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WESTERN UNION
Technical Review

CARRIER TERMINAL WITHOUT RELAYS

CUSACK AND MICHON

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WESTERN UNION TECHNICAL REVIEW

A publication for technically-minded members of the Company's organization, issued quarterly by the Committee on Technical Publication, 60 Hudson Street, New York 13, N.Y.

Western Union's President, in recent public statements and in testimony before Government bodies, has frequently stated that maintenance of the Company's vitality depends on its ability to utilize in telegraphy the results of modern science and engineering. On a world-wide scale, engineering devices have placed Western Union in the forefront of telegraphic progress. Its network of printerized circuits has no equivalent elsewhere. To a greater degree than any other telegraph administration, Western Union is going into reperforator switching with push button operation.

In keeping with its purpose, this issue of Western Union TECHNICAL REVIEW presents papers which are importantly related to recent progress. The leading article by F.H.Cusack and A.E.Michon is ahead of its day in that it describes a development of apparatus which has yet to be widely distributed throughout the field.

The C.H. Cramer article on Sunspots will form a background to intelligent handling of circuits during the period when earth currents, having paralyzed long distance radio transmission, begin to make themselves felt on telegraphic wires and submarine cables.

In the article by T. F. Cofer on "Printing Telegraphy and Inductive Disturbances", there is presented a summary of the subject which will find many practical applications in the Testing and Regulating man's daily work.

Thus this issue of TECHNICAL REVIEW takes another step toward its objective of informing the Company's 2000 or so technical employees regarding the scientific thinking and progress of their Company. Ultimately, the combined issues are expected to constitute a rather complete file of recent telegraph engineering literature.

* * *

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AN FM TELEGRAPH

TERMINAL WITHOUT RELAYS

By

F.H. Cusack and A.E. Michon

A paper describing Western Union Type 20 channel terminal, presented at the Summer General Meeting of the American Institute of Electrical Engineers in Montreal on June 12, 1947. Reprinted by permission of the A.I.E.E.

INTRODUCTION.

During the past eight years the use of frequency-modulated carrier telegraph equipment has been extended in the Western Union system at a greatly accelerated pace until the channel mileage in service now runs into the hundreds of thousands. A paper[1] published in 1942 described the FM channelizing equipment which is now in widespread use and discussed the advantages in transmission efficiency which it affords; namely, the singular ability of this system to tolerate large and rapid variations of received level, and its improved performance in the presence of noise. Since the FM method was first introduced there has been ample opportunity to compare its performance and continuity with that of the older method, amplitude modulation[2]. Experience has definitely established the superiority of the FM method, and as a result, all of the AM equipment has gradually been replaced. Meanwhile other workers in the field have published data confirming these conclusions[3,4] and FM telegraphy has found many applications in wire-line and radio service[5,6].

In the past, practically all of the FM carrier telegraph channels in the Western Union system have been of the high-speed type, designed for 70-cycle signalling and employing a 300-cycle spacing. Channel terminals were provided with elaborate facilities for monitoring operation and were equipped to work with almost any type of telegraph circuit. This universal ability to serve was extremely useful when relatively small numbers were involved and circuit extensions to all manner of grounded and metallic facilities were required. However, with the advent of microwave radio relay systems and a vast expansion in the use of wire carrier to supplant d-c telegraphy, a new, simplified carrier terminal became an economic necessity.

In the terminal described by this paper, the design has been limited intentionally to teleprinter and relatively slow-speed multiplex operation. Relays for transmitting and receiving have been entirely eliminated, and in their place, electronic devices have been used. All testing and regulating functions have been disassociated from the rack-mounted equipment and concentrated in a central test board. Individual monitoring equipment is not provided for each channel terminal, but rather in a ratio of one monitor set for every 18 channels. The channel terminal itself comprises only two units, one a panel mounting the sending and receiving filters, and the second a "transceiver" which, as the name implies, combines the transmitting and receiving functions. As a result of all these innovations, the cost of terminal construction has been materially reduced and equipment has been introduced which is more suitable for a telegraph system where carrier operation is the rule rather than the exception.

GENERAL DESCRIPTION

The new channel terminal has been designed for a maximum dot frequency of 35 cycles per second. This is sufficient for two-channel multiplex working at the present speed of 66 words per minute and provides ample transmission margin for teleprinter signalling at 75 or even 100 words per minute. Frequency modulation of the transmitted carrier is accomplished by raising the channel frequency 35 cycles above its mid-channel value to send a spacing impulse and by depressing the frequency 35 cycles below its nominal value for marking. The individual channels are given a band width of 80 cycles and are spaced at 150-cycle intervals in the spectrum.

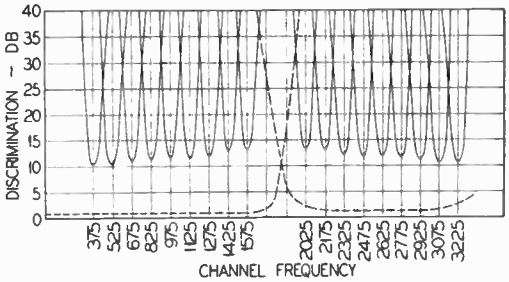

Fig.1 - Channel Layout.

These carrier telegraph terminals are furnished in nine different frequencies from 375 to 1575 cycles. Two groups, or a total of 18 channels, can be operated over a voice frequency transmission band approximately 3000 cycles wide. Figure 1 shows their relative positions in the spectrum and indicates the characteristics of the different receiving filters. One group of nine channels is transmitted directly while the second is modulated with a 3600-cycle carrier to obtain channels from 2025 to 3225 cycles. Flexibility of repeatering is improved and warehousing is simplified to some extent by standardizing only nine different types instead of designing channels to fill the entire band.

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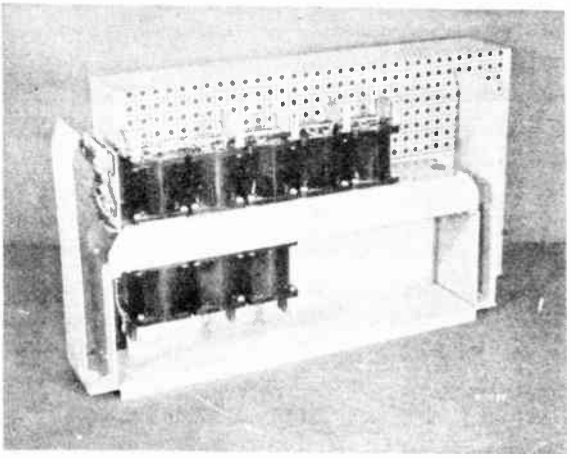

Fig.2 - Filter Panel.

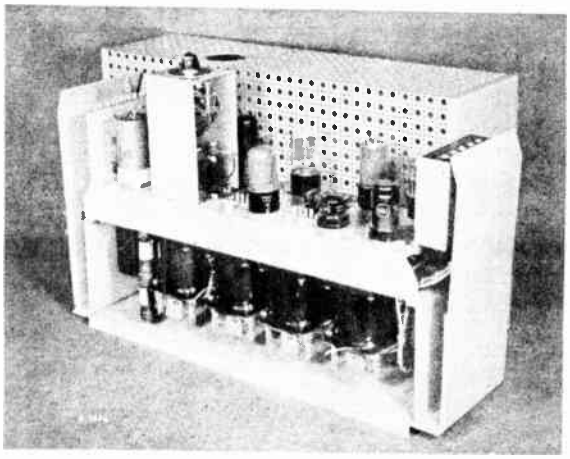

Fig.3 - Transceiver.

Figures 2 and 3 are photographs of the sending-receiving filter panel and of the transceiver, respectively. Together they occupy only 8 3/4 inches of space on a 19 inch rack. With a 10 foot ceiling height, it is possible to locate eight terminals, complete with power supply, on each rack face as shown in Figure 4. In practice the 375-cycle channel is sometimes omitted because of band width limitations, so racks of eight channels are manufactured and shipped completely assembled and ready for installation. When used, the ninth channel is located elsewhere. Figure 5 shows the test board where the control panels and monitoring equipment are concentrated.

Fig.4 - Rack Layout

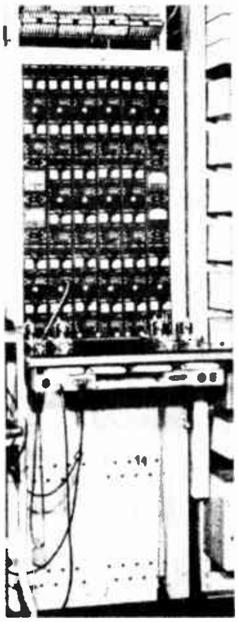

Fig.5 - Test Board.

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The essential elements of the terminal circuit are shown in the block diagram of Figure 6. The outgoing signals are transmitted by keying the sending leg to produce single-current telegraph impulses which in turn serve to switch a suitable reactance in the frequency-determining circuit of an oscillator. Electronic switching is employed, and the frequency is shifted abruptly between the spacing and marking conditions. The carrier is next amplified and padded to its proper level and is then transmitted through a band-pass filter to the sending bus. The incoming channel frequencies are selected from the receiving bus by a similar band-pass filter which is followed by an amplifier and limiter. The amplitude-limited signals are passed through a balanced linear discriminator and rectifier to obtain d-c telegraph signals. A low-pass filter removes the carrier and certain noise components after which a non-linear d-c amplifier with a square wave output feeds single-current telegraph impulses to the receiving leg. By interconnecting the sending and receiving legs of two transceivers the equipment can be made to function as a repeater. An arrangement is also provided to permit half duplex operation using the same leg for sending and receiving.

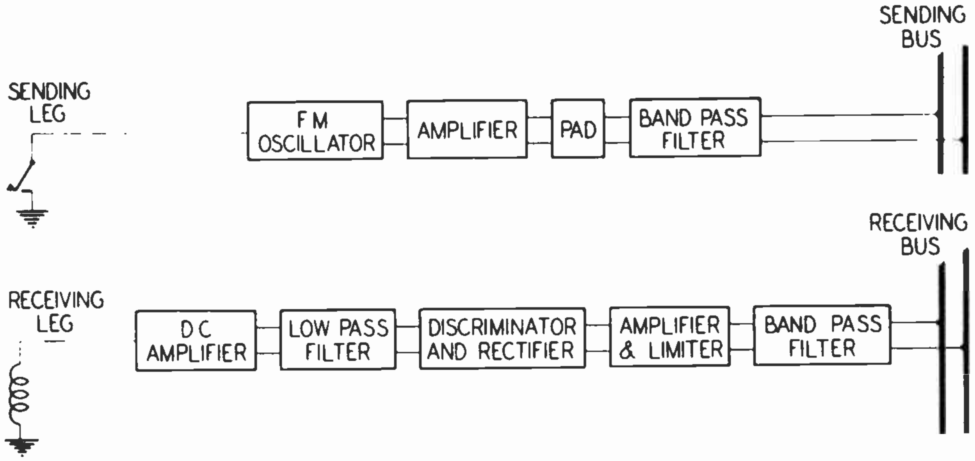

Fig.6 - Block Diagram of Terminal.

TRANSMITTING CIRCUIT

In multi-channel carrier telegraphy, considerations of spectrum economy make it essential that the transmitted band width be restricted to such frequencies as are required to minimize characteristic distortion. The transmission of higher order sidebands is certain to produce excessive interchannel interference at the receiver unless spectrum space is wasted by locating the channels farther apart than would otherwise be necessary. There are two methods commonly used to restrict the transmitted band

and both were employed in the equipment described by the previous paper[1]. A low-pass filter was interposed between the transmitting relay and the FM oscillator causing the pulses to approach a sinusoidal wave shape during the transition periods. Since the oscillator was so arranged that its output frequency increased or decreased in proportion to the magnitude of the control current, the frequency variations occurred gradually and the transmitted carrier reached its steady-state marking or spacing frequency only for a portion of each pulse. In addition, a band-pass filter was connected between the oscillator output and the sending bus to insure suppression of the higher order sidebands present to some extent even in sinusoidal frequency modulation.

The low-pass filtering method is not readily applied to a circuit from which the sending relay is omitted and the frequency is modulated directly by line telegraph signals. The character of the d-c signals will be somewhat influenced by conditions on the leg circuit, particularly during periods of variable line insulation, and hence it becomes practically mandatory to use an abrupt frequency variation responsive to small changes in signal amplitude. Sufficient discrimination is then provided in the sending filter to suppress the resultant higher order sidebands.

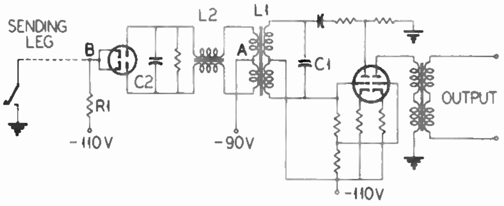

Fig.7 - Transmitter Circuit Diagram.

