Automatic Printing Equipment For Long Loaded Submarine Telegraph Cables

By A. A. CLOKEY

SYNOPSIS: The introduction of the permalloy loaded submarine cable has presented the possibility of telegraph transmission at speeds several times those obtainable on non-loaded cables and has made practicable the operation of printer telegraph equipment. The present paper presents the various factors which affect the design of operating equipment and describes the apparatus which has been developed and used for a considerable period of time under service conditions. The transmission speed attained may exceed 2,400 letters per minute. To a certain extent, the detailed design of the terminal apparatus is controlled by the electrical characteristics of the particular cable to which it is to be applied and this type of equipment cannot, therefore, be completely standardized.

GENERAL

AT the time the development of the loaded submarine telegraph cable was undertaken, non-loaded cables were generally being operated duplex at signalling speeds ranging from 5 to 8 cycles per second (160 to 260 letters per minute) in each direction. The transmitting apparatus consisted of transmitters of the reciprocating contact type controlled by perforated tapes and the signals were received and recorded by the delicate moving coil type of amplifiers (generally referred to as magnifiers), relays and siphon recorders which produced a received signal record of such a character as to require the employment of highly skilled operators to translate and type the messages in final form. Except for a few trials, automatic printers had not been applied commercially to the operation of submarine cables, although the highly successful results which had been previously obtained with multiplex printing telegraph equipment on land lines coupled with the increasing demands made upon the cable systems as a result of the World War had directed the attention of telegraph and cable engineers to the need for applying automatic printing telegraph methods to submarine cables.

Preliminary studies of the characteristics of permalloy as a loading material for long telegraph cables indicated that, through its use, transmission speeds many times that of non-loaded cables could be readily attained. As the then existing apparatus was incapable of operation at the high speeds thus obtainable and the operating methods in use were not suited to handling the greatly increased volume of traffic over a single cable, it became apparent that new operating methods and equipment would have to be developed if the full advantage afforded by the use of permalloy loading [1] was to be realized. The development of the permalloy loaded cable was, therefore, paralleled by a study of the newly presented operating requirements and the development of suitable operating methods for high speed loaded cables. It is the purpose of this paper to present the various factors which affect the design of operating equipment for use on long loaded cables and to describe the apparatus and principles of operation which have been developed. The system which is to be described is similar to the multiplex system now in use on American land lines [2] but has been modified in several important respects in order to adapt it to the requirements of cable transmission.

The Cable and Amplifier as a Transmitting System

Submarine cables have heretofore been thought of as transmitting media which greatly distorted the signals and so reduced them in amplitude as to require the use of a sensitive siphon recorder for reception. The effects of signal distortion were, to a certain degree, compensated for by the addition of sending and receiving condensers, magnetic shunts at the receiving end, and, to a slight degree, by the inherent characteristics of the siphon recorder itself. A separate instrument termed a cable magnifier, of which there are several different types, was inserted between the cable and the siphon recorder to "magnify" the signal delivered to the recorder and thus partially offset the effects of attenuation. No two cables are identical as regards the distortion and attenuation of the signals and the means which will effectively provide for the correction and amplification of the signals on one cable will not necessarily be suitable for use on another cable of different length or construction. The apparatus provided for the correction of distortion in and amplification of the received signals is therefore an essential part of a signal transmitting system which includes the cable, and, except for the necessary switching arrangements, is independent of the means employed for impressing the signalling impulses upon the cable and for producing a permanent record of the corrected signals. Thus the development of terminal equipment for loaded cables comprised two separate and distinct developments, viz. the study of signal distortion and design of suitable signal shaping amplifiers (described in a separate paper by Mr. A. M. Curtis which appears elsewhere in this issue), and the development of apparatus for delivering signals to the system comprising the cable

[1] O. E. Buckley, "The Loaded Submarine Telegraph Cable," *Jour. A. I. E. E.*, June 26, 1925.

[2] J. H. Bell, "Printing Telegraph Systems," *Trans. A. I. E. E.*, Vol. 39, Part 1, 1920.

and amplifier and for converting the signals delivered by that system into a permanent printed record.

With the combination of cable and signal shaping amplifier, signals which are transmitted into the sending shaping network and the cable as square topped impulses as shown in Fig. 1 emerge from the amplifier

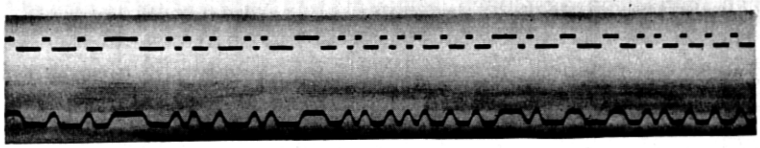

Fig. 1

as rounded impulses from which the high frequency components have been removed as a result of the attenuating effect of the cable. The receiving and printing system must therefore be capable of accurately translating rounded signals of this nature into printed characters.

Requirements of Operating System for Loaded Cables

The outstanding characteristic of the loaded cable is the enormously increased speed of transmission which may be as high as 2,400 letters per minute or more. For practical utilization of such high speeds the operating system must include some means for dividing the line time to provide a number of traffic channels. This is necessary in order to facilitate the distribution of the work of preparing the perforated transmitting tapes and checking the received message records among the required number of operators. The system must also provide for efficient two-way operation to avoid delay in the transmission of traffic from either terminal and should be capable of being joined with other cables or land lines through automatic repeaters to avoid the delay and expense introduced by manual methods of repetition.

As the shape of the received signal is determined by the cable-amplifier system and also by the character and amount of interference present which cannot be eliminated by the distortion correction networks, the operating system must be able to take the partly corrected signals delivered to it by the amplifier and accurately restore them to the form in which they were originally transmitted before using them to control the final recording mechanism.

The apparatus associated with loaded cables will in practically all cases be installed in the same offices as the equipment in use on non-loaded cables and, in order to avoid the necessity for duplicating the operating and maintenance staffs, it should be of such a nature as to permit of its being operated and maintained by men familiar with the operation of apparatus in use on land lines and ordinary cables.

