behavior of a complex signal train may be worked out by analyzing it into its Fourier components and treating them separately. The phase shift is, however, of importance mainly as regards the shape of the received signals and their amplitude may, in general, be obtained from the attenuation constant alone. Thus if it is known that the signal shape can in any case be corrected by terminal networks there is no need to be concerned with more than the attenuation constant to compute the speed of the cable.

In the case of a cable of the permalloy loaded type $\alpha$ is given with an approximation [6] sufficiently close for the purpose of this discussion by the equation,

$$\alpha=\frac{1}{2}\sqrt{\frac{C}{L}}\left(R+\frac{G}{C}L\right).$$

For the purpose of computing $R$ it is convenient to separate it into its components, giving

$$\alpha=\frac{1}{2}\sqrt{\frac{C}{L}}\left(R_c+R_e+R_s+R_h+\frac{G}{C}L\right),$$

where

$R_c$ = copper resistance per unit length
$R_e$ = eddy current resistance per unit length
$R_s$ = sea return resistance per unit length
$R_h$ = hysteresis resistance per unit length

The copper resistance $R_c$ is that determined by a direct current measurement of the loaded conductor since the resistance of the loading tape is so high and its length is so great that the current flowing longitudinally through it may be safely neglected.

The eddy current resistance $R_e$ is given approximately by the formula,

$$R_e=\frac{m\mu^2t^3f^2}{\rho(d-t)},$$

where $t$ is the thickness or diameter of the loading tape or wire, $d$, the outside diameter of the loaded conductor, $f$, the frequency, $\rho$, the resistivity of the loading material, $\mu$, its magnetic permeability and $m$, a constant which depends on the form of the loading material and is in general greater for tape than for wire loading. Although it is possible to compute a value of $m$ the value found in practice is always larger than the theoretical value which is necessarily based on simple assumptions and does not take into account such a factor as variation of permeability through the cross-section or length of the loading material. Accordingly it is necessary to determine $m$ experimentally for any particular type of loaded conductor.

The sea-return resistance may be safely neglected in the computation of slow speed non-loaded cables, but it is a factor of great consequence in the behavior of a loaded cable. By sea-return resistance is meant the resistance of the return circuit including the effect of the armor wire and sea water surrounding the core of the cable. Although the exact calculation [7] of this resistance factor is too complex to be discussed here, the need for taking it into account may be quite simply explained. Since the cable has a ground return, current must flow outside the core in the same amount as in the conductor. The distribution of the return current is, however, dependent on the structure of the cable as well as on the frequencies involved in signalling. If a direct current is sent through a long cable with the earth as return conductor the return current spreads out through such a great volume of earth and sea water that the resistance of the return path is negligible. On the other hand if an alternating current is sent through the cable the return current tends to concentrate around it, the degree of concentration increasing with the frequency. With the return current thus concentrated the resistance of the sea water is of considerable consequence. It is further augmented by a resistance factor contributed by the cable sheath. This may be better understood by considering the cable as a transformer of which the conductor is the primary and the armor wire and sea water are each closed secondary circuits. Obviously the resistances of the secondary circuits of armor wire and sea water enter into the primary circuit and hence serve to increase the attenuation. The presence of the armor wires may thus be an actual detriment to the transmission of signals.

To take account of the hysteresis resistance, $R_h$, and also of the increased inductance and

[6] For accurate computation of attenuation the complete formula for $\alpha$ must be used.

[7] See Carson and Gilbert, *Jour. Franklin Inst.*, Vol. 192, p. 705, 1921; *Electrician*, Vol. 88, p. 499, 1922; *B. S. T. J.*, Vol. I, No. 1, p. 88.

eddy current resistance at the sending end of the cable it is most convenient to compute the attenuation of the cable for currents so small that $R_h$ may be safely neglected. The attenuation thus computed is that which would be obtained over the whole cable if a very small sending voltage were used. The additional attenuation at the sending end for the desired sending voltage may then be approximated by computing successively from the sending end the attenuation of short lengths of cable over which the current amplitude may be considered constant, the attenuations of separate lengths being added together to give the attenuation of that part of the cable in which hysteresis cannot be neglected. In this computation account must, of course, be taken of the increased inductance and eddy current resistance accompanying the higher currents at the sending end.