Figure 7 is a circuit diagram of the FM oscillator. When the sending leg is open it draws no current except for possible leakage effects, and therefore the potential at point A is about 20 volts positive with respect to that at B. As a result the diode conducts and acts as an electronic switch to cut capacitance C_2 out of the tank circuit of the oscillator. The transmitted frequency is now determined by the values of L_1, L_2 and C_1 which are proportioned to produce the desired spacing frequency. As soon as the sending leg circuit is closed, a current flows which produces a drop of approximately 40 volts in resistor R_1 and causes the potential at A to become about 20 volts negative with respect to B. Consequently the diode becomes non-conducting and C_2 is switched into the tank circuit to lower the oscillator frequency. The value of C_2 is so chosen that the marking frequency is just 70 cycles below the spacing frequency. It should be noted that the oscillator represents a low impedance termination regardless of whether the leg is opened or closed at the sending operating position. This reduces the effect of any induced interference on the line, while the fact that the termination is entirely resistive provides signals free from bias.

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The resonant frequencies of the oscillator circuit are given by the following formulas:

$$f_s = \frac{1}{2\pi\sqrt{\frac{L_1 L_2}{L_1+L_2} C_1}} \qquad (1)$$

$$f_m^2 = \frac{f_s^2 + f_x^2 \pm \sqrt{(f_s^2+f_x^2)^2 - 4f_0^2 f_x^2}}{2} \qquad (2)$$

Where $f_0 = \frac{1}{2\pi\sqrt{L_1 C_1}}$ and $f_x = \frac{1}{2\pi\sqrt{L_2 C_2}}$

It will be observed that Equation (2) has two possible solutions indicating that the circuit has two natural periods of oscillation when C_2 is present. One of these is the desired marking frequency while the other is considerably higher depending upon the choice of values for the reactive elements. Conflict is avoided by making the resonant impedance at the higher frequency sufficiently low that a value of feedback which produces stable oscillation at the lower frequency is not enough to permit oscillation at the higher frequency. The rated output power of the oscillator and its associated amplifier is +10 dbm.

When reactive circuit elements are switched electronically to produce direct frequency modulation, it is often difficult to obtain a satisfactory abrupt deviation. The sudden transition of the telegraph impulse induces a transient in the tuned circuit of the oscillator which can persist for the duration of the transition interval or even longer. This may cause considerable signal distortion. The problem was solved by using the balanced circuit configuration represented by the differential transformer, the split inductor L_2, and the twin diode of Figure 7. Switching transients are balanced out in the transformer secondary and thereby prevented from reaching the oscillator circuit.

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Figure 8 shows the manner in which the oscillator frequency is varied by the control current in the leg circuit. The entire frequency swing occurs during the interval when the current ranges from 25 to 45 milliamperes. Since this current is normally adjusted to 70 milliamperes for marking, it is apparent that the proper deviation will be produced regardless of line variations within limits ordinarily encountered.

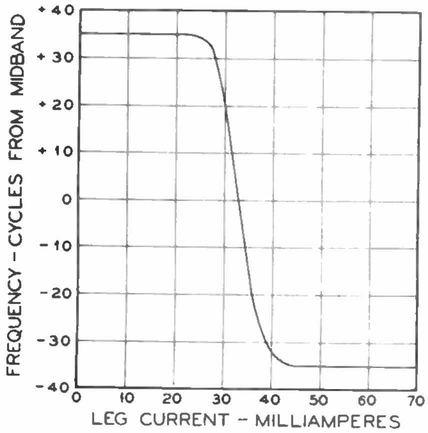

Fig.8 - Transmitter Frequency vs Leg Current.

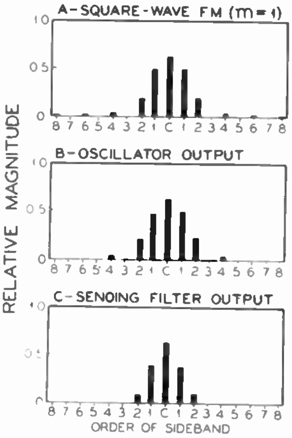

Fig.9 - Sideband Distribution Diagrams.

Figure 9 will serve to indicate the nature of the resulting frequency modulation. Diagram A shows the sideband amplitudes for square-wave modulation with a deviation ratio of unity[7]. Diagram B shows the sideband distribution measured at the output terminals of the oscillator for the comparable condition, i.e., when transmitting reversals at 35 cycles. The degree of agreement between the theoretical and measured values is sufficient to indicate that the frequency is being modulated very abruptly. Diagram C shows the sidebands remaining after the signals have passed through the band-pass filter to the sending bus. The carrier and first order sidebands predominate and account for about 98 percent of the transmitted power. The second order pair, which contain the remainder, fall between channels and are now so small that they are readily suppressed by the receiving filters.

RECEIVING CIRCUIT

At the receiving terminal of a carrier telegraph system the band width assigned to a channel determines the permissible signalling speed as well as the amount of noise and interchannel interference experienced. Figure 10 shows the characteristics of a representative receiving filter and also the corresponding

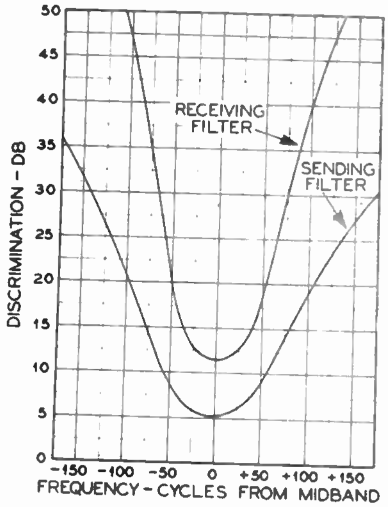

Fig.10 - Filter Characteristics.

sending filter. Interference is kept within tolerable limits by providing the receiving filter with at least 30 db discrimination against the spacing frequency of the channel below or the marking frequency of the one above and at least 20 db discrimination against second order sidebands from these channels. The overall band width of the sending and receiving filters in tandem has been made 2.3 times the maximum intended signalling frequency. This is slightly more than the theoretical minimum and has been found sufficient to permit operation without appreciable characteristic distortion.

Figure 11 is a schematic diagram of the receiver circuit. Incoming signals are amplified by the first section of twin triode V_1 and amplitude limited by the second section of this tube and by pentode V_2. The limiting action helps to reduce the fortuitous signal distortion caused by noise and renders the received signal immune to the influence of variations in received level. The output of the limiter is made constant for input levels between -50 and +10 dbm.

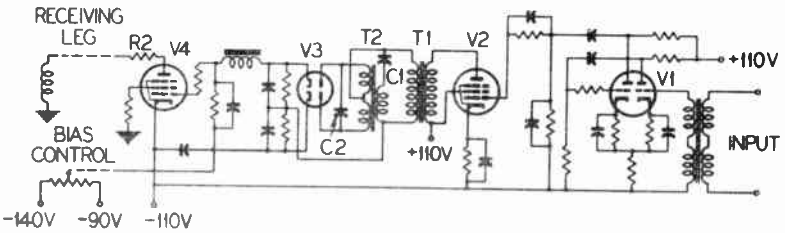

Fig.11 - Receiver Circuit Diagram.

Following the limiter is the familiar balanced discriminator represented by Transformers T_1 and T_2, with their associated capacitances C_1 and C_2, and the twin diode V_3. The output voltage developed by one side of the diode has an amplitude-frequency characteristic whose slope is the opposite of that delivered by the other side. After these outputs are differentially combined, the rectified signal voltage, as shown by Figure 12, is approximately linear for frequencies within the useful range and passes through zero at midband.

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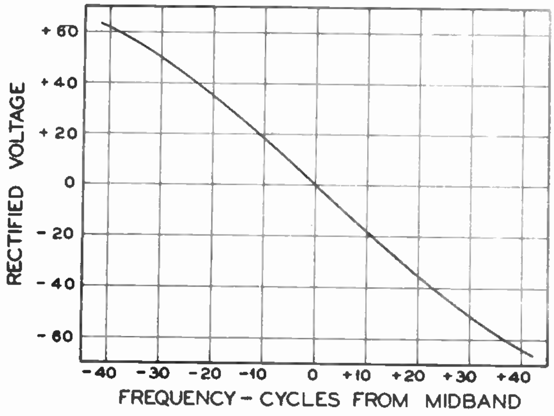

Fig.12 - Discriminator Characteristic.

After filtering to remove the carrier, the rectified voltage is used to control the output pentode V_4. A plate current of 70 milliamperes flows in the receiving leg for a marking signal and is cut off for spacing. A control on the d-c grid bias is provided to permit adjustment of the operating point to secure unbiased signals. The non-linear amplifier is made responsive to small changes in input and hence delivers a signal voltage approximating a square wave shape.

The low-pass filter inserted between the discriminator and the final amplifier is of interest because of the effect of this filtering on transmission. In addition to removing carrier, the low-pass filter is also useful in minimizing the effect of noise components whose frequencies lie outside the band assigned to the channel and thus performs a function somewhat similar to that of the band-pass receiving filter. Consider, for example, any interference from an adjacent channel which succeeds in getting through the band-pass filter and into the receiver. The amount of frequency deviation imparted to the received signal by a given level of interference is proportional to its frequency separation from the signalling carrier. This results in the triangular noise spectrum obtained with a linear discriminator and may permit considerable fortuitous distortion to be produced by a relatively small amount of interference. However, it must be remembered that the deviation of the signal frequency is produced at a cyclic rate which also depends on the frequency separation between the interference and the carrier, and it is this rate of deviation which determines the frequency of the rectified interference. For a steady marking or spacing tone on the adjacent channel, the minimum possible frequency is 80 cycles. The interference component in the received signal will either range between 80 and 150 cycles or between 150 and 220 cycles. These frequencies are sufficiently far above the 35-cycle maximum signalling speed that the low pass filter can be designed to reduce the interference and still not introduce characteristic distortion.

HALF DUPLEX AND REPEATER CIRCUITS

As mentioned previously, the channel terminals are not restricted to full duplex operation with separate leg circuits for the sending and receiving functions but are also equipped for two other methods of working. A three-position switch on the face of the transceiver panel is provided for converting the circuit arrangement from duplex to half duplex or to repeater service.

With the half duplex arrangement shown in Figure 13, transmission is obtained in either direction, but not in both directions simultaneously. Signals are transmitted by opening and closing the leg circuit to control the oscillator in exactly the same manner described for the duplex case. In fact the duplex and half duplex circuits are electrically equivalent just so long as a marking signal is being received to keep tube V_4 in a conducting condition. The method of receiving is also the same as that described previously. Single-current signals are supplied to the leg circuit by the plate current of tube V_4, and just so long as the leg is kept closed, the oscillator is effectively isolated from the circuit. When leg current is flowing for a marking signal, there is a drop of approximately 40 volts in tube V_4 and resistor R_2, so point A is about 20 volts negative with respect to B and the diode is non-conducting. When the leg current is cut off by V_4 for a spacing signal, point A is 90 volts negative with respect to B and the diode remains nonconducting. Thus the received signals can have no effect on the transmitting oscillator which continues to deliver a marking frequency.

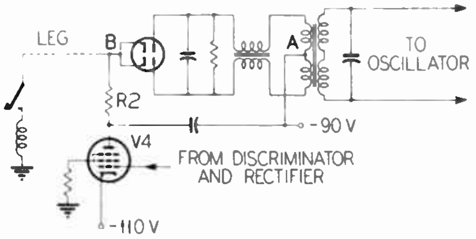

Fig.13 - Half Duplex Circuit.

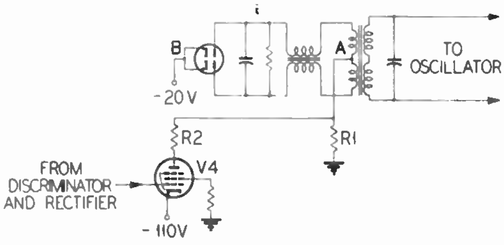

Fig.14 - Repeater Circuit.

In this way the system is used for transmission by either station provided the leg is kept closed at the distant station. One operator may then "break" the other by opening his leg circuit. If at that instant a marking signal is being received, this will transmit a spacing signal to stop the distant operator from sending. If the leg is opened at a time when a spacing signal is being received, there will be no polarizing potential applied to the diode of the sending oscillator. It so happens that the oscillator will transmit a marking frequency for this condition, but this is immaterial because the leg at the distant station is open. As soon as the leg circuit at either station is closed, a correct control of the transmission is once more established.

To repeat a channel from one carrier system to another, the sending and receiving legs of two transceivers are interconnected and the circuit arrangement is modified as shown in Figure 14. To repeat a marking signal, plate current from tube V_4 flows through resistor R_1 where it produces a drop of approximately 40 volts to make point A about 20 volts negative with respect to B. This makes the diode nonconducting and consequently the marking frequency is transmitted. When tube V_4 is cut off by a spacing signal point A is 20 volts positive with respect to B and the diode becomes conducting to cause transmission of the spacing frequency.