Codes

The signalling speed attainable on any telegraph circuit, the effect of interference upon the received signals, and the design of the operating equipment depend to a certain extent upon the telegraph signal code used. A great variety of codes have been devised from time to time with a view to effecting greater economy of line time or greater freedom from the effects of interference, but only a few of them have been generally adopted in commercial practice. These may be divided into two general groups: the two-element codes which are composed of various combinations of positive and negative current impulses, of which the continental Morse and the Baudot codes are well-known examples, and the three-element codes in which a zero or no-current interval is employed to separate individual pulses of a group or as a third element in the combinations. The cable code and three-unit code are examples of the three-element type.

The codes in each of these two groups may be subdivided into two classes, those known as uniform codes in which all characters are composed of the same number of equal time units and those known as non-uniform codes in which the impulses forming the characters vary in length, number or both. The non-uniform codes are well adapted for use where the received signals are translated manually, but are not so well suited to automatic translation as the uniform codes on account of the mechanical and electrical complications introduced by the necessity for distinguishing between signal combinations of varying length.

Of the uniform codes which have been used in automatic printing telegraph systems, the Baudot or two-element five-unit type of code possesses advantages over the three-element three-unit type of code which make it much better suited for automatic operation of submarine cables. The three-element three-unit code employs, as does also the cable code, a zero interval of unit length in forming the signal combinations representing each character or letter and the shape of the received signals must be sufficiently refined to make this zero interval easily distinguishable (see *A*, Fig. 2) in order to prevent confusion in translation. Even with the best shaping obtained to date on long non-loaded cables operated at high speeds the presence of this zero interval may be indicated only by a difference in slope of the recorded curve as shown in *B*, Fig. 2. Interference currents, which are present to some extent in all cables, are superposed upon the

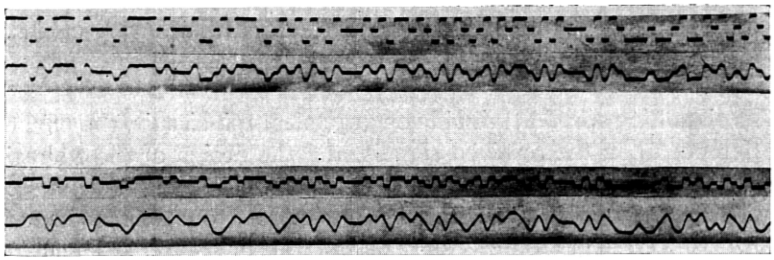

Fig. 2

received signals and cause troublesome distortion in the zero intervals and the length of the sustained pulses. The absence of these zero intervals of unit length in the two-element five-unit code, combined with the fact that only the middle portion of each received signalling impulse is used to operate the selecting mechanism of the printers, considerably reduces the effect of interference upon the accuracy of translation and makes it unnecessary to secure such refined signal shape.

The accurate evaluation, in terms of transmission speed, of the relative merits of the various telegraph codes is a highly complex problem which does not readily lend itself to solution through purely theoretical methods since it involves consideration not only of the total number of separate combinations which must be provided to represent the letters of the alphabet and all other characters to be transmitted, the frequency of occurrence in traffic of the various characters, and the average number of unit impulses required to form the combinations, but also depends upon the characteristics of the line or cable and the nature and distribution of the interference encountered and its effect upon the shape and definition of the received signals. The application of a code to any specific case also involves the more practical considerations of the type and operating characteristics of the apparatus employed. Practical experience therefore probably forms the best guide to the choice of a code.

In consideration of the conditions referred to above and the experience previously gained through the extensive use of the Baudot type of code on automatic telegraph circuits both in the United States and Europe, it was concluded at an early stage in the development that the multiplex code used on American land line multiplex circuits would be the most suitable for high speed automatic submarine cable transmission. Subsequent experience has indicated that the original conclusion was amply justified and has shown that the Baudot type of code, when used in connection with terminal apparatus of suitable design, is probably faster than any of the other types of codes which have been considered for high speed loaded cable operation.

Outline of System

The multiplex system [3] used on land telegraph lines was in many respects well suited to the requirements of loaded cable operation. It was capable of operation at high transmission speeds, was more economical of line time than other methods which were considered, and provided for the division of traffic between a number of traffic channels in a manner which afforded great flexibility in the handling and routing of traffic and permitted the channel speeds to be fixed at values which would allow the operating staff to work at maximum efficiency. Its long continued use on land telegraph lines had resulted in bringing the apparatus, operating methods and routines to a high degree of perfection and the development of a thoroughly trained staff skilled in the operation and maintenance of the equipment, all of

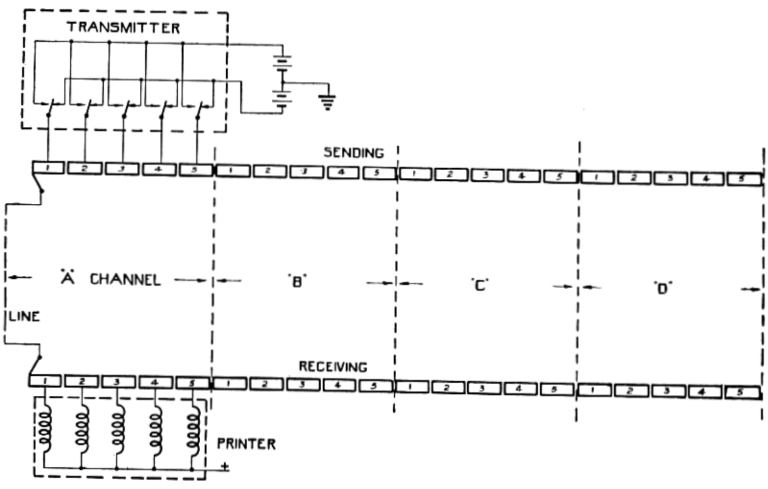

Fig. 3

which was of inestimable importance in the successful application and operation of printing telegraph methods to submarine cables.