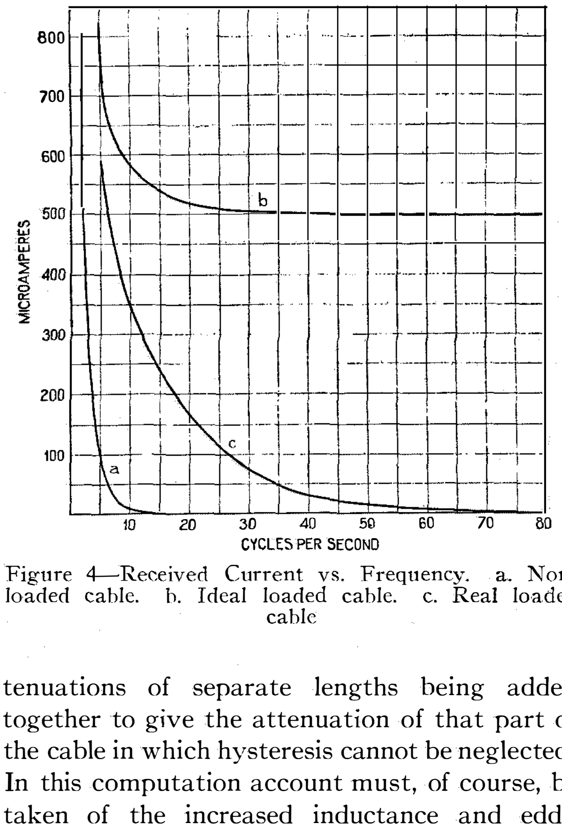


Figure 4—Received Current vs. Frequency. a. Non-loaded cable. b. Ideal loaded cable. c. Real loaded cable

Having calculated or obtained by measurement the several resistance factors and knowing the capacity, leakance and inductance, the whole attenuation of a cable for any desired frequency may be computed and a curve drawn showing the variation of received current with frequency for a given sending voltage. This relation for a particular case is shown in Curve c of Figure 4. Curve a shows for comparison the relation between frequency and received current of a non-loaded cable of the same size, that is, a cable having a conductor diameter the same as that of the loaded conductor and having the same weight of gutta percha. Curve b shows the behavior of an ideal loaded cable having the same inductance, capacity and d.c. resistance as the real loaded cable of Curve c, but in which the leakance and alternating current increments of resistance are assumed to be zero.

Now, if the level of interference through which the current must be received is known, the maximum speed of signalling for the loaded cable may be obtained from Curve c. It is that speed at which the highest frequency necessary to make the signals legible is received with sufficient amplitude to safely override the superposed interference. Just what the relation of that frequency is to the speed of signalling cannot be definitely stated, since it depends on the method of operation and code employed as well as on the desired perfection of signal shape. J. W. Milnor[3] has suggested that for cable code operation and siphon recorder reception a fair value is about 1.5 times the fundamental frequency of the signals, that is, the fundamental frequency when a series of alternate dots and dashes is being sent.

By referring again to the equation for $\alpha$, above, it can now be explained why high permeability is a necessary characteristic of the loading material if a benefit is to be obtained from continuous loading. The addition of the loading material has two oppositely directed effects; on the one hand it tends to improve transmission by increasing the inductance and consequently decreasing the attenuation, and on the other hand it tends to increase the attenuation by increasing the effect of leakance and by the addition of resistance. Not only are the hysteresis and eddy-current factors of resistance added by the loading material but it must also be looked upon as increasing either the copper resistance or the capacity on account of the space it occupies. Generally it is more convenient to look on the loading material as replacing some of the copper conductor in the non-loaded cable with which comparison is made, since by so doing all of the factors outside of the loaded conductor are unchanged. Now, if the

[3] *Journal A. I. E. E.*, Vol. 41, p. 118, 1922. Transactions A. I. E. E., Vol. 41, p. 20, 1922.