PERFORMANCE DATA

The results of various tests of the overall performance of the new channel terminals are given in Figures 15 to 19 inclusive.

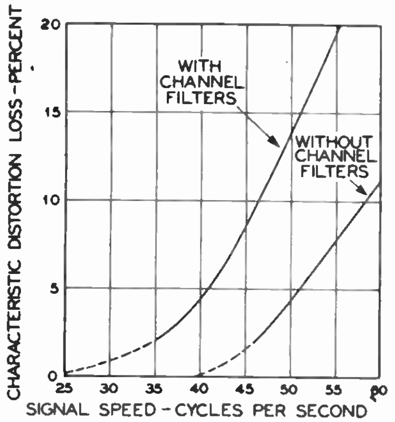

Fig.15 -Characteristic Distortion Loss.

Characteristic distortion loss varies somewhat from channel to channel because each of the nine terminals employs a different pair of band-pass filters with slightly different characteristics. The curve given in Figure 15 for distortion with channel filters represents the average obtained with all types. At the nominal maximum signal speed of 35 cycles the characteristic distortion loss is not more than 4 percent on any channel. The effect of the low-pass filter which follows the discriminator in the receiver can be observed by removing the channel filters from the circuit. As shown by the second curve of Figure 15 characteristic distortion from this source is not appreciable until the signal speed reaches 45 cycles.

In Figure 16 the fortuitous signal distortion in milliseconds is plotted against the r.m.s. noise-to-signal ratio at the receiving bus. The channel was operated at signalling speeds between 30 and 35 cycles and was subjected to a disturbance consisting of random noise uniformly distributed over a band about 3000 cycles wide. The noise-to-signal ratio at the output of the

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receiving filter was 17 db lower than the value at the receiving bus. Except at the high noise levels where the curve is breaking sharply toward failure, the measurements of Figure 16 indicate a tolerance to noise in the neighborhood of 8 to 9 db greater than that obtainable on a comparable amplitude-modulated channel.

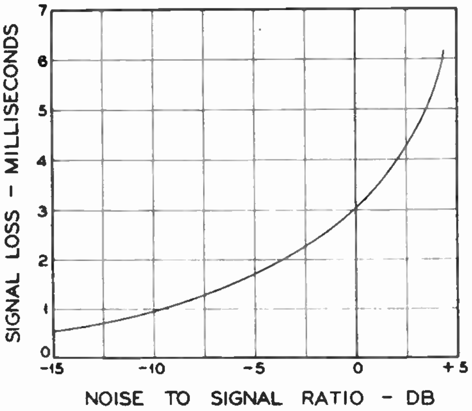

Fig.16 - Effect of Random Noise.

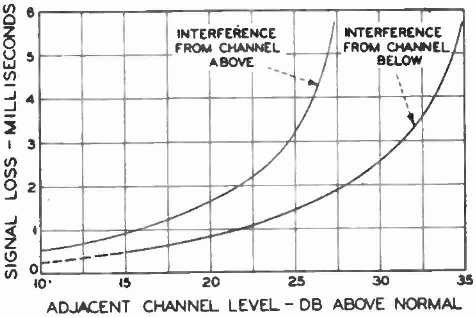

Fig.17 - Effect of Interchannel Interference.

Figure 17 shows the effect of interchannel interference on the received telegraph signal. The distortion loss is not measurable with either of the adjacent channels working at its normal level and is small with levels 10 to 15 db higher than normal. Interchannel interference is not an important consideration under any conditions encountered in service.

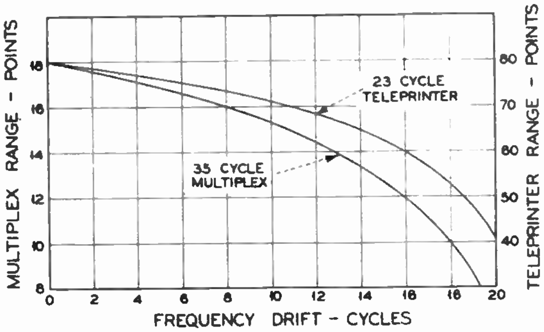

Fig.18 - Effect of Frequency Drift.

It is universally recognized that frequency stability must be carefully maintained in a system operated by frequency modulation. Any drift in the received carrier frequencies creates an inequality between the spacing and marking signals delivered by a linear discriminator and thereby results in biased reception. From printing range measurements shown in Figure 18, it is concluded that the bias distortion is scarcely noticeable unless the frequency drift is permitted to exceed 4 or 5 cycles. This is a tolerance of about one part in 300 to 400, a degree of stability which is not difficult to exceed with simple circuit components. Channel oscillator frequencies are checked in a routine manner every three months and are easily readjusted whenever small errors develop. In the carrier systems over which the channels are operated the drift due to variations in translating carrier frequency is not permitted to exceed one cycle.

Figure 19 shows printing ranges measured on a circuit consisting of many successive carrier systems operated in tandem. At the end of each section two transceivers were interconnected as a repeater so that the overall circuit was entirely electronic. At the maximum speed a satisfactory operating range was obtained over a 6500 mile circuit consisting of 9 successive carrier sections. Therefore it appears unlikely that all-carrier circuits within the geographical limitations of the United States will ever be sufficiently long to require regenerative repeaters anywhere in their makeup.

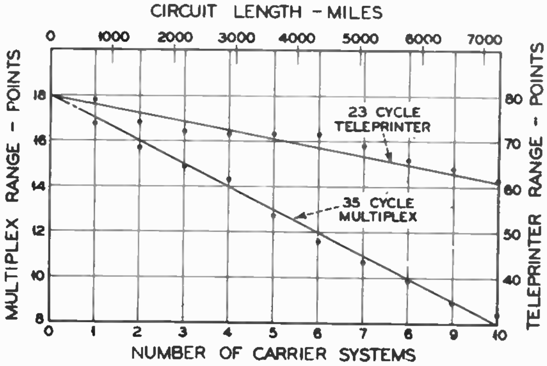

Fig.19 - Printing Range on Multi-Section Circuit.

CONCLUSION

The development of this new carrier telegraph channel terminal has provided an improved type of equipment which is already finding widespread application in the Western Union system and is expected to appeal to many other users. A high grade of transmission efficiency has been achieved by taking full advantage of the superior performance obtainable through the use of frequency modulation. A method of operating d-c leg circuits electronically has been developed which is free from any abnormal effects caused by the presence of noise or leakage. This has made it possible to employ a system of direct transmission which avoids the use of relays anywhere in the overall circuit between ultimate operating positions. Equipment complexity has been minimized, operating and maintenance procedure has been simplified, and savings in space have been effected by concentrating the supervisory functions in a central location and by reducing the types of leg operation. These features have resulted in significant economies in initial expense and also in operating and maintenance costs.

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OCTAVE CHANUTE MEDAL

The Western Society of Engineers has awarded the Chanute Medal for 1946 to Mr. G. C. Hillis for his paper "Telegraphy - Pony Express to Beam Radio." He has been further honored by having his paper chosen for inclusion in the General Appendix of the 1947 Report of the Smithsonian Institution. Mr.Hillis, a Lake Division inspector when the paper was prepared, has since joined the general office staff in the capacity of General Inspector.

The Committee on Technical Publication knows that readers of this REVIEW will share its pride in this achievement by a Western Union Author, and the Committee hopes that this accomplishment will encourage others to the preparation of technical articles which may be of interest to readers of the REVIEW.

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By

C.H. Cramer

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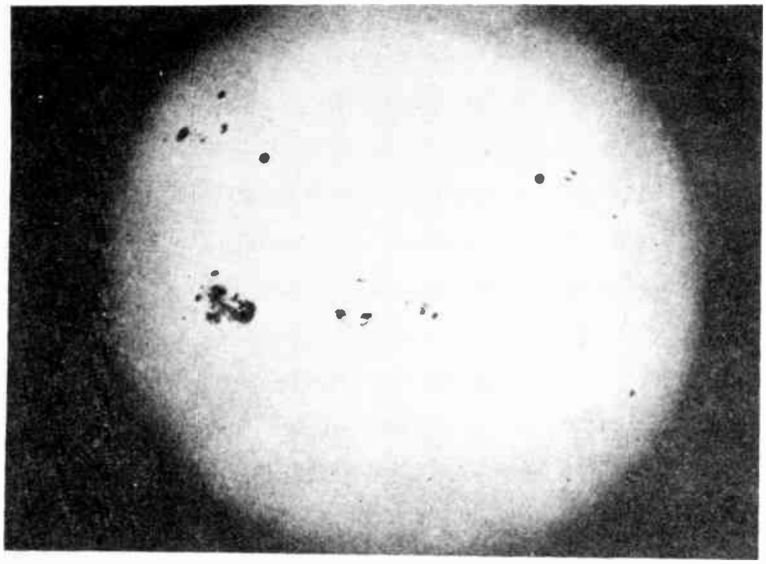
Plaguing domestic and international communications and disrupting transatlantic air transportation schedules, the severe magnetic storms* in February and March 1946 were emphatic reminders of nature's inexorable laws. Detailed factual knowledge of the unfathomed processes which combine to produce these phenomena still is largely unassembled, although theorization and speculation have not been meager. The source of the magnetic storm has been established as 93-million miles distant, at the center of our solar system, and the cause definitely is related in some manner to the well-known sunspots. It also is known that, coming after a period of relative inactivity, the 1946 storms were but the vanguard of disturbances to be expected during the next several years. Since the initial storms, sunspot activity has been increasing, with spots of record size on two occasions and several periods of terrestrial disturbance.

No record of any observation of the darkened areas on the sun now known as sunspots has come down from ancient times. The earliest study of sunspots appears to date back to 1609, the year Galileo constructed the first astronomical telescope. Through his observations of sunspots and their apparent motions, he established, if only to his own satisfaction at the time, that the sun turns on its axis. By 1750 observations were being made with some regularity, and beginning in 1849 data were recorded systematically. Today, from photographs of the sun at various observatories, accurate day-by-day information is obtained of the number, size, and position of spots on the hemisphere of the sun visible from earth.

*The term, "magnetic storm," is used here in a general sense to include the aurora and radio propagation and earth-current effects, as well as disturbances of the earth's magnetic field.



(Mount Wilson Observatory photo.)
The Sun and Sunspots, August 12, 1917.

THE SUNSPOT CYCLE

Eventually it was discovered, as is true of so many of nature's phenomena, that sunspots occur in rather well-defined cycles. When the relative sunspot numbers are plotted, as in Figure 1, it is evident that maximum activity recurs regularly at intervals of approximately 11 years. Between the peaks are valleys of minimum activity. Another fact apparent from the graph is that since 1848 alternate 11-year peaks have been of somewhat greater magnitude than the intervening peaks. Other periodicities are present, some of which have been disclosed only by complex mathematical analysis.

From a casual inspection of the graph, it might be concluded that the next peak will occur near the middle of 1948 and that it will be of smaller magnitude than the 1937 peak. While it is as certain as tomorrow's sunrise that a peak will occur within the next several years, with accompanying disturbances on the earth, authorities have reached varying conclusions as to its exact time and relative magnitude. The predictions of the time of occurrence, arrived at by different methods of analysis, range from early 1948 to 1951. Some authorities expect a low maximum, consistent with recent cycles; others predict a peak of considerably greater magnitude than the last. Support for the early high-peak predictions is found by some in the rapid rise in sunspot activity during and since 1945.

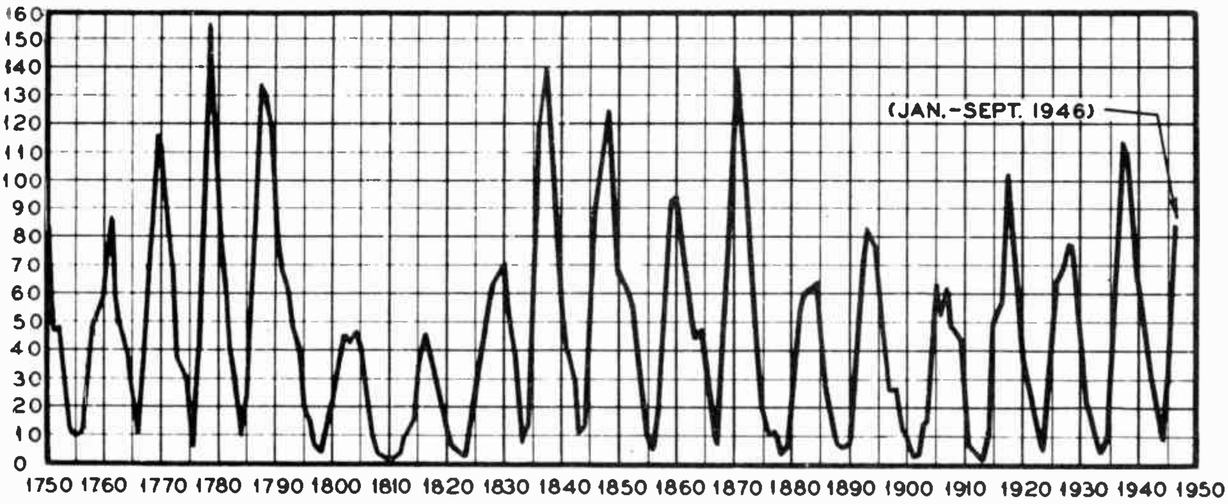


Fig. 1 - Relative Sunspot Numbers.