The multiplex system provides for associating the line at the sending

[3] J. H. Bell, loc. cit.

end with each one of a number of transmitters in rotation by means of a rotating brush which passes over a segmented commutator to which the transmitters are connected as illustrated in Fig. 3. In this figure the commutator segments are shown developed for sake of simplicity. At the receiving end, the line is similarly associated in rotation with each one of a corresponding number of printers by means of the receiving brush and commutator. The commutator brushes at the two ends of the line are maintained in nearly exact synchronism by short correcting impulses which are derived from reversals in the received signalling currents, and their phase relation is such that each of the five segments connected with the "*A*" channel transmitter will be connected in rotation through the line to the corresponding segments of the "*A*" channel printer once during each revolution of the brushes, and the impulse transmitted from any one sending segment will pass through the corresponding receiving segment and operate the printer selector magnet which is connected to it. Similarly the transmitter on each of the other channels will be connected to its corresponding printer once during each revolution of the brushes. The commutators and the associated brushes together with the mechanism provided for correcting the phase relation of the brushes are usually referred to as distributors.

In the operation of this system a transmitting tape is prepared in which the characters to be transmitted are represented by combinations of holes perforated in the tape by means of a keyboard perforator which resembles a typewriter. The tape thus prepared is drawn through a transmitter which is arranged to apply to its associated distributor segments, positive and negative battery in the proper combination to form the five-unit impulses corresponding to the perforations in the tape. The received signal combinations control the operation of an automatic telegraph typewriter or printer which converts the signals into printed characters. Detailed descriptions of the perforating, transmitting and printing apparatus and the various methods for maintaining synchronism used in the multiplex system are given in the paper by Mr. J. H. Bell, previously referred to, and also in an excellent book by Mr. H. H. Harrison entitled "Printing Telegraph Systems and Mechanisms."

On account of the many advantages which this system embodied, it was chosen in principle as a basis for the development of the new system, although in several important respects much of the apparatus and operating methods employed were entirely unsuitable for loaded cable operation. The multiplex had been employed almost entirely in the operation of duplexed circuits and therefore was not applicable to simplex operation of cables. The character of the received signals and interference on long cables is such as to require the use of entirely different methods of reception in order to utilize the line time most efficiently, and the higher transmission speeds expected on cables necessitated departure from standard land line practices in the matter of apparatus design and number of channels employed. The system as finally developed embodies the following important improvements over previous methods.

1. An entirely automatic means for quickly reversing the direction of transmission on a simplex circuit at short intervals which can be altered as required to accommodate varying traffic loads in the two directions.

2. A synchronous vibrating relay which corrects for the residual distortion in the signals delivered by the amplifier, and practically doubles the speed of transmission.

3. A high degree of precision and refinement in the design and construction of apparatus which is justified by the great cost of the cable relative to that of the terminal apparatus.

The inclusion of these improvements in a modified multiplex system involved, of course, the solution of a number of important incidental problems such as the provision of Morse "talking circuits" which could be made instantly operative, and the development of suitable arrangements for linking two simplex cable sections together through repeaters.

Two Directional Working

The use of duplex methods in the operation of non-loaded cables enables communication to be carried on simultaneously in both directions and usually effects an increase of from 60 to 90 per cent in the total traffic capacity of the cable. As only a moderate capital expenditure is required to equip a non-loaded cable for duplex operation practically all cables of this type are now equipped in this way as a matter of economy. The characteristics of the loaded cable, however, are such as to require the use of highly complicated and extremely expensive artificial lines and balancing equipment for duplex operation and it is quite doubtful whether the total duplex traffic capacity thus secured would equal that obtainable by the use of simplex methods. Duplexing the loaded cable therefore appeared to afford no certain economic gain over simplex operation and the extremely high cost of duplexing could hardly have been justified merely for the sake of securing simultaneous transmission in both directions.

The apparatus and methods formerly employed for reversing the direction of transmission on manually operated simplex cables were so time-consuming that it was impracticable to reverse direction oftener than once every quarter or half hour. The delay in transmission which would result from the adoption of the older methods could not be permitted on the loaded cable and it therefore became necessary to develop special apparatus for automatically reversing the direction of transmission at comparatively short intervals in order to approximate simultaneous transmission in both directions and reduce traffic delays to an absolute minimum.

The design of suitable switching arrangements which would permit stopping transmission on a long cable operated with multichannel printing equipment and almost immediately starting transmission in the opposite direction presented several difficult problems. On account of the lack of uniformity in the lengths of the messages to be transmitted and the number of channels employed, it rarely happens that the transmitters on all channels complete the transmission of their respective messages at exactly the same instant, therefore it was necessary to arrange for making the change in direction of transmission at more regular and frequent intervals even though the transmitters on all channels had only partly completed the transmission of their respective messages at the time the change was made. To accomplish this without introducing any errors or other evidence of the interruption into the final printed message necessitates first stopping the transmitters on all channels at precisely the right instant, then allowing an interval equal to the time of signal propagation over the cable to elapse before cutting off the printers at the distant end, and finally upon resumption of transmission in that direction starting all of the transmitters and printers at the proper time and in the correct sequence to avoid the loss, repetition, or mutilation of any character.

The last signals transmitted into the cable before changing to the receiving position result in leaving the cable charged to a potential which would paralyze or "block" the amplifier were it to be immediately connected. Part of this charge must be dissipated and the current due to the residual charge and the presence of any interference or earth currents must be allowed to attain its steady value in the shaping network and input transformer elements of the amplifier before connecting any of the actual amplifying elements to the cable. The switching operations involved in applying the amplifier to the cable must be effected in the proper sequence and at precisely timed intervals in order to leave the amplifier in the proper condition to avoid mutilation of the first signals received from the distant end.

The required degree of accuracy in timing the various switching operations involved in reversing the direction of transmission was secured by utilizing the rotating shafts of the distributors at both stations to control a timing mechanism which determined the lengths of the transmission intervals in the two directions.[4] This timing mechanism is essentially an electrical revolution counter which can be set to count any desired number of revolutions of the distributor shaft and close within a fraction of a revolution of that number the circuit which controls the operation of the various contacts which do the actual switching. As the distributor shafts at the two ends of the cable are maintained in exact synchronism in a manner previously described, the timing mechanisms will therefore also operate in synchronism, and if at the time of setting up the circuit they are started in the proper phase relation the correct phase relationship will be maintained as long as the operation of the circuit continues without interruption. The timing mechanisms are driven from the distributor shafts through the medium of an electrically operated clutch which when disengaged permits the timing mechanisms at all stations to be manually set in their proper positions and started together in this relationship by means of a starting impulse sent over the line which causes the clutches to engage.