loading material is to be of any benefit, the decrease in attenuation due to added inductance must more than offset the increase due to added resistance, including the added copper resistance due to the substitution of loading material for copper. In the limiting case the lowest permeability material which will show a theoretical advantage from this point of view is that which, as applied in a vanishingly thin layer, gives more gain than loss. For any particular size and length of cable there is a limiting value of permeability which will satisfy this condition, this limiting value being greater the longer the cable and the smaller the diameter of its conductor.[9] For transatlantic cables of sizes laid prior to 1923 the minimum initial permeability required to show an advantage is higher than that of any material known prior to the invention of permalloy. Actually a considerably higher permeability than this theoretical minimum was, of course, required to make loading an economic advantage since there are practical limits to the thickness of loading material and since the cost of applying it has also to be taken into account. Further, there are limits on methods of operation imposed by loading which necessitate still higher permeability to make loading worth while.

Since the addition of loading has two opposite tendencies in its effect on attenuation, the practical design of the cable must be based on a compromise between them. Thus, to secure the maximum gain from loading a cable of a given size, the loading material should be chosen of such a thickness that the gain due to increased inductance from a slight increase of thickness just offsets the loss due to increased resistance and dielectric leakance. In practice, of course, economic considerations of the cost of various thickness of loading must also be taken into account.

In designing the New York-Azores cable some assumption had to be made as to the extraneous interference which would be encountered. Theoretical considerations led us to believe that the loaded cable would be no more subject to external interference than non-loaded cables. It even appeared that it would be less affected by some types of interference, for, owing to the shorter wavelength for a given frequency, a disturbance which affects a great many miles of cable simultaneously is less cumulative in its effect at the terminal of a loaded than a non-loaded cable. A reasonable assumption seemed to be that the total overall attenuation which could be tolerated for the loaded cable was at least as great as that which experience had shown to be permissible for simplex operation of non-loaded cables. This maximum permissible attenuation depends, of course, on conditions of terminal interference and no fixed value can be given as applicable to all cables. However, for average conditions of terminal interference in locations free from power line disturbances and where the cable lies in relatively deep water near to its terminal landing, a reasonable value of total attenuation constant for the fundamental frequency of cable code is about 10 (86.9 T.U.) for recorder operation and about 9 (78.2 T. U.) for relay operation. These were the approximate values assumed for the New York-Azores cable and later experience has demonstrated that they were well justified.

Throughout all of the preceding discussion it has been assumed that the relation between attenuation and terminal interference would limit the speed of simplex operation rather than that distortion of signal shape would be the limiting factor. Although this is, in fact,[10] the case with non-loaded cables it was not self-evident as regards the loaded cable, and to make reasonably certain that the speed could be determined from the attenuation-frequency relation required a demonstration that the signal distortion of a real loaded cable could be corrected by suitable terminal apparatus. One of the merits long claimed for loading was that it would reduce distortion and, indeed, an ideal loaded cable with constant inductance and without magnetic hysteresis, eddy current loss, dielectric leakance and sea return resistance would have very little distortion and would give a speed limited only by terminal apparatus. However, a real loaded cable, the inductance of which varies with both current and frequency

[9] See British Patent No. 184,774—1923, to O. E. Buckley.

[10] Recent work of J. R. Carson (U. S. Patent 1,315,539—1919) and R. C. Mathes (U. S. Patent 1,311,283—1919) has shown that with the combined use of vacuum tube amplifiers and distortion correcting networks, distortion in non-loaded cables can be compensated to any desired degree.

and in which all the above noted resistance factors are present, may give, and in general will give when operated at its maximum speed, greater distortion of signals than a non-loaded cable.

To solve the question of distortion on a purely theoretical basis required consideration of the transmission of a transient over the loaded cable. This was made extremely difficult by the existence of numerous possible causes of signal distortion, the effects of which could only be approximated in the solution of the transient problem. In addition to the distortion resulting from the rapid increase of attenuation with frequency due to the various sources of alternating current losses, distortion peculiar to the magnetic characteristics of the loading material had also to be taken into account. There are several types of magnetic distortion to be concerned about. First, there is the production of harmonics as a result of the non-linear magnetization curve of the loading material; second, there is a possible asymmetrical distortion due to hysteresis, and third, there is a possible modulation resulting from the superposition of signals on each other, that is, in effect, a modulation of the head of the wave of one impulse by the tail of the wave of a preceding impulse. The first two of these are effective at the sending end of the cable and the third near the receiving end.