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TERRESTRIAL PHENOMENA

The terrestrial effects produced by, or at least in some way coincident with, sunspots and which occur in similar cyclic patterns, are the most important phase of the phenomena to the workaday world. A definite relationship has been established between the sunspot cycle and auroral activity, variations of the earth's magnetic field, earth currents, and radio propagation effects, the disturbances or variations in these reaching a maximum during the sunspot peak. All of these effects are magnified highly during the great magnetic storms.

Attempts have been made and still are being made by a host of investigators to correlate the sunspot cycle with a wide variety of terrestrial phenomena and activities in addition to the more direct electrical and magnetic effects. Similar and related periodicities have been claimed or suggested in such diverse fields as weather, plant and animal life, periods of prosperity and depression, market indexes, human behavior, and the course of world events. The degree of validity of the numerous alleged relationships probably varies as widely as the types of phenomena involved. The following discussion will be confined to the well-established electrical and magnetic effects, particularly to severe storm conditions.

DISTRIBUTION BY LATITUDE

Sunspots occur principally in the solar zone between 10 and 30 degrees north latitude and in the corresponding south-latitude zone. The larger the spot or group of spots, the greater is the probability of an accompanying storm, although size alone does not seem to be the determining factor. Thus far, solar photographs disclose no distinctive differences between spots that produce storms and those that do not. In each case, they have the appearance of irregular darkened areas which have been described as resembling vortexes in the gaseous outer layer of the sun. This suggests that spots which are coincident with storms are accompanied by some other solar activity. Some evidence is advanced for a relationship with chromospheric eruptions or solar flares, which are associated almost exclusively with sunspots and at times extend immense distances out from the sun.

THE PHYSICS OF THE DISTURBANCES

Whatever its exact nature, uncertainty also exists about the manner in which the solar activity is transmitted across 93-million miles and translated into various disturbances of terrestrial normality. The explanation most frequently heard is that streams of corpuscles or charged particles are projected out into space; another suggests that some form of radiation or ray is

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involved. If it is assumed that the earth is most likely to be in the path of corpuscles transmitted from areas at or near the sun's central meridian, then it appears that appreciable time elapses before the incidence of terrestrial effects. Present indications are that a magnetic storm follows within one or two days after passage of the related spot across the meridian. As the solar energy approaches the earth, it apparently is influenced by the earth's magnetic field and directed toward the magnetic poles, producing effects in the earth and the earth's atmosphere, varying from maximum near the poles to zero or at least minimum in the equatorial region. Theory, substantiated by radio propagation tests, holds that ionization of the ionosphere in the affected zone is distorted and increased, causing the several reflecting layers to vary erratically in height, or perhaps at worst to disappear, so that radio waves are absorbed rather than reflected. These disturbances are most pronounced in the short-wave spectrum, sometimes resulting in complete "black-outs" although under severe conditions there may be some degree of disturbance to all radio transmission except on short-distance circuits.

Obliged to depend more completely upon theoretical considerations, scientists account for the other effects of magnetic storms by the hypothesis that, along with increased ionization, forces exist which drive the ions in drift currents of enormous total magnitude encircling the earth. It follows that these currents in turn alter the earth's magnetic field, produce the aurora, and induce the abnormal currents in the earth's crust known as earth-current storms.

Abnormal earth currents are the phase of the disturbance directly concerning the operation of wire communication systems, particularly normal landline d-c telegraph circuits and ocean cable circuits which utilize the earth as a return path for the signaling currents. Any such circuit forms a shunt to the paralleling portion of the earth, so that a part of the earth current may be diverted to the wire. In severe storms, with the absence of corrective measures, transmission on earth-return circuits may be blacked out at times just as completely as radio transmission.

FREAK CURRENTS ON CABLES

Earth currents as observed on wire circuits are alternating currents of irregular and varying wave form, apparently containing prominent frequency components from a fraction of a cycle per hour to nearly 60 cycles per hour. Higher frequencies of small magnitude have been observed on ocean cables up to approximately one cycle per second. The character of the disturbance is illustrated graphically by the section of recording meter chart reproduced in Figure 2. This measurement was made on a cable between New York and Bay Roberts, Newfoundland. The maximum peak in this

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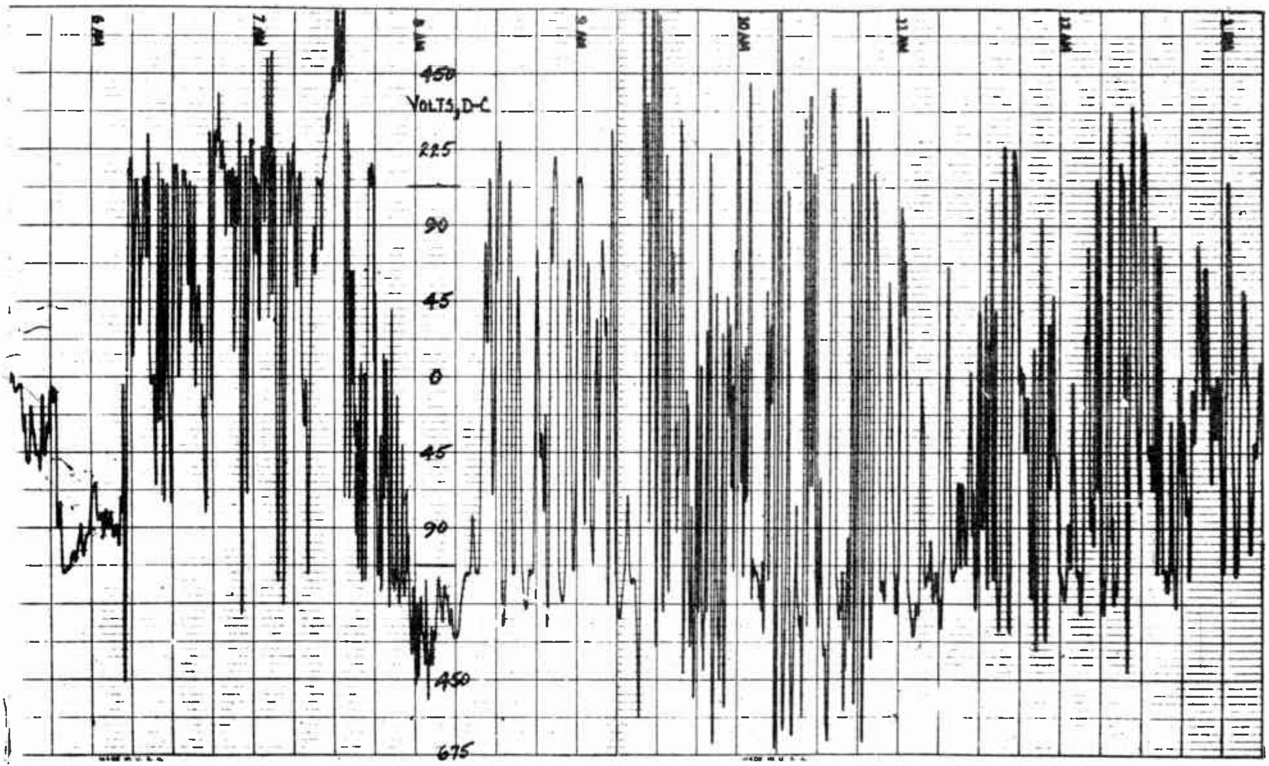

Fig. 2 - Earth Potentials on A New York-Newfoundland Ocean Cable During A Magnetic Storm.

instance exceeded 600 volts, which is not unusual on ocean cables in the North Atlantic in severe storms. Voltages in excess of 500 have been observed on landline circuits, which are considerably shorter (that is, between earth connections) than the usual ocean cable.

Observations of earth currents and related operational disturbances in the domestic telegraph system and the ocean cable system of the Western Union Telegraph Company confirm the statement that the maximum disturbance occurs in the higher latitudes. The section of the United States most affected comprises the states along or near the northern border. In exceptional storms, however, the disturbance may be felt even in the southernmost states to an appreciable extent. The voltage measured on a wire is maximum when the wire lies in the direction of flow of the earth current and is zero when the wire is at 90 degrees to that direction. Tests on circuits out of New York, N.Y., indicate the direction of flow to be nearly constant, being roughly northwest and southeast in that vicinity.

As has been stated, no appreciable success has been attained in attempts to forecast the time or severity of individual magnetic storms. When a storm has occurred, there is some probability that it will recur generally with less intensity at intervals of 27 days, the effective rotational period of the sun. However, it is more likely that the solar disturbance will have cleared before a rotation has been completed or, if the sunspots are still in evidence, the coincident phenomena which cause the original storm are no longer present in sufficient degree to produce terrestrial disturbance of storm magnitude. Some success is claimed in predicting quality of radio propagation several days in advance, and periods of propagation disturbances a month ahead on the basis of solar, geomagnetic, ionospheric, and propagation data.

IMPROVED EQUIPMENT

Though not introduced primarily for that purpose, many of the advances in telegraphy in recent years have been of a nature to lessen considerably the susceptibility of the service to magnetic storms. In the field of international communications, the principal North Atlantic cable systems in large part have been modernized by the introduction of rugged electronic amplifiers and greatly improved signal-shaping networks or filters. The amplifiers have displaced the delicate electromechanical types of signal magnifiers, thus overcoming the hazard of circuit interruption through damage of terminal equipment by abnormal voltages or currents. The modern signal-shaping networks very effectively reject frequencies below the range required for signal reception, thus substantially excluding earth currents. The cable on which the chart of Figure 2 was obtained operated throughout the storm without interruption.

DETOURING THE SUNSPOT ZONES

Experience during the war years has shown that a large measure of freedom from disturbance in long-distance radio transmission can be obtained by avoiding direct transmission paths which pass through or near the zone of maximum disturbance. This may be accomplished by establishing one or more intermediate relay points between the terminals of a radio circuit. Of pertinent interest is the proposal to establish a trunk equatorial belt radio relay system, with lateral north and south links to the terminals of the various circuits. A more immediate example is the installation of an automatic relay station at Tangier, Morocco, in a New York-Moscow circuit as an alternative to the direct circuit which crosses the magnetic storm region.

At the time of the last sunspot maximum, the domestic telegraph system was operated almost exclusively on a d-c earth-return basis. That condition no longer exists, but the d-c circuits are still of major, although decreasing, importance. Though metallic operation or measures analogous to the signal shaping employed on ocean cable circuits can be utilized, the considerable cost can not be justified, particularly as, in the most disturbed sections of the country, transmission interruptions of importance during business hours from this cause were found to average only three

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hours per year over an 11-year period. For economic reasons, the sporadic and short-lived nature of the storms thus has relegated the application of specific corrective measures essentially to emergencies. In recent years methods have been standardized in which the more important earth-return circuits in the telegraph network, in effect, are converted to metallic operation as required. Additional relief may be obtained by rerouting circuits through less disturbed areas. Were accurate storm forecasts available, these emergency measures could be arranged in advance.

The rapid expansion of carrier current telegraphy in the past decade to provide additional facilities and improved trunk-circuit transmission is also unquestionably an important development with respect to earth-current disturbances. The extensive multichannel wire carrier installations already in service utilize metallic circuits and frequencies far removed from earth-current frequencies. Immunity to these occasional disturbances, although not a controlling factor in bringing about carrier operation, is, nevertheless, one of the important advantages derived.

RADIO RELAY.

The first commercial installation of the radio beam relay system in the domestic telegraph plant is under construction, the forerunner of a projected nation-wide network for trunk telegraph service to replace a large part of the present wire plant. This wide-band transmission system provides, through carrier channelizing methods, a very large number of telegraph channels. The line of sight propagation is independent of both ionospheric and earth-current disturbances.

Western Union carrier telegraph systems already operating and those now under construction or scheduled for early completion, both wire and radio relays, total more than 300,000 channel miles. Beyond this, the complete improvement program, to be carried out as rapidly as practicable, will add about two million channel miles.

Although the advantages of reliable advance information on magnetic storms largely are denied it thus far, American telegraphy faces the coming storm period in a considerably stronger position than it occupied during previous sunspot maxima.

* *

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PRINTING TELEGRAPHY AND INDUCTIVE DISTURBANCES

By

T. F. Cofer

Presented at the Engineering Conference of the
Missouri Valley Electric Association at Kansas
City, Mo., April 11, 1946.