In order to provide for transmission intervals of various lengths in the two directions, the timing mechanism includes a number of timing elements each representing a different division of the line time, any one of which can be quickly selected at will by the movement of an indicating lever to control the length of the transmitting and receiving periods.

Upon the completion of the predetermined number of revolutions of the distributor the timing mechanism operates a direction control relay, see Fig. 7, the contacts of which are arranged to operate and cut off the transmitters, discharge the cable, and connect the amplifier and the printers in properly timed sequence. The actual time consumed in making all of the circuit changes necessary to reverse the direction of transmission, measured from the time of transmission of the last signal combination to the time of printing the first character on the printer at the same station, is of the order of five seconds but will vary somewhat on different cables according to the length of the cable and the magnitude and character of the interference and earth currents encountered.

During the interval in which the actual switching operations are taking place no signals are being transmitted in either direction so

[4] A. A. Clokey, U. S. Patent No. 1,601,941.

that neither of the distributors will receive any correction impulses and as a result the sending and receiving brushes may depart considerably from their normal phase position. This would cause errors to occur in the first signals received upon resumption of transmission if means were not taken to bring the brushes back into proper phase relationship before the transmission of actual signals was begun. This is provided for by arranging to have the distributors transmit, at the close of each switching period, a number of "spacing" signals which do not affect the receiving printers since they are not connected in circuit until a sufficient number of reversals have occurred in the line current to correct the receiving brush into the proper position. The transmission of signals which must be recorded by the printer is then started.

As the length of the interval allowed for these switching operations is determined by a definite number of revolutions of the distributor shaft, which may be set to rotate at various speeds, the gearing between the distributor shaft and the timing mechanism is designed to allow for a five-second switching period when the distributor is rotating at a speed which corresponds to the maximum transmission speed of the circuit.

Although this system lacks the advantage of absolutely continuous communication in both directions, it possesses another feature which goes far toward offsetting, if it does not entirely outweigh, the advantages afforded by the duplex method. Almost all of the long cables of the world run in an east and west direction and the difference in time between the terminal stations of those cables results in an unequal distribution of traffic in the two directions except perhaps during a comparatively short time each day. The provision of the selective timing mechanism permits the total traffic capacity of the cable to be divided between eastward and westward transmission in about the same proportion as the eastward traffic load bears to the westward load and thus permits efficient utilization of the entire traffic carrying capacity of the cable.

The Synchronous Vibrating Relay

The vibrating relay principle was first suggested by Gulstad [5] who applied it to short cables for overcoming the effects of distortion. As originally used, it consisted of a sensitive polarized relay provided with a line winding, upon which the received signals were impressed, and two auxiliary windings included in a local vibrating circuit adjusted to cause the relay armature to vibrate continuously when

[5] K. Gulstad, "Vibrating Cable Relay," *Elec. Rev.*, London, Vol. 42, 1898; Vol. 51, 1902.

the line winding was de-energized. The rate of vibration was adjusted to be approximately the same as the frequency of the transmitted signals and the amplitude of the vibrating current was adjusted to be approximately equal to the received signalling current so that the latter, if of one polarity, would neutralize the effect of the vibrating impulse and prevent the movement of the relay armature and if of the same polarity would aid the vibrating impulse. The effect of this combined action of the vibrating and received signalling impulses is to reproduce, in the local circuit, signals of approximately the same shape and duration as the original transmitted signals.

The frequency attenuation characteristic of a system comprising a long telegraph cable and its signal shaping amplifier and networks when the latter are adjusted for the maximum transmission speed is such as to cause the impulses of unit length, which represent half cycles of the fundamental signalling frequency, to be received in considerably smaller amplitude than the impulses of two units (or more) length which represent half cycles of one half (or less) the fundamental signalling frequency.[6] The highest signalling speed obtainable on a given cable is therefore determined by the length of the shortest impulses which must be received in sufficient amplitude to exercise control over the receiving apparatus and at that speed the two-unit and longer impulses will be received in much greater amplitude than is necessary for operation of the receiving apparatus. Gulstad pointed out [7] that as the received impulses of unit length always occur in the proper direction to aid the vibrating impulses they may therefore be greatly reduced in amplitude without impairing the accuracy of reception. On account of this fact the speed of signalling may be increased to a point where only the two-unit and longer impulses are received in sufficient amplitude to overcome the effect of the locally generated vibrating impulses and control the movement of the relay armature. At this increased speed the impulses of unit length will be either greatly diminished in amplitude or entirely removed by the attenuating effect of the cable and at such times the armature of the vibrating relay will be operated by the locally produced impulses.

As the rate of vibration of the Gulstad relay was determined entirely by the values of the resistances and capacities in the local vibrating circuit, the vibrations of the relay armature did not exactly coincide either in frequency or phase relation with the signals sent by the distant transmitter so that complete restoration of the incoming signals to their original form was impossible and full advantage of the speed

[6] The fundamental signalling frequency is defined as the fundamental frequency of a train of alternate positive and negative impulses of unit length.

[7] K. Gulstad, loc. cit.

possibilities of the device could not be realized. For these reasons its use was limited almost entirely to comparatively short cables where the strength and shape of the received signals were sufficiently good to control the relay directly with only a small improvement in shape and with no amplification. The original arrangement was later modified [8] to adapt it to the operation of longer unloaded cables.

One of the principal features of the cable multiplex herein described is the synchronous vibrating relay [9] which was developed particularly for high speed operation on long cables, and is a great improvement over the Gulstad device. The vibrating impulses, instead of being derived from an adjustable vibrating circuit, are generated by a segmented commutator located on the receiving head of the distributor. As the brushes on the receiving head of the distributor rotate in nearly exact synchronism with the transmitting brushes, it is evident that the rate of vibration of the relay will coincide exactly with the frequency of the transmitted signals and by properly adjusting the angular position of the vibrating segments, the time of closure of the relay contacts with respect to the incoming signalling impulses can be accurately fixed. The accuracy with which the missing impulses of unit length in the received signals are reinserted by this means makes it possible to realize the full speed possibilities of the vibrating relay principle and obtain faithful reproduction of signals on a given cable at almost double the speed obtainable through the use of ordinary non-vibrating relays.