A computation of distortion, including the peculiar magnetic effects, by a steady state a.c. method based on measurements of short loaded conductors indicated that the cable should operate satisfactorily with ordinary sending voltages. Further evidence that none of these various types of distortion would be of serious consequence and that the distortion of a loaded cable could be corrected by terminal apparatus, was obtained by experiments with an artificial line constructed to simulate closely, with regard to electrical characteristics, the type of loaded conductor with which we were then experimenting. This artificial line was loaded with iron dust core coils which served the purpose admirably, not only as regards inductance and alternating current resistance, but also as regards magnetic distortion. Iron dust is, of course, very different in its magnetic characteristics from permalloy. However, owing to the large number of turns on a coil, it is operated at much higher field strengths and on a part of the magnetization curve corresponding approximately to that at which permalloy is operated on the cable. The case for magnetic distortion was in fact a little worse on the artificial line than in the then proposed cable. Figure 5

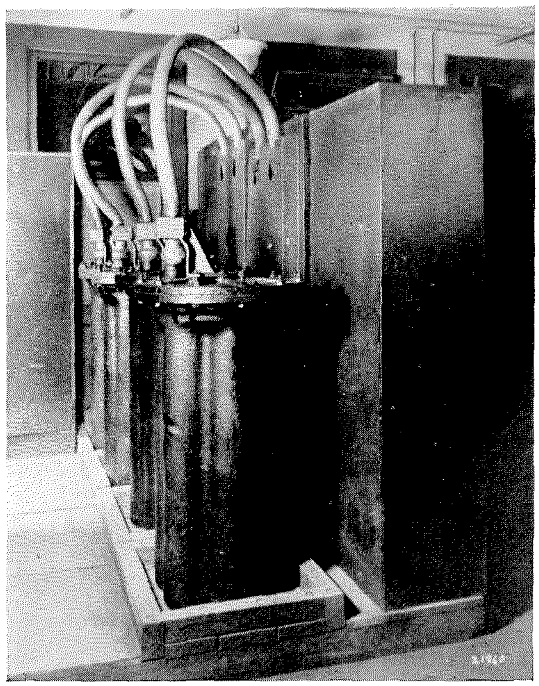

Figure 5—Loaded Artificial Line

shows a photograph of the artificial line, the coils of which are in the large iron pots and the resistance and paper condenser capacity units of which are in the steel cases. This line was equivalent to a 1,700 nautical mile cable loaded with 30 millihenries per n.m. and over it legible signals were secured at speeds up to more than 2,600 letters per minute. Such a speed of operation was quite beyond the range of the then available telegraph instruments, and accordingly special transmitting and receiving instruments were required. The multiplex distributor of the Western Electric printing telegraph system proved an excellent transmitter for experimental purposes and, for receiving, use was made of a combined vacuum tube amplifier and signal shaping network, the signals being recorded on a string oscillograph. Figure 6 shows part of a test message received over the loaded artificial cable at a speed of 2,240 letters per minute.

The results of the tests with the artificial loaded cable were entirely in agreement with our calculations and showed that it was possible to obtain satisfactory signal shape with a coil-loaded cable having alternating current resistance and distortion factors approximating those

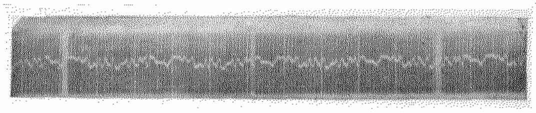

Figure 6—Test Message. Signals received April 16, 1920, over coil-loaded artificial line equivalent to a 1,700 n.m. cable with 30 m.h./n.m. Speed, 2,240 letters per minute

of the permalloy-loaded cable. The exact behavior of the proposed cable, including such factors as sea return resistance and a somewhat variable distributed inductance, could not, of course, be duplicated without prohibitive expense. The approximation was considered, however, to be sufficiently good to justify proceeding with a loaded cable installation so far as questions of signal shaping were concerned. It is interesting to note that the factor which limited the operating speed of the artificial loaded cable was one which is not present in a continuously loaded cable but which would possibly be a serious factor in the operation of a coil loaded cable, namely the oscillation [11] resulting from the finite size and separation of the inductance units.