Ever since Samuel Morse, the artist, had the original idea, the basic theory of telegraphy has been as shown in Figure 1. This prime consideration is that the intervals of opening and closing a contact at one end of the circuit must be closely matched by the movement of an armature associated with an electromagnet at the other end of the line. Wonderful and weird have been the devices dreamed up to produce this result or to take advantage of it, yet whenever the excrescences are removed, the final purpose is this same simple function. This paper will attempt to describe and discuss only a few of the many devices, and since the grounded telegraph circuit is the most susceptible to inductive disturbances, the discussion will be largely confined to this variety.

Fig.1 - Single Morse Circuit.

The arrangement of Figure 1 may be used successfully for short distances, particularly on city lines in cables. Where lines are electrically long, however, the effect of line reactance lengthens the "break" portion of the pulses, thus tending to alter the relative lengths of make and break. In addition, if the lines are exposed to the weather, changes in the leakage of the line alter the amplitude of the "make" portion of the pulses, thus disturbing the relation between spring tension on the armature and the magnetomotive force of the magnet. The relative lengths of the make and break pulses will be adversely affected by this condition, also. To overcome these difficulties in the line portion of the circuit, the "polar duplex" may be used, as shown in Figure 2. This circuit was originally devised to provide simultaneous operation in both directions in addition to the other features. Note that through the use of a center-tapped winding together with a suitably balanced "artificial line", current applied locally produces no flux in the magnet core. Current entering from the line, however, does produce flux, since the windings are series-aiding to such currents. The armature may now be polarized by means of a permanent magnet included in the device and both polarities of direct current may be furnished at the transmitting contacts. The result is an

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improvement in operation over make-and-break signals for the same impressed voltage to ground, since the rate-of-change of current in the line is hastened by the reversal of polarity, the line is energized for either position of the transmitter, and the armature now moves back and forth in response to the direction of current in the magnet winding rather than to the relation between the pull of a spring with respect to that of the magnet. If the armature also be relieved of making a loud noise, as in a sounder, the weight can be greatly reduced, contacts may be put on it to operate an auxiliary circuit, and the device becomes a telegraph "polar relay". (Any resemblance to the gargantuan assemblies commonly called "relays" by the power industry is pure coincidence. This telegraph relay is just a place where the electric circuit gets a fresh start, like passing the baton at a track meet. There is no inverse time limit, reverse current, wattless component, or other strange characteristic as in a power network).

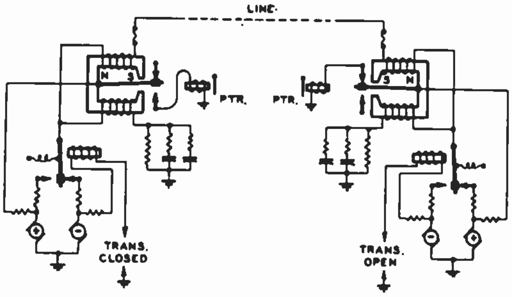

Fig.2 - Polar Duplex Circuit.

But it is here at the polar relay that the telegraph and power industries begin to have a common interest, — the transmission of alternating currents. Both of us must count the cycles, the power company to see that the clocks get their allotted 5,184,000 a day and the Western Union in order to decipher the messages. Since one kind of cycle looks much like another when mixed in the same circuit, it is sometimes hard to tell the "sheep from the goats" on a telegraph circuit exposed to power induction. Although it is pretty obvious that trouble will result if large amounts of alien currents traverse a telegraph line, it may not be clear why smaller values are objectionable. But to illuminate this facet of the problem requires an excursion into the design of printing telegraph equipment and its method of operation.

An early printing system employed a series of alternating current impulses which stepped a type-wheel around from letter to letter. This system was slow and subject to error from lost orientation of the wheel. An improved version of this truly cycle-counting system still exists in sports ticker service.

Several papers have been given previously covering the effect of power induction on the Multiplex telegraph system. Briefly, this latter arrangement depends upon synchronized disc commutators, at each end of the circuit, which are arranged to

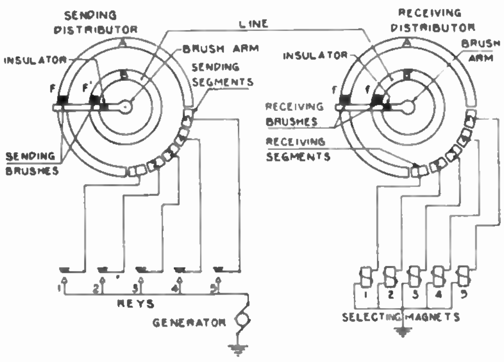

Fig.3 - Multiplex Circuit.

divide the line-time among two or more individual channels. Each channel is assigned five adjacent segments, as shown on Figure 3. Since these segments may be energized individually, a "five-unit-code" shown in Figure 4 may be used to transmit characters over the line. A decoding device attached to each receiving printer determines the character desired during the period it is connected to the commutator brushes and utilizes the remaining time for printing and performing auxiliary operations.

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2		2				2		2	2	2	2				2	2	2			2	2	2					2	2	2	
		3			3		3	3		3		3	3		3	3		3		3	3		3	3				3		3
	4	4	4		4	4			4	4		4	4	4			4				4		4			4		4	4	
	5					5	5				5	5		5	5	5			5		5	5	5	5	5			5	5	

Fig.4 - Multiplex Code.

Although the Multiplex is still the most useful system for trunk line service between important telegraph centers, the present trend in future expansion is toward more and more use of the Teleprinter, which requires less complex terminal equipment. It seems best, therefore, to confine this paper to the printing telegraph of the "start-stop" variety, to which class the Teleprinter belongs. So let us see how this kind of printer works before we undertake to describe how it sometimes doesn't work.

For your benefit, as you will find out later, I will describe the principle of "start-stop" operation with the aid of Figure 5. The sending device may be represented by a disc commutator with seven segments over which brushes may be driven by a clutch from a constant-speed shaft. A mechanical latch, controlled by a locally operated magnet, is arranged to stop the rotation of the brushes when they are on a segment marked "R" for REST. A slip-ring on the commutator completes the circuit, this being connected via a suitable line circuit to the receiving end. Note that the sending REST segment is permanently connected to a source of d.c. potential so that current traverses the line when the brushes are at rest, but that the segment next following in the direction of rotation is permanently not connected to anything. This latter segment is marked "S" for START, for reasons to be shown later. The remaining five segments are arranged to be energized according to the five unit code shown previously in connection with the description of the Multiplex. (Fig. 4).

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Now at the receiving end a somewhat similar arrangement of brushes, commutator, and latch may be used, except the magnet associated with the latch is now connected to the line circuit. A steady current in this magnet serves to hold the latch in a position to stop the brushes on the REST segment. Connections from the five code segments lead to a deciphering device which could be similar to the multiplex printer mentioned previously.

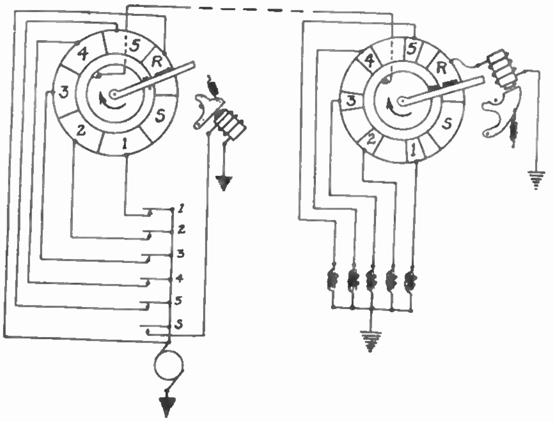

Fig.5 - Start-Stop Circuit.

Fig.6 - Tape Teleprinter.

Consider that the sending operator sets up the code for the character desired on the sending segments and then trips the brush latch. The sending brushes unlock, rotate to the dead segment, the line current falls, and the receiving brushes are unlocked by the release of their tripping magnet. From here on, if everything goes right, the brushes at both ends of the line will be on the same code segments at the same time, the code set up at the sending end will be transferred to the decoder, and after one revolution the whole thing will stop again in the position of REST. Synchronism of a sort is required between sending and receiving brushes, but it may readily be seen that absolute synchronism is not necessary to keep the system in line for only one revolution. Refinements of the system include altering the length of the receiving start segment to make up for inertia in the machinery, shortening the live parts of the receiving code segments to reduce the chance of over-lapping, and arranging these short segments so they may be rotated somewhat with respect to the REST segment to improve the centering of the signals.

While Figure 5 describes only the principle of the start-stop system, an arrangement similar to that shown was used in early versions, and is in use today in repeaters for such systems. But somewhere along the line the mechanical engineers stepped into the picture and "simplified" the apparatus. They did put the printer into a nice container as shown on Figure 6. The device depicted is the usual form of Western Union Tape Printer, about the size and shape of a large typewriter, but somewhat heavier. The machine performs the functions of coding, sending, receiving, and decoding the telegraph signals, using only the make-and-break transmission

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shown in Figure 1. Duplexing and polar line signals may be obtained by adding equipment as in Figure 2. The printed characters appear on a paper tape, gummed on the back, which must be pasted to a larger sheet of paper to complete the receiving process. The use of this tape method facilitates the delivery to the addressee of errorless messages, well centered on the telegraph blank.

Now if you are all students of Rube Goldberg's inventions, and have remembered the lesson given with Figure 5, we can approach Figure 7 without trepidation. This is how the mechanical engineers interpreted the printer operation previously described.

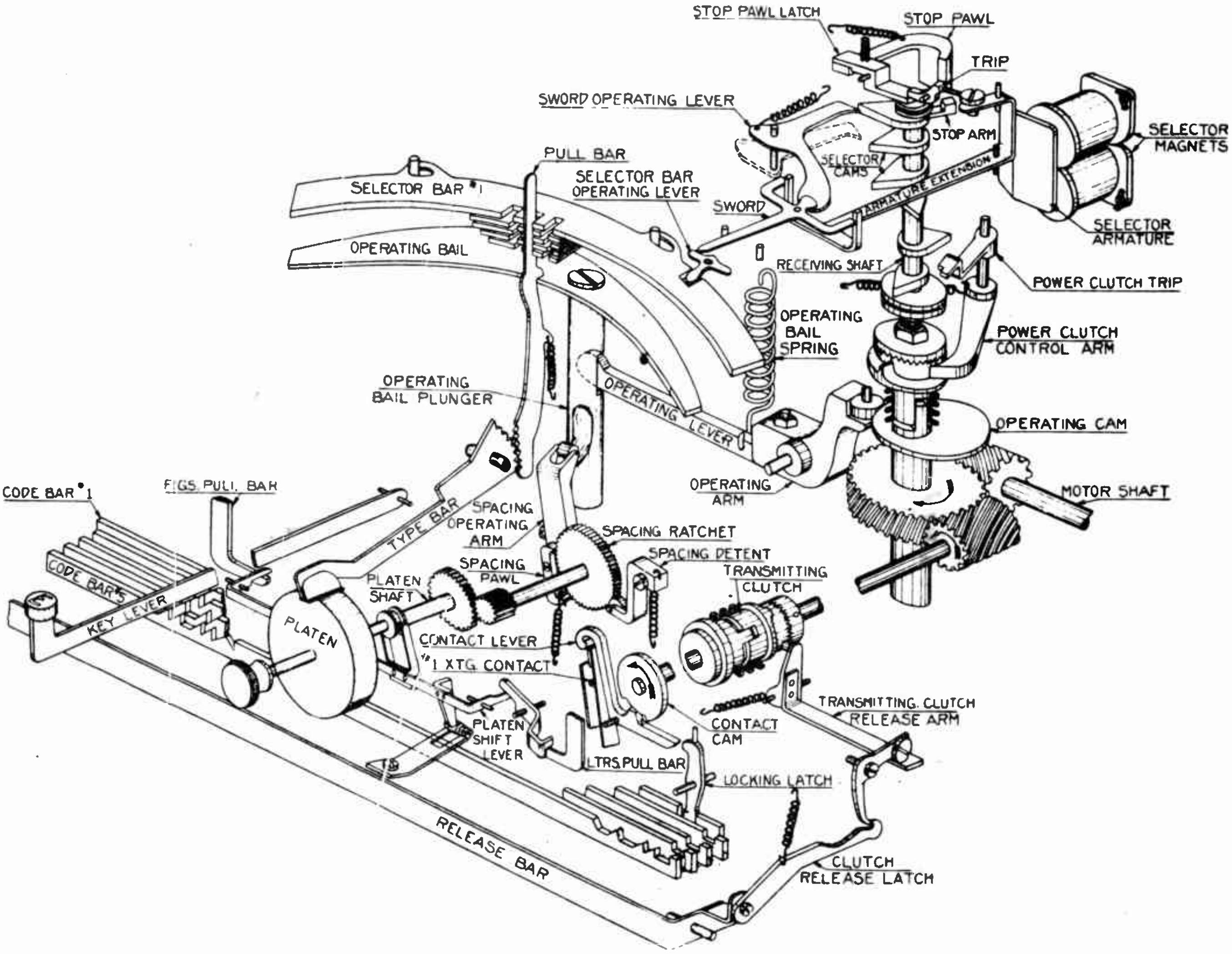

Fig.7 - Mechanism of Tape Teleprinter.