Another important advantage gained through the use of the synchronous vibrating relay is greater freedom from the effects of extraneous interference. The amplitude of the received signals is sufficiently great to permit of its being reduced by the effects of interference to approximately half of the normal value before the distortion becomes sufficiently great to cause errors in printing. Likewise interference occurring during the zero intervals in the received signals must attain a value of approximately half of the normal received signal amplitude before causing errors. Interference occurring during the intervals between vibrating impulses will, of course, produce no effect upon the relay unless the amplitude of the interference attains a sufficiently large value to operate the relay directly. This ratio of interference to received signal amplitude represents the absolute limit of operation and some margin must obviously be allowed. It has been found that continuous satisfactory operation can be maintained so long as the interference does not

[8] W. Judd, British Patent No. 9,768, April 25, 1913; G. R. Benjamin and Herbert Angell, U. S. Patent No. 1,579,999, April 6, 1926.
[9] A. A. Clokey, U. S. Patents Nos. 1,521,870 and 1,522,865.

exceed one third of the normal signal amplitude. The presence of a proportionate amount of interference in the received signals in ordinary cable code operation would cause the recorder record to be so mutilated as to render it entirely illegible.

A detailed description of the operation of the synchronous vibrating relay is given in the appendix.

Refinement

The extreme speed at which the apparatus must operate to utilize the entire capacity of a loaded cable precludes making any adjustments while in operation and the importance of maintaining uninterrupted service for long periods demands that the apparatus shall be absolutely reliable in its operation and as free as possible from any variation in adjustments which would require occasional correction. This degree of reliability is secured through a refinement in mechanical and electrical design and a precision in construction which might be considered uneconomical for ordinary land line operation. The extra expense incurred in the design and construction of such highly refined apparatus is well justified by the resultant large increase in traffic capacity of the cable and the small cost of even the most refined apparatus relative to that of the cable on which it is used.

A general idea of the type of apparatus and construction used can be gained from one of the terminal distributors which is illustrated in Fig. 4. The greatest permissible variation in the phase relation

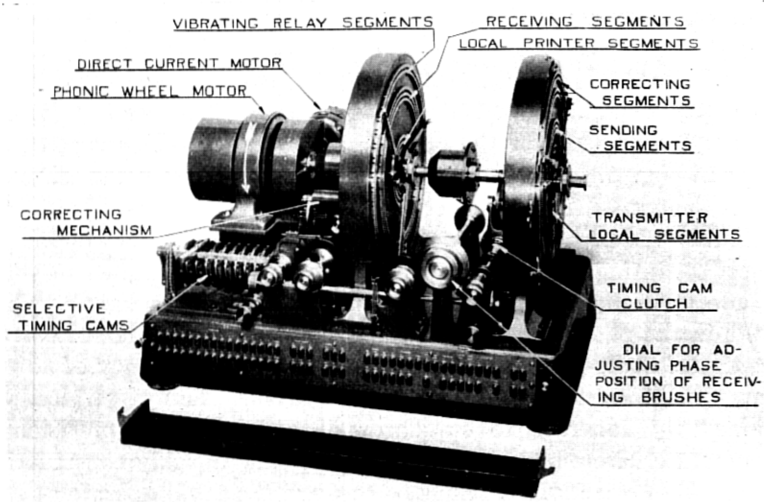

Fig. 4

between the brushes on the distributors at the two ends of the cable is only about one and one half degrees of revolution and in order to hold within this limit it was necessary to design a driving unit in which the phase shift, resulting from variations in the line voltage, was reduced to a minimum, and to arrange the gearing and coupling between the driving motor shafts and the various rotating brush arms so as to reduce to a minimum any lost motion or back lash. The driving unit consists of two motors: the one which supplies the power for driving the brushes is a dynamotor in which the DC side is used as a motor to supply the power and the AC side is included in a circuit with an electrically driven tuning fork which controls the motor speed within very close limits; and the other is a phonic wheel or La Cour motor driven from the same driving fork. This motor normally supplies little if any power for driving the distributor but by increasing or decreasing the load it prevents the occurrence of any appreciable phase shift in the DC motor due to variations in the driving voltage. In order to prevent slight shifting in the phase of the brushes due to vibration and axial twisting in the shafts and gears, it was necessary to employ much heavier construction in the rotating parts than is actually required to transmit the small amount of power used. The cutting of the gears, the distributor segments, and timing cams was done with the utmost precision to eliminate mechanical errors. The distributor segments included in the vibrating relay circuit are heavily faced with coin silver to reduce variation in the resistance of the contact between them and the rotating brushes.

The satisfactory operation of the system depends upon the accuracy with which the various relays in the system follow and repeat the signals. None of the available types of relays were found to be sufficiently reliable to permit of use in the system and it became necessary to develop for the purpose a new type of high speed relay shown in Fig. 5. The size and inertia of the parts comprising the moving system of this relay were reduced as much as possible in order to secure quick response and freedom from contact chatter at the highest operating speeds. A magnetic circuit was designed in which the effects of magnetic hysteresis are practically negligible, which results in the relay always operating upon the same value of current irrespective of its previous magnetic history. Permanency of adjustment, which is essential in relays used in this class of service, was obtained by adhering to standards of accuracy and precision of manufacture heretofore considered unnecessary in relay construction. The accuracy with which relays of the new type will operate at high speeds and the entire freedom from contact chatter is illustrated in the oscillogram reproduced in Fig. 6, which shows 200- and 600-cycle sine waves applied to the relay windings and the character of the reversals repeated by the contacts. At these and lower frequencies

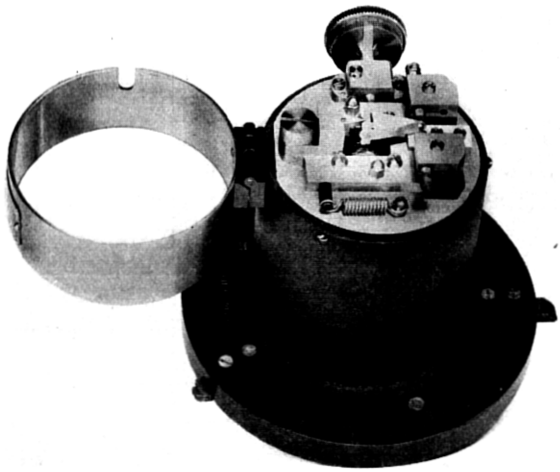

Fig. 5

the adjustment of the relay is sufficiently stable to permit of its being operated continuously for long periods without requiring readjustment or other attention.