With the completion of the artificial loaded cable tests there was still one principal question of transmission which had to remain unanswered until a cable had been installed. This was the question of balancing the cable for duplex operation. Ordinary submarine cables are generally operated duplex, the total speed in the two directions being usually from about 1.3 to 2 times the maximum simplex or one-way speed. Except in cases where the external interference is very bad, the limiting speed of duplex operation is determined by the accuracy with which an artificial line can be made the electrical equivalent of the cable. Ordinarily the artificial line is made up only of units of resistance and capacity arranged to approximate the distributed resistance and capacity of the cable. Sometimes inductance units are added to balance the small inductance which even a non-loaded cable has. In the actual operation of cables, artificial lines are adjusted with the greatest care and a remarkable precision of balance is obtained. This is necessary because of the great difference in current amplitude of the outgoing and incoming signals, the former being of the order of 10,000 times the latter. It is quite obvious that it will be much more difficult to secure duplex operation with a loaded than with an ordinary cable, since not only do the copper resistance and the dielectric capacity have to be balanced, but the artificial line must also be provided with inductance and alternating current resistance. Also the sea return resistance and inductance which vary with frequency must be balanced.

In view of these difficulties it will probably be impossible to get as great a proportionate gain from duplex operation of loaded cables as is secured with ordinary cables. However, it is quite evident that it will be possible to secure duplex operation at some speed, since with loaded as with non-loaded cables, the ratio of received to sent current increases rapidly as the speed is reduced and on this account it is much easier to duplex the cable at low speeds than at high. To make duplexing worth while on a cable with approximately equal traffic loads in both directions it is in general only necessary to get a one-way duplex speed half as great as the simplex speed. In fact in some cases the operating advantages of duplex would warrant even a slower duplex speed. On the other hand, there are cables on which the traffic is largely undirectional through most of the day and which would accordingly require a one-way duplex speed somewhat higher than half the simplex speed to justify duplex operation. Whether a sufficiently great speed of duplexing could be secured to justify designing a cable on the basis of duplex operation could not be judged in advance of laying the first cable, and accordingly it was decided to engineer that cable on the basis of simplex operation.

Although it was expected that the new cable might at first have to be operated simplex, it

[11] Carson, Trans. A. I. E. E., Vol. 38, p. 345, 1919.

should not be supposed that any great difficulty or loss of operating efficiency was anticipated on this account. The speed of the New York-Azores cable is so great that to realize its full commercial advantage practically requires working it on a multi-channel basis as, for example, with a Baudot code, multiplex system, similar to that used on land lines. Such a system may be conveniently adapted to automatic direction reversal and with this modification most of the common objections to simplex operation are removed. Indeed, simplex operation may in this case possess a real advantage over duplex from the commercial point of view since it permits dividing the carrying capacity of the cable most efficiently to handle the excess of traffic in one direction.

Although means have been made available for making efficient use of the loaded cable it should be recognized that the method of operation best suited to satisfy commercial demands must be determined from future experience with cables of the new type. This is especially true with regard to relatively short cables. The discussion of the loaded cable problem in this paper has been confined wholly to the realm of long ocean cables where the limitations of the cable rather than terminal equipment or operating requirements determine the best design. This is the simplest case and the one which at present seems to show the greatest gain from loading. Where traffic requirements are limited and where there is no prospect of ever requiring higher speed than can be obtained with a non-loaded cable of reasonable weight, the advantage of loading is less and becomes smaller as the weight of non-loaded cable which will accomplish the desired result decreases. It should not be concluded, however, that loading will not find important application to short cables. Many short cables are parts of great systems and must be worked in conjunction with long cables. In such cases it may pay to load short sections where otherwise loading would not be justified. Permalloy loading also offers great possibilities for multiple channel carrier telegraph operation on both long and short cables and with this type of operation in prospect it is too early, now, to suggest limits to the future applications of permalloy to cables or to predict what will be its ultimate effect on transoceanic communication.

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