Note that a shaft from a small electric motor included in the printer but not shown here, drives a horizontal shaft through a clutch to a set of cams at the right of the keyboard. There are six of these cams and a like number of contact levers, mostly not shown in the figure. The contacts are connected in parallel and these, with their cams, take the place of the transmitting disc commutator and brushes of Figure 5. The motor also drives a vertical shaft replete with clutches, cams, and levers located at the right rear of the machine near a very lonesome-appearing pair of electromagnets. This formidable array of machinery takes the place of the receiving disc commutator and the decoding portion of the multiplex printer. The rest of the space inside the tape printer is filled with the levers, bars, and gears of a typewriter. And this is how it works,- and it is a salute to accurate machining that so many interlocking parts can function so well.

To send the letter "E", for example, find the third key in the second bank and push down. Those triangular cuts in the bars at the bottom of the machine will move Code Bar #1 to the left and the other four code bars to the right. The #1 Contact Lever will be unlatched and ride the face of its cam. The other four contact levers will stay latched up so their contacts will remain open. The #6 contact, having no code bar anyway, has been keeping the circuit closed all this time, sending a REST pulse. Now the key lever we pushed strikes the release bar, which throws the transmitting clutch into engagement. The horizontal shaft then rotates once, the cams causing the various contacts to cause the circuit to OPEN, CLOSE, OPEN, OPEN, OPEN, OPEN, CLOSE at intervals of 22 thousandths of a second. This series may be recognized as a START pulse, the five-unit code symbol for "E", and a REST pulse by those who wish to investigate Figure 4 again.

Imagine that the above signals have been sent over a suitable line circuit and have arrived at the magnets of the receiving portion of the printer shown here. During the REST pulse, the armature was held to the right, causing the stopping mechanism to prevent rotation of the receiving cam system. When the first OPEN (the START pulse) comes in, the stop pawl is tripped and all the cams begin to rotate, since they are fastened together. About 22 milliseconds later the #1 Sword Operating Lever is pushed to one side by the #1 cam, drawing the #1 Sword backward toward the Armature Extension. Meanwhile the #1 Code Pulse has come in, a CLOSE, pulling up the armature and moving the armature extension to the right. The sword therefore engages its right fork and its point pivots to the left. Shortly thereafter the #1 cam drops off the sword operating lever very suddenly, the sword is thrust forward by its spring into the left side of the #1 Selector Bar Operating Lever. The force of the thrust sends the #1 Selector Bar to the right. As successive cams bring up their swords, the armature remains open, the other swords are pivoted to the right, and the last four selector bars are thereby pushed to the left. "Oneright and four left"; if the selector bars are positioned in this manner the slots in the bars, operating in the manner of the combination of a safe, line up a completely open slot behind the "E" Pull Bar, and nowhere else. When the #6 cam, following the others around, trips the power clutch, the Operating Lever lifts the Bail, which had hitherto restrained all the pull bars from falling back. Upon a slight upward movement of the bail the "E" pull bar is impelled into the open slot behind it by a spring, the projection on this bar catches on the bail and causes the pull bar to rise. All the other pull bars are restrained from engaging the bail by one or more of the selector bars being in the way. So the "E" type bar triumphantly slaps the tape on the platen, and as the bail returns to its original position the spacing arm latches up the right amount of tape to be ready for the next character. Somewhere along the way the stop arm has engaged its pawl and the cam system has stopped rotating after one revolution.

As may be imagined, a different set of signals would cause another combination to be set up on the selector bars so that some other pull bar would engage the bail and a different character would be printed. Since all of this mechanical sleight-of-hand takes place in only 154 milliseconds, about 390 characters or 65 words may be printed per minute. The maximum frequency of the line signals is just under 23 cycles.

To improve the orientation of the receiving cams, a "ranging arm" with associated scale is attached to the starting mechanism of the receiving system. With this arm the starting latch may be rotated with respect to the position of the #1 receiving cam; by this means determining whether the position of the sword points at the time of their final thrust will be decided by the leading edge, center, or trailing edge of the signal. The total travel of the range arm is made 1.2 times the length of one signal pulse, so the scale is graduated to 120 points, 100 points representing the ideal range for a perfect signal and perfect mechanism. Due to mechanical tolerances, wear of parts, and other slight instabilities, the normal "good" printer will not show more than 80 points short-circuit range, and this is not necessarily centered at 60 on the scale.

It should be noted that the ranging of the receiving cam system relative to the start pulse in no way alters the angular displacement between the selection points of the individual signal pulses themselves. Furthermore this ranging process is not continuous, but is an adjustment performed only in checking the performance of the apparatus, say at the opening of a circuit for message traffic. In this case, once the two limits of the range have been established by test, the range arm is moved to the scale division corresponding to the arithmetical average between the upper and lower limits and fastened there by a thumb-screw. It is

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presumed that if a suitable range has been obtained at "line-up-time", any subsequent disturbances will not shorten the range enough to cause the printing of wrong letters. These expected disturbances are very real, are not few in number, and seldom fail to put in an appearance.

In commercial telegraph operation the ranging process is important since experience has dictated that a printer circuit at "line-up-time" should have the ability to print correct characters over a range of at least 50 points to be suitable for message traffic. It can be shown that loss of range is the first and most disturbing result of the presence of the small quantities of continuous extraneous current in the telegraph circuit.

For a specific example of the effects of induction, consider a circuit set up in the Laboratory in New York about equivalent in transmission to a circuit from Kansas City to St. Louis. The terminals were arranged for polar duplex working, but transmission in only one direction was used. On the "mate" or adjacent wire in the simulated line another printer circuit was set up to provide the usual "crossfire" from other telegraph circuits on the same line. A transformer coupled into the line through a 50 ohm resistance provided the means for introducing 60 cycle disturbing currents.

TABLE I

ARRANGEMENT OF LINE FOR PRINTER TEST

MAKE-UP	Trans. end cable	- 15 mi. 13 ga.
	Open line	-230 mi. #9 Cu.
	Rec. end cable	- 10 mi. 13 ga.
Total #9 Cu equivalent		-350 mi. (measured)
OPERATION:	Test Circuit,	Half duplex, polar, 17-B relays 160 volts, plus and minus Line current - 56 ma. E.R.C.
	Mate,	Trans. Testing Machine, 23 cps. 160 volts, plus and minus
A.C. Disturbance:		60 cycles, Edison. Current - 27 ma. E.R.C.
Breakover Observed:		From mate - 23 ma. From 60 cycles - 23 ma. From both - 50 ma.

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TABLE II

OBSERVATIONS OF TRANSMISSION

TRANS. OVER	RANGE LIMITS	CENTER	RANGE
Short Circuit	7½ to 87½	47½	80
Undisturbed line	10 to 85	" "	75
Line crossfire only	15 to 70	42½	55
Line 60 cycles only	20 to 72	46	52
Line both disturbances	35 to 57	46	22
Same, 10 ma. signal bias	42½ to 45	43¼	2½
Same, wet weather leakage	NONE	(Will not print)	

Note: "RY" transmission, 2 minute observations

With the circuit set up as shown on Table I observations of telegraph transmission were obtained as shown on Table II. The characteristic deterioration of range when disturbances distort the signals may be seen. The effect of the disturbances on the signals is illustrated in Figures 8 and 9. In both of these figures the reference point is the beginning of the start pulse. The natural time-lag in the line is therefore not indicated nor is any distortion which affects the absolute time of initiation of the start pulse. The viewpoint is therefore that of the receiving end of the line. (The signal trains have also been inverted in these figures for better inspection, the REST condition being made the origin for the make-and-break signals.)

Figure 8 shows the signal train for the letter "R" measured at three points in the circuit, first at the transmitter; second in series with the line under three conditions of disturbance; and finally at the magnets of the printer under the most severe disturbance conditions shown. Comparison of the top and two bottom trains illustrates how well the receiving relay is able to integrate the badly distorted polar line signal to produce a signal train closely resembling the original in appearance, providing the disturbance is not large enough to break through the signal.

On Figure 9, however, a number of these received signal trains taken from one minute's transmission under the most disturbed condition are arranged for closer comparison with the transmitted signal. Note that while these signals resemble the original in general, there are certain serious differences. In A and D, for example, all the pulses except #1 are displaced almost half the distance toward the trailing edge. Such a shift might be corrected by a range rotation were it not for those signals such as E, where the fourth pulse is shortened and displaced toward the leading edge, or C where the second pulse is also somewhat shortened. Note that in B the signal is nearly normal except for a lengthening of the fifth pulse, while in E the final pulse occurs early.

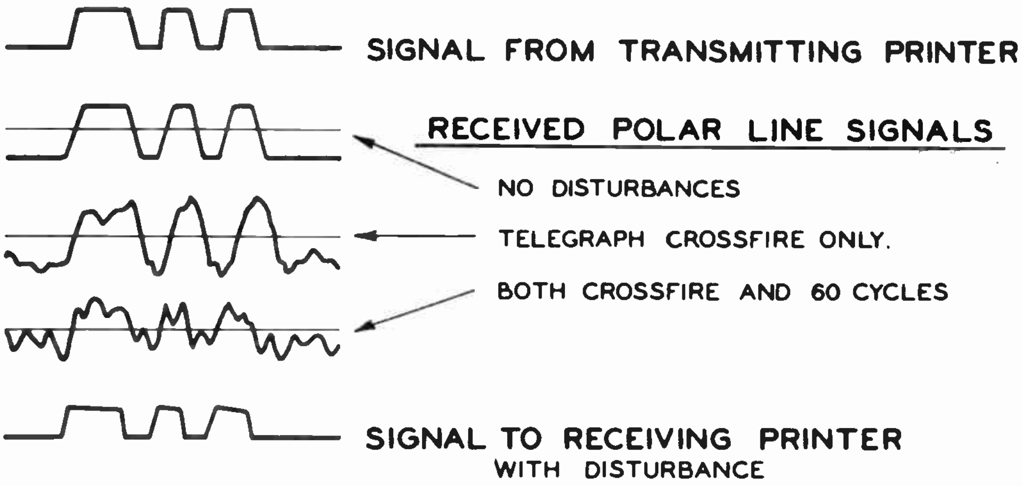
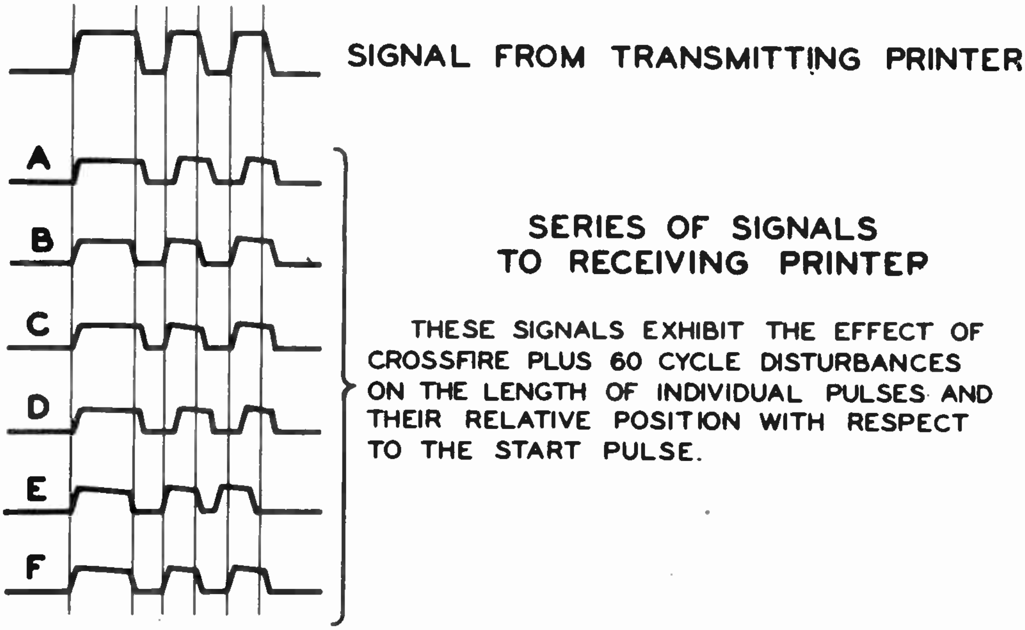


Figure 8



THESE SIGNALS EXHIBIT THE EFFECT OF CROSSFIRE PLUS 60 CYCLE DISTURBANCES ON THE LENGTH OF INDIVIDUAL PULSES AND THEIR RELATIVE POSITION WITH RESPECT TO THE START PULSE.