Apparatus of this nature is frequently installed in isolated stations where materials or parts needed for making repairs cannot be obtained promptly, and the climatic conditions at some of these stations often

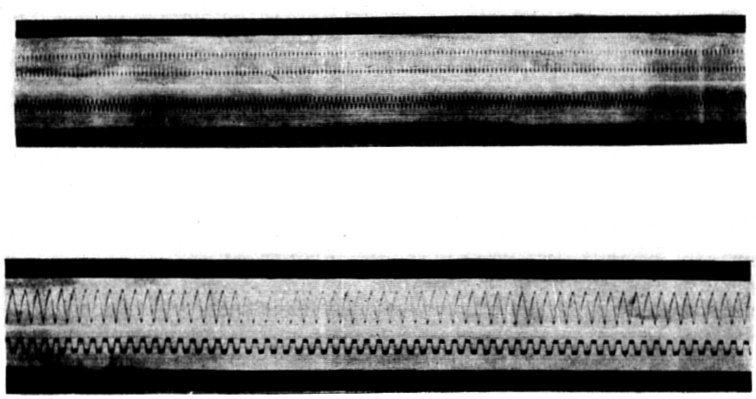

Fig. 6

impose quite severe requirements upon the mechanical as well as the electrical portions of the apparatus. In designing the apparatus, the greatest care was therefore exercised in selecting, for the construction of even the smallest details, materials which would withstand the most severe usage and be unaffected by the most severe climatic conditions.

Summary of System

The inclusion of these newly developed features in the multiplex system and the application of the modified system to a long loaded cable presents a number of interesting aspects and new possibilities. The entire system is shown schematically in Fig. 7.

The use of an amplifier containing no mechanical moving parts, in which all adjustments are made by alteration of the constants of electrical circuits, makes it possible to determine at the time of installation the proper amplifier adjustments to give satisfactory signal shape at a number of different transmission speeds and thereafter the amplifier may be quickly set for any speed by duplicating the adjustments that were previously found suitable for that speed. As the operation of the correcting relays and circuits and the vibrating relay depends to some extent upon the shape of the signals delivered by the amplifier, the ability to reproduce accurately a signal shape which has been previously found satisfactory is of considerable importance in the operation of the system.

Although the amplifier and shaping networks are considered a part of the cable system rather than an element in the transmitting and receiving system, their operation must be controlled by the direction control switching mechanisms. The relays included in the direction control system which switch the amplifier circuits are built in the amplifier to simplify wiring and maintenance. The speed of the distributors is controlled as in the multiplex system by vibrating tuning forks, but in order to secure under certain conditions greater stability and freedom from speed variations due to alteration in the fork contact adjustment and changes in room temperature and voltage of the power supply there was developed a constant temperature vacuum tube driven fork. The distributor, with its driving fork, the relays included in the direction control and vibrating relay circuits, and the apparatus usually provided in land line multiplex equipments for phasing and lining up the circuit, including the Morse talking circuit, are mounted in accessible positions on a table which is separated from the operating tables on which the printers and transmitters are located.

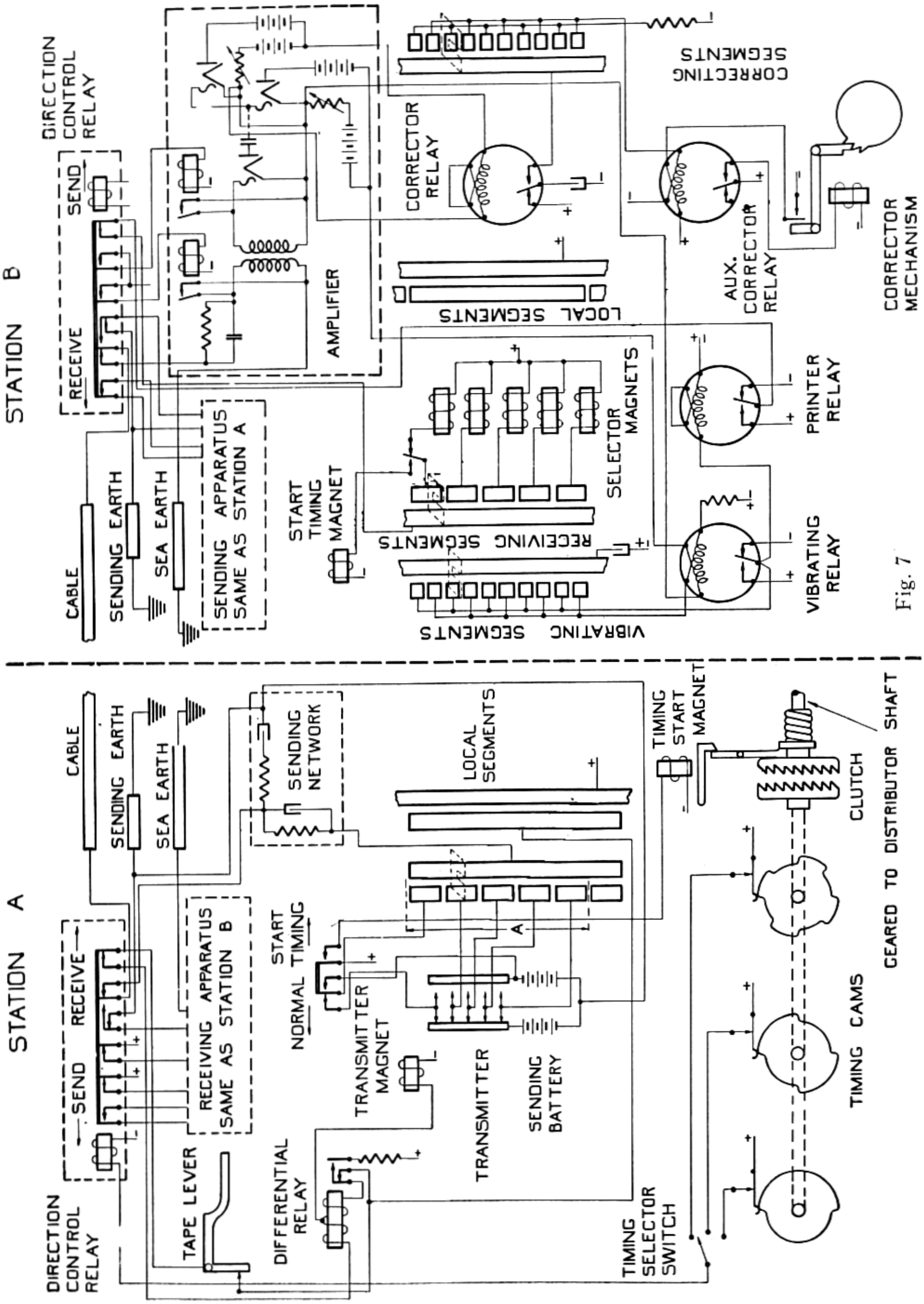
STATION B
DIRECTION CONTROL RELAY
SEND
RECEIVE
CABLE
SENDING EARTH
SEA EARTH
SENDING APPARATUS SAME AS STATION A
AMPLIFIER
CORRECTOR RELAY
CORRECTING SEGMENTS
LOCAL SEGMENTS
AUX. CORRECTOR RELAY
CORRECTOR MECHANISM
START TIMING MAGNET
SELECTOR MAGNETS
RECEIVING SEGMENTS
VIBRATING SEGMENTS
PRINTER RELAY
VIBRATING RELAY
STATION A
DIRECTION CONTROL RELAY
SEND
RECEIVE
CABLE
SENDING EARTH
SEA EARTH
RECEIVING APPARATUS SAME AS STATION B
SENDING NETWORK
LOCAL SEGMENTS
TIMING START MAGNET
GEARED TO DISTRIBUTOR SHAFT
CLUTCH
TAPE LEVER
DIFFERENTIAL RELAY
TRANSMITTER MAGNET
NORMAL
START
TIMING
TRANSMITTER
SENDING BATTERY
TIMING CAMS
TIMING SELECTOR SWITCH