Figure 9

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The alteration in the position of the signal pulses is a result of the intimate mixture of two or more frequencies in the line current. If the telegraph signals could be transmitted over a line composed entirely of resistance, so that the transitions from one polarity to the other could take place instantaneously, "square topped" pulses would be received which would retain their relative spacing unless the amplitude of the extraneous currents becomes equal to or exceeds that of the signal currents. But the line contains reactance as well as resistance and hence will not transmit efficiently the frequencies necessary to maintain square-topped pulses. (We would be in trouble anyway if we tried to transmit square waves because the transient of the abrupt reversal would cause disturbances between telegraph circuits and between telegraph and telephone circuits that probably could not be tolerated).

The undistorted line signal of Figure 8 exhibits a slope such that the steady-state portion of the wave is only about half the total pulse length. During the gradually changing portion of the wave, extraneous currents of less amplitude than the steady-state value may combine with the signal train in such a manner as to produce shifts in the transition points as illustrated in Figure 9. In the case of any printing telegraph signal train the amount of useful signal will be decreased by such distortion, but in start-stop telegraphy an added opportunity is present.

Because the start pulse is the orientation point of the receiver, the effective position of the entire receiving cam mechanism may be advanced or retarded by a shift in the leading edge of this portion of the signal alone. For example, if the machinery has started rotating ahead of the proper time, the range measured on a following series of perfect code pulses will be shortened by the amount of the advance of the start pulse. Furthermore, if the start pulse be so advanced and a subsequent signal pulse be retarded, the pulse will appear to the printer to be retarded by the sum of the actual retardation plus the advance in the start pulse. In order to visualize more clearly the effect of absolute pulse position on range, refer to Figure 10.

In the upper portion of Figure 10 is a representation of a perfect signal for the letter "R" laid out on a time base, with the printer ranging system indicated as a set of five selection points, fastened together, but the set capable of scanning over the signals. A range scale opposite the beginning of the start pulse measures the excursions. Two such sets are shown for convenience, the upper set being shown locating the trailing edge of the range while the lower set is locating the leading edge of the range. The mechanical distortions existing in the printer itself have been represented here by a "fuzz" on the signal.

It should be noted that as each selection point approaches the edge of its own pulse of the signal, the other four points are also approaching the corresponding edges of their signals. With a

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signal such as this the break-up position will be characterized by the printing of a miscellaneous combination of letters as the various pulses all tend to break up at once. The range indicated for the perfect signal is 80 points, and the range setting for operation of the printer would be at 60 on the scale.

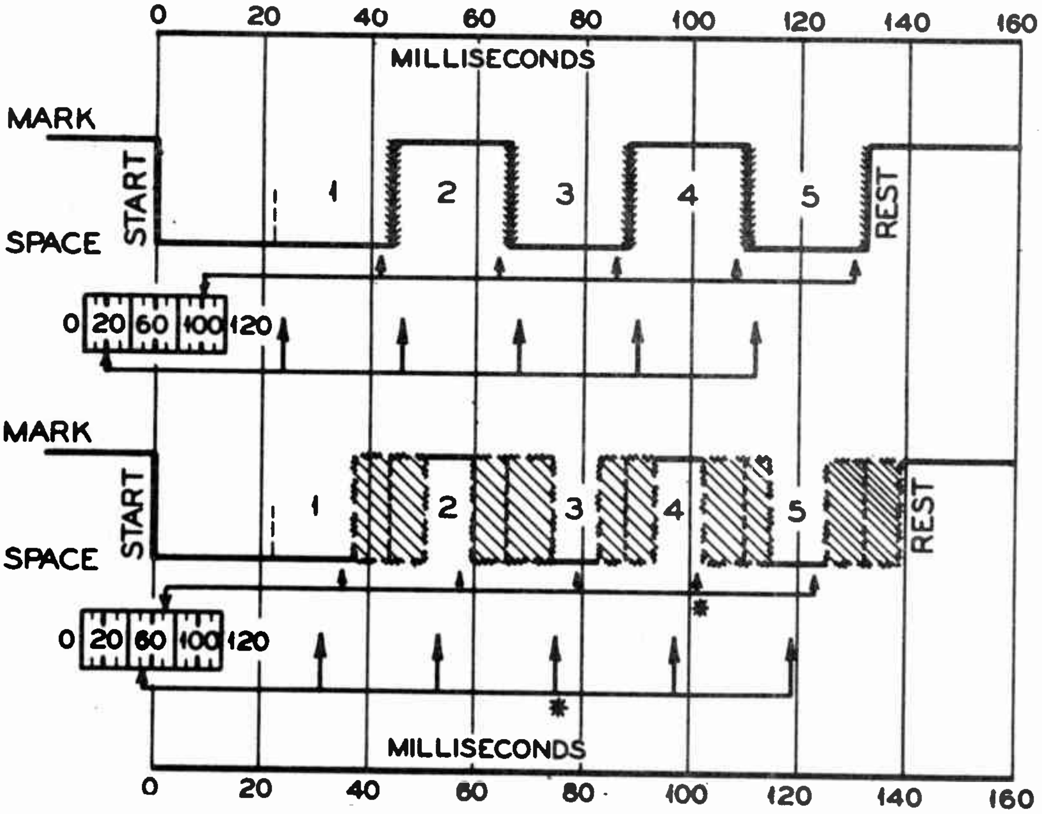

Fig.10 - Range Illustration.

In the lower portion of Figure 10 is shown a signal obtained by plotting the intervals between the start pulse and each of the other pulses in one minute of transmission of the letter "R" over the disturbed hypothetical line between Kansas City and St. Louis. The dashed lines inside the crosshatched areas indicate the correct transition points between pulses and the wavy lines indicate the observed maximum excursions of the actual pulses. The crosshatched portion of the signal is therefore unreliable for printing purposes. The white area between the cross hatched areas denotes the "solid signal" or undisturbed portion. But not all of this solid signal is useful to the printer, as may be seen from the range measurement. Note that the excursions of the transition points are not centered on their proper positions denoted by the dashed lines. When the trailing edge of the range is explored, the 4th pulse will therefore fail while the others are unchanged, causing an "Equal sign" to print instead of the letter "R". Similarly when the leading edge of the range is explored, the 3rd pulse will fail before the others, causing the letter "C" to be printed instead of "R". The correct printing range obtained is therefore only about 20 points although the length of the shortest solid signal is equivalent to almost twice that figure.

It is obvious that a printer circuit with this range would not be suitable for commercial operation, since as shown on Table II the range disappeared entirely when wet weather conditions were simulated. In order to operate the circuit described it would be necessary to obtain a reduction in the amount of disturbance, in the effective length of the line, or in both.

The transmission engineer, confronted with problems of this nature frequently, needs tools of his trade to ease the effort of solution. The figure next following depicts graphs of disturbance values versus circuit operation which may be used in determining the conditions under which a circuit may be expected to work satisfactorily. In making up the transmission chart the disturbances are assumed to be derived from a large number of sources of different frequencies such as the crossfire encountered on a heavily loaded telegraph line. When used to interpret recurrent phenomena some increase in the loss indicated is to be expected, but this increase may usually be estimated readily.

The upper part of Figure 11 shows Signal Time Loss in milliseconds plotted against the electrical length of circuit for a family of "Breakover" curves. The term "breakover" is defined as the amount of direct current required in the coils of the receiving polar relay to just prevent the armature from moving in response to the disturbing currents received from the line. Breakover is therefore a measure of the amplitude of the disturbance in terms of the dynamic characteristics of the relay. Since the relay tends to integrate the disturbance peaks from an energy-level standpoint, the breakover measurement gives the most consistent estimate of the disturbing effect of the extraneous currents. Because the electrical length of the line provides a measure of the rate-of-change of current at reversal, the combination of breakover and line length offers a means of estimating the shift in transition points under the influence of the disturbing currents. The time loss in milliseconds is the length of the unreliable portion of the signal. If the time loss derived from the upper portion of Figure 11 is brought down to the lower set of curves, the range to be expected from the operation of various types of printing telegraph circuits at the speeds available for service may be found. Only one such graph line for the teleprinter will be found, and that lies between the lines giving the data for the two channel multiplex and the three channel multiplex. The ranges suitable for commercial purposes are shown as solid lines, the ranges unsuitable are shown in dashed lines.

Suppose we check the data obtained on Tables I and II from transmission on the hypothetical circuit between Kansas City and St. Louis, on Figure 11. Our circuit was 350 miles in electrical length and had 23 mils of breakover from telegraph crossfire alone. Such a circuit shows a time loss of 3.0 milliseconds on the graph.

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TRANSMISSION CHART

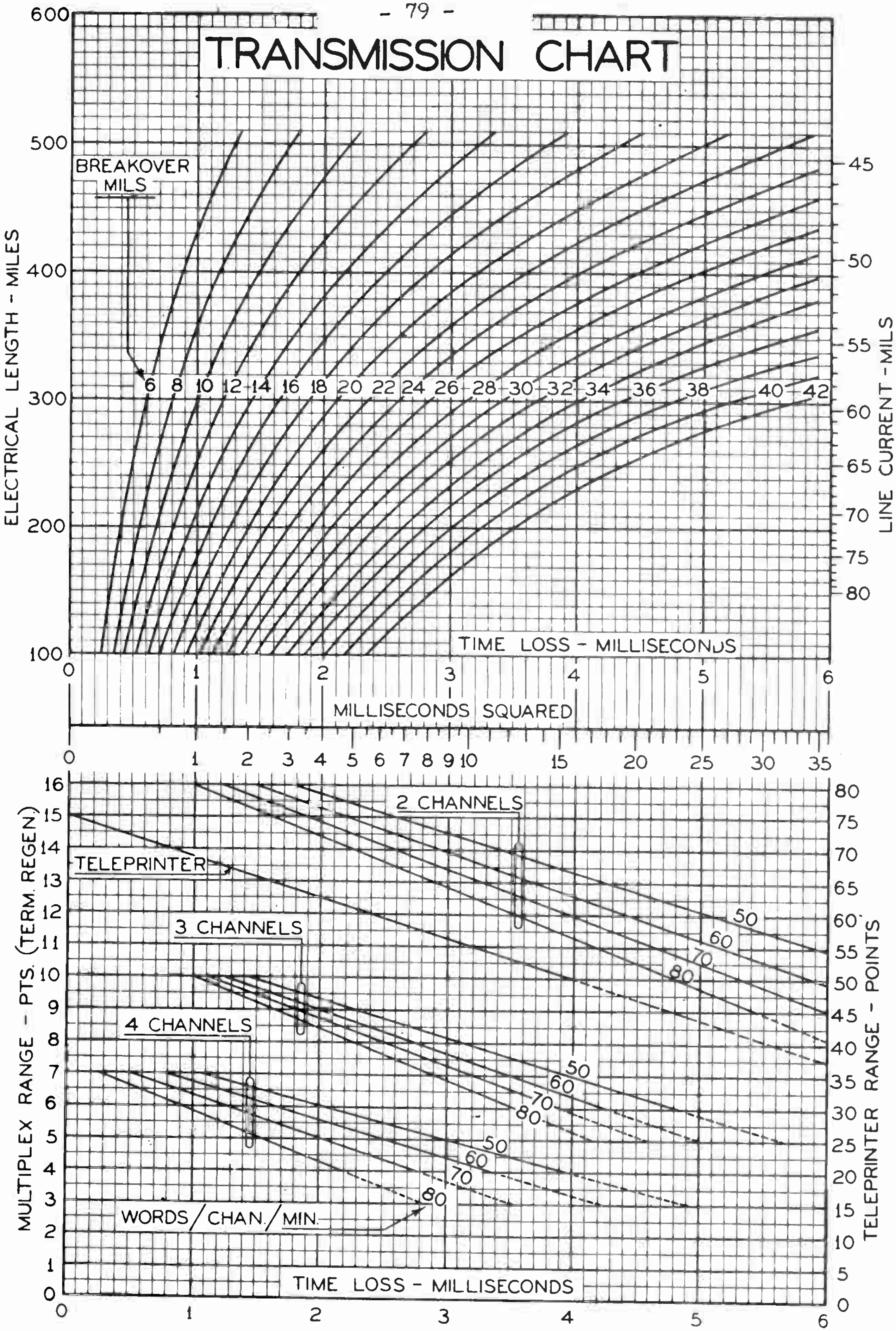

FIGURE 11

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The breakover from the 60 cycles alone was also 23 mils, which would apparently give the same time loss on this graph. The combined breakover was 50 mils, which may be noted to be considerably over the 6 milliseconds limit of the chart. Let us try these data on the lower section.