Fig. 7

The adaptation of the multiplex to cable operation does not involve any modifications which affect the design of the perforators, transmitters, or printers, so that it is possible to employ in this system the same type of instruments used in land line operation.

In cases where it is desirable to link two cable sections together automatic repetition is provided for by the provision of additional sending and receiving commutators on the repeater distributor for transmitting and receiving on the second section. A photograph of such a repeater distributor is shown in Fig. 8. The incoming signals

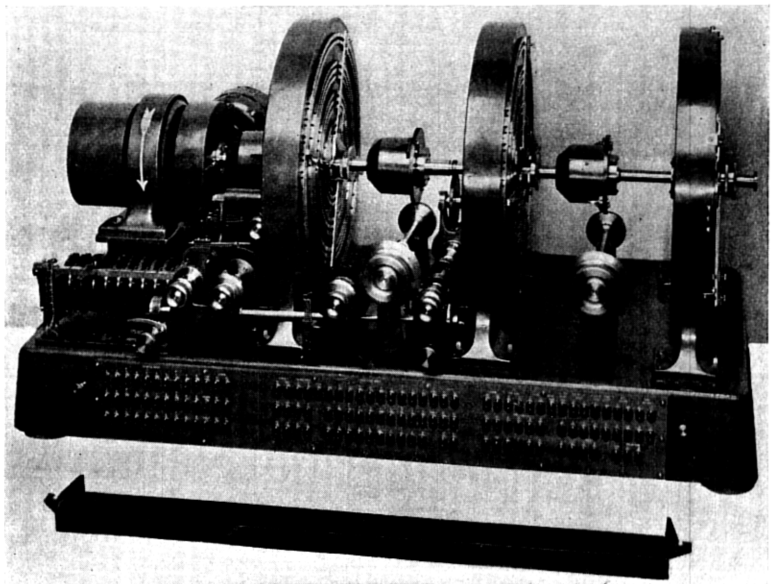

Fig. 8

at the repeater are received in the regular way and operate the vibrating relay which applies the completely corrected impulses to the receiving segments. The receiving segments, instead of being connected to the selector magnets of a printer, are connected to the windings of storing relays which are operated by the incoming signal combinations and set up the identical combinations on the corresponding sending segments associated with the next section of cable. The storing relays thus perform the same function as a tape transmitter except that they are controlled directly by the received signals instead of a perforated tape. With this method [10] of repetition it is possible to replace the storing relays on any channel with a printer and trans-

[10] E. P. Bancroft, et al., U. S. Patent No. 1,541,316.

mitter on each section so that one or more channels on both cable sections may be terminated at the repeater station without interfering with automatic repetition of traffic on the remaining channels.

Not only is it possible to link two or more simplex cable sections together through automatic repeaters, but it is also possible to link such a system through repeaters with a duplexed land line multiplex without introducing serious complications. The printer on the receiving side of each channel of both the land and cable circuits at the repeater station may be replaced with an automatic reperforator which will prepare from the incoming signals a perforated tape for retransmission. As this tape leaves the reperforator it is automatically drawn through a standard transmitter which will transmit the signals into the corresponding channel of the next section of line or cable. In moving between the reperforator and transmitter the tape passes under a contact closing lever arranged to stop the operation of the transmitter when the slack in the retransmitting tape drops below a predetermined minimum as the result of a difference in transmission speed on the two sections or the stoppage of the reperforator on the simplex section during the transmitting periods. This avoids the possibility of mutilation of the transmitted signals or tearing the tape.

The provision of a comparatively large number of traffic channels and automatic repeaters by means of which traffic on any or all channels may be automatically repeated into the other cable sections or land telegraph lines affords a high degree of flexibility in handling and routing traffic and permits the several channels to be terminated at the two ends in widely separated points.