With a 3.0 millisecond loss a teleprinter range of 56 points could be expected. On Table II the range measured with crossfire only was 55 points, a fair agreement. The range measured with the same breakover of 60 cycles was, however, only 52 points, so it would appear that the recurrent disturbance gives about 0.5 millisecond more loss than the graph indicates on the basis of fortuitous disturbances. The sum of the two disturbances yielded a range of 22 points, but since the printer line leaves the sheet at 6 ms. and 37 1/2 points, all we can tell here is that the circuit is unsuitable. It would appear that the time loss must be reduced by one of the methods previously mentioned to not less than 4.0 milliseconds.

The effect of introducing an intermediate repeater can be estimated by the use of the transmission charts plus some intelligent guessing as to the division of the disturbances. For example, if a location be available for a repeater truly intermediate to both the line length and the induced voltage, the estimate would proceed as follows:

The new line length would be 175 miles, the crossfire would be reduced about 25% to 17 mils breakover, the 60 cycle E.R.C. would be reduced about 40% to 16 mils and the new total breakover would be 33 mils. (This is not half of the old 50 mil total because it is assumed that the remaining circuits on the line continue to operate straight through, producing secondary induction effects on each side of the new repeater.) Figure 11 gives 2.3 milliseconds loss for the section under these conditions, to which we will add 0.5 millisecond for recurrent phenomena, obtaining 2.8 milliseconds as the probable maximum time loss per section. The time loss in both sections may be obtained conveniently by the use of the "milliseconds squared" scale, which assumes random addition of the disturbances in the two sections. Since we have already applied a factor for recurrence, this summation will probably serve. By the squared scale we find 2.8 squared equals 7.8, taken twice equals 15.6, and the square root equals 3.9 milliseconds total for the entire circuits including a non-regenerative repeater. It is therefore possible to obtain a satisfactory circuit at the trouble and expense of installing and maintaining an intermediate repeater, but without reducing the total disturbance.

But if the circuit is to be retained without the repeater, which in most cases would be necessary because of lack of suitable locations for the apparatus, it will be found from Figure 11 that to obtain the required 4.0 ms loss, no more than 29 mils of breakover can exist. Measurements made in the field indicate that the

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breakover from telegraph crossfire on lines between Kansas City and St. Louis will average about 18 mils with all practical corrective measures installed. Thus no more than 11 mils of breakover from 60 cycle disturbances should be present. At about this time, in the practical case, the Division Plant Engineers would sally forth to do some inductive coordination.

If you have been mystified that up to this point we have talked about current in the telegraph circuit rather than the voltage that is usually measured in coordination procedures, it is not surprising. However, it is the current which causes the transmission loss. The important voltage is the one that occurs infrequently, we hope, of a value sufficient to break down protective equipment. When that happens the kind of transmission we are discussing here is out of the picture. But we can make an attempt at connecting up the voltage and the currents for smaller values of continuous induction.

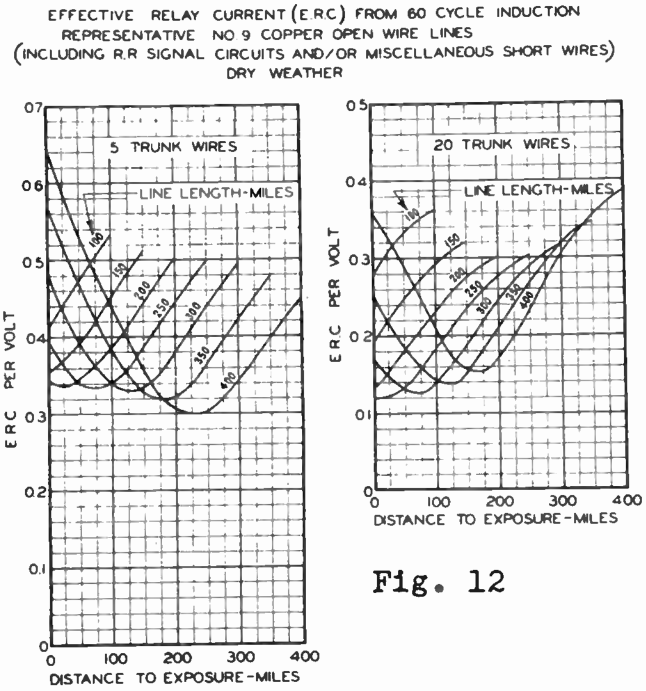

Fig. 12

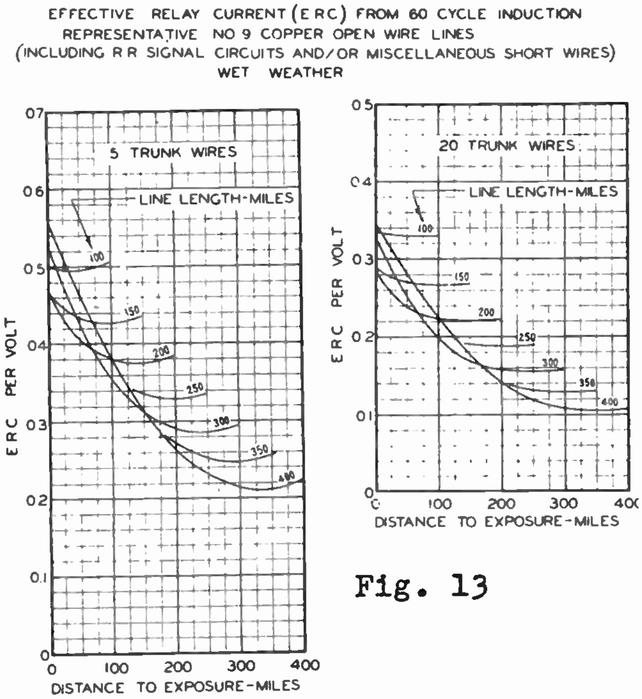

Fig. 13

On Figures 12 and 13 are depicted the current-voltage ratios for two sizes of telegraph line, both kinds of weather, and a family of line lengths. The smaller line of five trunk wires may some day be representative, but the larger line of twenty wires is more like the heavy trunk lines of today. The ratio "E.R.C. per Volt" defines the effective 60 cycle current which flows in the windings of a polar relay connected to one wire of a line when the entire line is subjected to one volt of longitudinal induction. You may appreciate the fact that the flux of the induction sees the pole line as a bundle of conductors much like a stranded wire, hence to determine what happens in one individual wire requires complicated computations. The values of Figures 12 and 13 have been computed from the theory and checked experimentally at enough points to prove-in the method. It should be noted that the line length used in these figures is the actual length of the open-wire rather than the electrical length used on the Transmission Charts.

Assuming the line we have been using as an example is a five-wire line, we can enter the chart for dry weather with the 230 miles of open-line from Table I, to find that 1/2 mil per volt is the worst condition of position of exposure. To obtain the E.R.C. of 27 mils of Table I, 54 volts of induction at the end of the line is necessary. To reduce this to 22 volts requires a reduction of 60%. If all the 60 cycles comes from one source the problem is not likely to be difficult, but such is not usually the case. Under ordinary conditions the Plant Engineers find that in the two or three hundred miles of line between repeaters at least two and perhaps four or five power systems are involved including rural lines and series lights on highways. It is a difficult task to determine "which current is whose", as it is usually impractical to open the entire line opposite the limits of each power system in order to make precise measurements. It often becomes necessary to approach all of the contributing companies with a view toward reducing the induction from each as much as practicable. The power engineers whose lines are contributing only a few volts to the "kitty" are sometimes indignant over what appears to be a picayune case. But where the total disturbance is made up of a number of small parts, only a concerted reduction of most or all the parts will materially reduce the whole.

There is also the problem, sometimes asked in coordination meetings, of the answer to "How much can you stand?". We can with considerable effort work out the transmission for each regularly assigned circuit on a given line and give an approximate answer to the question. But a section of line between two cities is used not only for circuits between those points but ordinarily is used for one section of long circuits between remote terminals. While the circuits are repeatered at proper intervals, these repeaters cannot all be the regenerative type hence some disturbances are accumulated from section to section. For such service it is customary to grade lines according to their time loss characteristics as in Table III. Printer circuits may be operated over "Good" lines for 4 or 5 sections, over "Fair" lines 2 or 3 sections, and over "Poor" lines for only one section before the signals need be regenerated.

TABLE III

Time Loss	Grade of Line
Less than 1.5 milliseconds	Good
1.5 to 2.5 milliseconds	Fair
2.5 to 3.5 milliseconds	Poor
Over 3.5 milliseconds	Very Poor

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For a number of years, Western Union has been engaged in an expansion of telegraph coverage which has for a goal a more rapid and more stable system for the transmission and delivery of messages. While heretofore a message passing from point to point was often copied manually from telegraph blank to printer circuit several times, the new "reperforator" offices are eliminating the necessity for such copying at any office other than the originating point. Once the message has been perforated on a paper tape in the "five-unit-code", it may then proceed over the printer circuits, across offices, and on to its destination for final printing without handling other than the necessary switching at circuit junctions. The rapidity of operation obtained coupled with the more impersonal handling by machines puts a premium on circuit accuracy and stability.

Already several thousand miles of wire-line carrier are in operation. The ultimate plan provides for extensive use of carrier both on wire-lines and on radio channels. These circuits will replace much of the present grounded system with communications not affected by the continuous 60 cycle induction discussed in this paper. But there are numerous small centers of population which must be reached for service but which will not have sufficient traffic to demand a multi-channel connection such as carrier affords. These points will continue to be served by grounded circuits of the Teleprinter type described here.

As long as we have such circuits we can expect to have disturbances from various sources, of which the power line is only one. The telegraph equipment is subject to troubles of its own. But while equipment troubles may be traced and repaired and weather will clear, the induction from power systems often appears day after day to the dismay of the personnel who are battling to keep the errors down and the traffic moving. The power induction is not subject to correction by any adjustments provided in the normal telegraph plant, prevents the most diligent maintainer from ever attaining "spot clear" circuits, and if allowed to remain in truly disturbing magnitude, can produce an alarming decrease in efficiency. The latter is due to the fact that the operators become prone to blame everything on the one obvious disturbance.

Since it is likely to be many years before all the grounded circuits can be eliminated from our plant, the problem of induction from power systems bids fair to continue. Even where the important circuits have been placed on wire-line carriers we are still confronted by prostrations engendered by short circuit conditions on paralleling power systems. This latter subject cannot be covered within the scope of this paper. But we hope that the description given here of the requirements of modern telegraphy will aid in improving the understanding in future joint discussions with members of your Association.

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AUTHORS

F.H. CUSACK, a native of Metropolitan New York, studied engineering at Cornell University, receiving his degree in 1929. He joined the Research Division of Western Union upon graduation. His preparation for development work on carrier systems included a broad experience in d-c telegraph transmission, disturbance mitigation and carrier frequency transmission. During the past five years, Mr. Cusack's efforts have resulted in many advances in the carrier art. In the field of high frequency carrier, Mr. Cusack is credited with the application of crystal rectifiers to the suppressed carrier modulator. His paper on balanced modulators, presented before an A.I.E.E. section meeting in Philadelphia, is considered a valuable contribution to carrier literature. He is a member of the A.I.E.E.

A.E. MICHON was born in New York State and is a graduate of Rensselaer Polytechnic Institute and Columbia University. After a year with the General Electric Co., he began his employment with the Western Union in the office of the Plant Manager of Ocean Cables, in which position he was responsible for the layout and design of cable stations. In 1932, he transferred to the Research Division and was active in the development of cable signal shaping amplifiers. One of his major assignments was the installation of Cable Photo equipment at Bay Roberts, Nfld. In 1941 he became associated with the carrier group, where he developed the Transceiver described in this issue. Mr. Michon is a member of the Rensselaer Society of Engineers, I.R.E. and A.I.E.E.

C.H. CRAMER, Assistant Transmission Research Engineer, is a native of Cramer, Penna. He graduated from the University of Michigan in 1918. Following six months in the Signal Corps and the Radio Section of the Air Service, he joined the staff of the Research Engineer in February 1919. For many years, he held the position of Assistant Research Engineer. His research activities have been chiefly concerned with submarine cable and interference problems. Mr. Cramer contributed to the application of permalloy loaded cables and to subsequent cable system improvements involving amplification, shaping, balancing and interference elimination. Through this work, sunspots and their effects became a major interest. He represented the Company at the Pan-American Radio Conference at Rio de Janiero, in 1945. A Member of the A.I.E.E., he has contributed to technical literature through that medium.

T.F. COFER was born in Virginia and studied engineering at Virginia Polytechnic Institute, where he graduated in 1923. In July of the same year, he joined the Research Division of Western Union and has been with that division ever since, except for eleven months when he served as Assistant Consulting Engineer. Mr. Cofer had considerable experience in Inductive Coordination during his earlier years with the Company, and more recently has been engaged in carrier transmission studies, work on coaxial cables and facsimile. He designed the open-wire transposition scheme used for 30 kc. transmission by the Western Union and many railroads. His advice is frequently sought by the Association of American Railroads, on the committees of which he has had many assignments.

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