Conclusion

Although the general principles of the system and the general design of the apparatus described herein are applicable to all loaded cables irrespective of length or construction, it is quite obvious that the detailed design of the various pieces of apparatus required will be determined to a great extent by the electrical characteristics of the particular cable to which they are to be applied and by the operating and traffic requirements which that system must fulfill. Equipment of this type can not therefore be standardized to the degree possible in the case of similar equipment for land line service, and the provision of apparatus for each cable becomes a special engineering problem which must be worked out with the cooperation of the engineers of the operating company in order to make the apparatus capable of satisfactorily meeting all of the conditions which will obtain in subsequent commercial use.

A complete operating equipment embodying the general principles described has been designed with the cooperation of the engineers of the Western Union Telegraph Company for the New York-Azores permalloy loaded cable and has been in actual commercial operation for many months. Provision has been made in the design of this apparatus for the extension of the circuit to Emden, Germany, over the Azores-Emden cable of the Deutsch-Atlantische Telegraphengesellschaft, and automatic repeaters for the Azores station and terminal equipment for the Emden station have been installed and are now undergoing tests preliminary to the establishment of through-operation between New York and Emden.

Appendix I

Synchronous Vibrating Relay

There are several methods which may be employed to obtain the synchronous vibrating feature, one of which is shown schematically in Fig. 9. The relay is of the polarized type having two separate

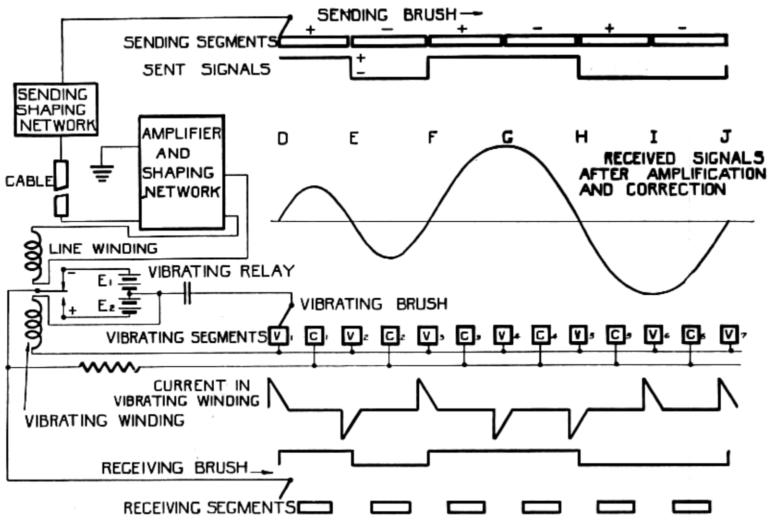

FIG. 9

Fig. 9

windings, one of which, termed the line winding, is connected directly in the output circuit of the amplifier, and the other, or vibrating winding, is included in a circuit comprising the vibrating condenser, the vibrating segments V and the vibrating brush of the distributor. The distributor segments are shown developed for the sake of clearness. Disregarding the line winding for the moment, the passage of the vibrating brush over segment C_1, when the relay armature is resting against the negative contact, causes the vibrating condenser to be negatively charged by the battery E_1, and as the brush continues its rotation and passes upon segment V_1, the charged condenser is disconnected from the charging circuit and is connected to the vibrating winding through which it immediately discharges in the proper direction to cause the relay armature to be moved against its opposite or positive contact. This change in the position of the relay armature connects all of the "C" segments to positive battery, so that the passage of the brush over segments C_2 and V_2 in succession causes the condenser first to be positively charged, then to discharge through the vibrating winding which restores the relay armature to its former position against its negative contact. This cycle of operations will be repeated as long as the brush rotates and the rate of vibration can be made to coincide exactly with the frequency of the transmitted signals by suitably arranging the vibrating brush so as to be corrected from the incoming signals in a manner similar to that employed in the standard multiplex system.[11] The armature of the vibrating relay, in addition to controlling the polarity of the charge upon the vibrating condenser, controls the polarity of a battery applied to the receiving brush which distributes the received and corrected signalling impulses to the selector magnets of the receiving printer. In practice an intermediate relay, not shown in the figure, is employed between the armature of the vibrating relay and the receiving brush.

The line winding of the vibrating relay is connected in the amplifier circuit in the direction which will cause its armature to move toward its positive contact in response to incoming signalling impulses of positive polarity and vice versa, and as the amplitude of the current in that winding is adjusted to be approximately equal to that of the vibrating impulses, the effect of impressing the amplified and partially corrected positive impulse D upon the line winding at the time the vibrating brush is passing over segment V_1 would be only to aid the condenser discharge current in reversing the position of the relay armature. Every received impulse of unit length and the current during the first interval of unit length in every sustained pulse will produce the same result as shown at D, E, F and H, but the effect of current in the line winding due to the second and all succeeding time units of every sustained pulse will be neutralized, as shown at G, I

[11] J. H. Bell, loc. cit.

and J, by a pulse of approximately equal amplitude and opposite polarity in the vibrating winding and the position of the relay armature will therefore remain unchanged. Thus as the relay is actually operated by the energy supplied by the locally generated vibrating impulses and the received signalling current is employed only to neutralize the effect of the vibrating impulses during the second and succeeding time units of the sustained pulses, a considerable amount of distortion may be present in the signals without causing errors in reception, in fact the impulses of unit length may be entirely missing without interfering in any way with the accuracy of reception.

Ordinary polarized relays not provided with the vibrating feature are operated by the energy supplied by the amplified signals, which must consequently be quite free from distortion in order to insure faithful reproduction of the transmitted signal. The speed of transmission on long submarine cables employing non-vibrating relay reception cannot exceed that frequency at which the received signalling impulses of unit length are reduced by the attenuation of the cable to an amplitude which is only enough greater than the interference currents present to cause positive operation of the relay. The vibrating relay, however, does not require the pulses of unit length to be present at all, so that its limiting speed is that at which the impulses of two units length are received in just sufficiently large amplitude to prevent the relay from vibrating and allow a reasonable margin for overcoming the effects of any interference currents that may be present. This limiting speed is approximately double that obtainable with the use of non-vibrating relays.