Feb. 15, 1944. W. D. CANNON ET AL 2,341,902

ELECTRONIC TELEGRAPH REPEATER

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FIG. 1

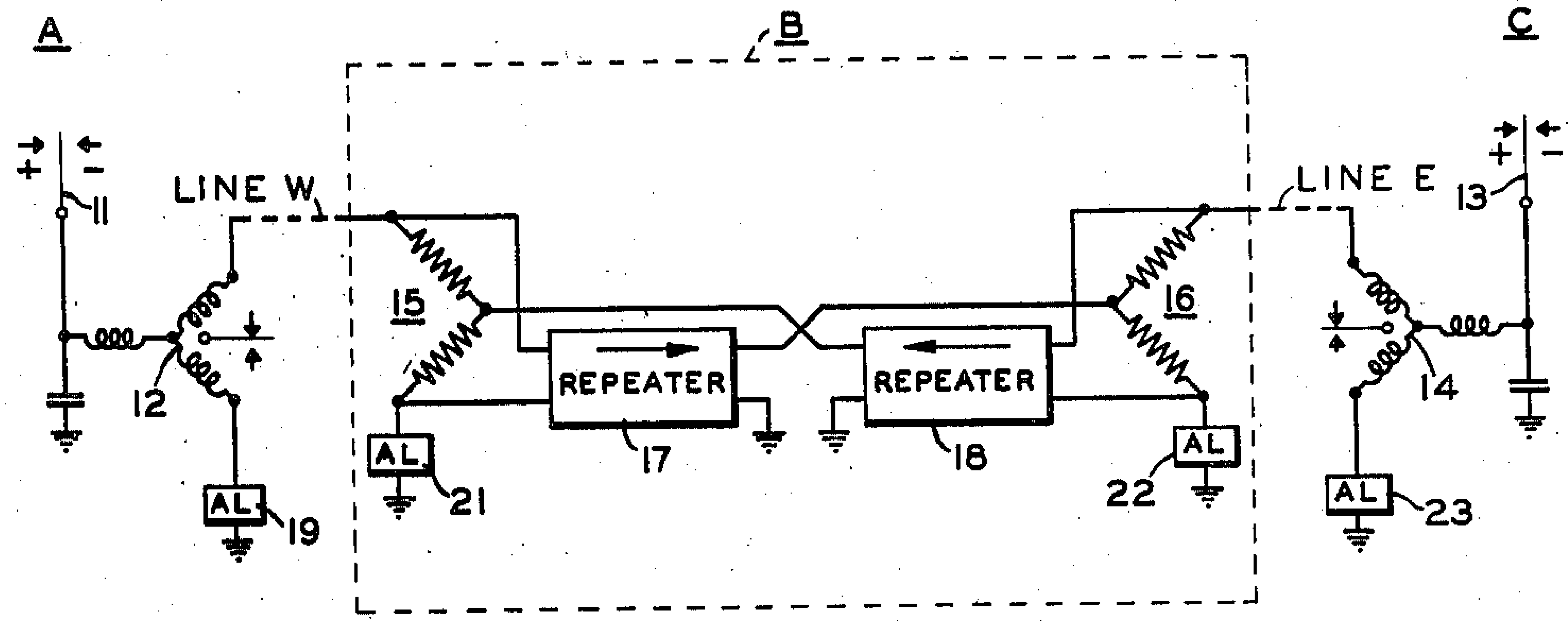

FIG. 3

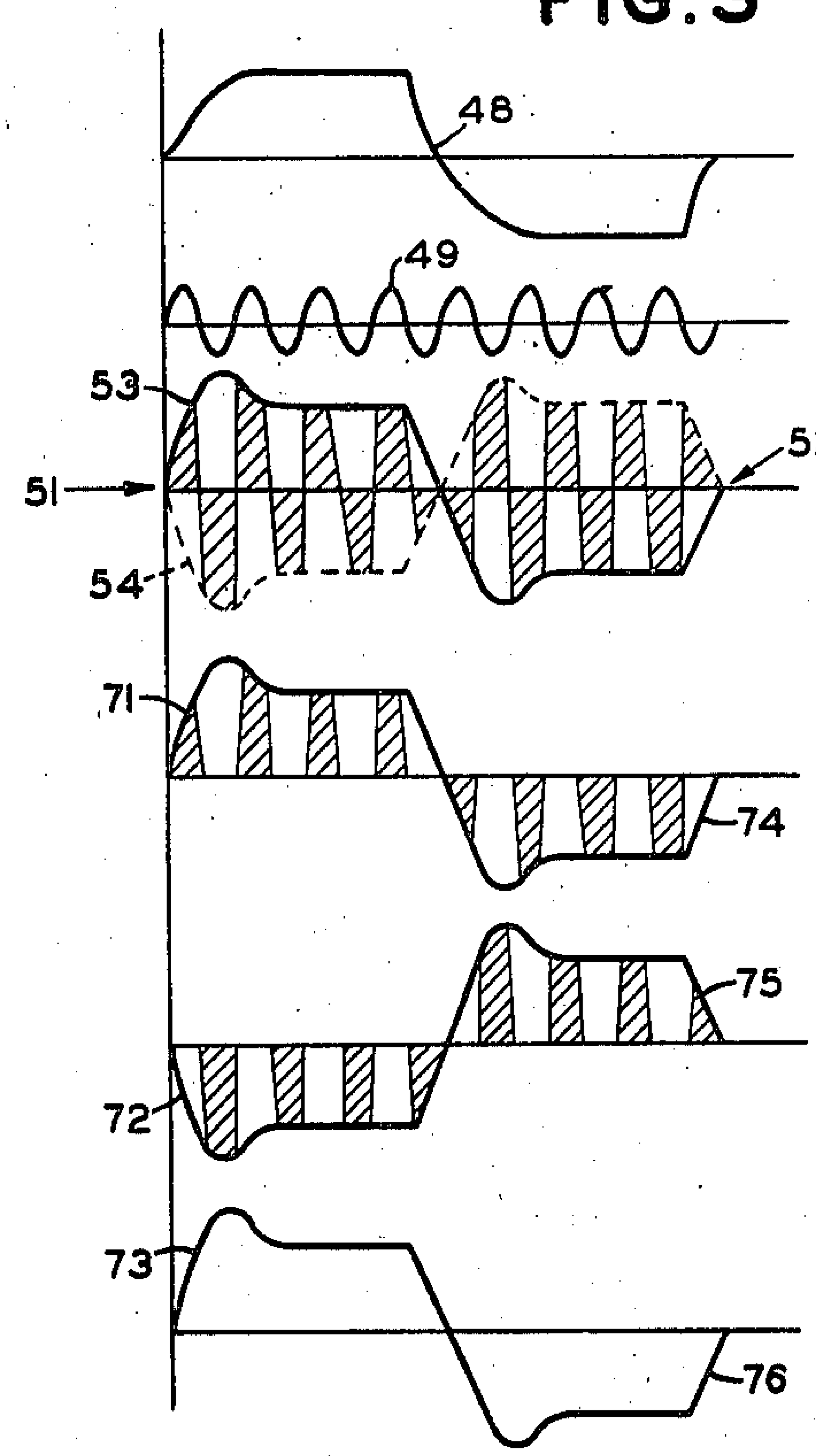

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FIG. 2

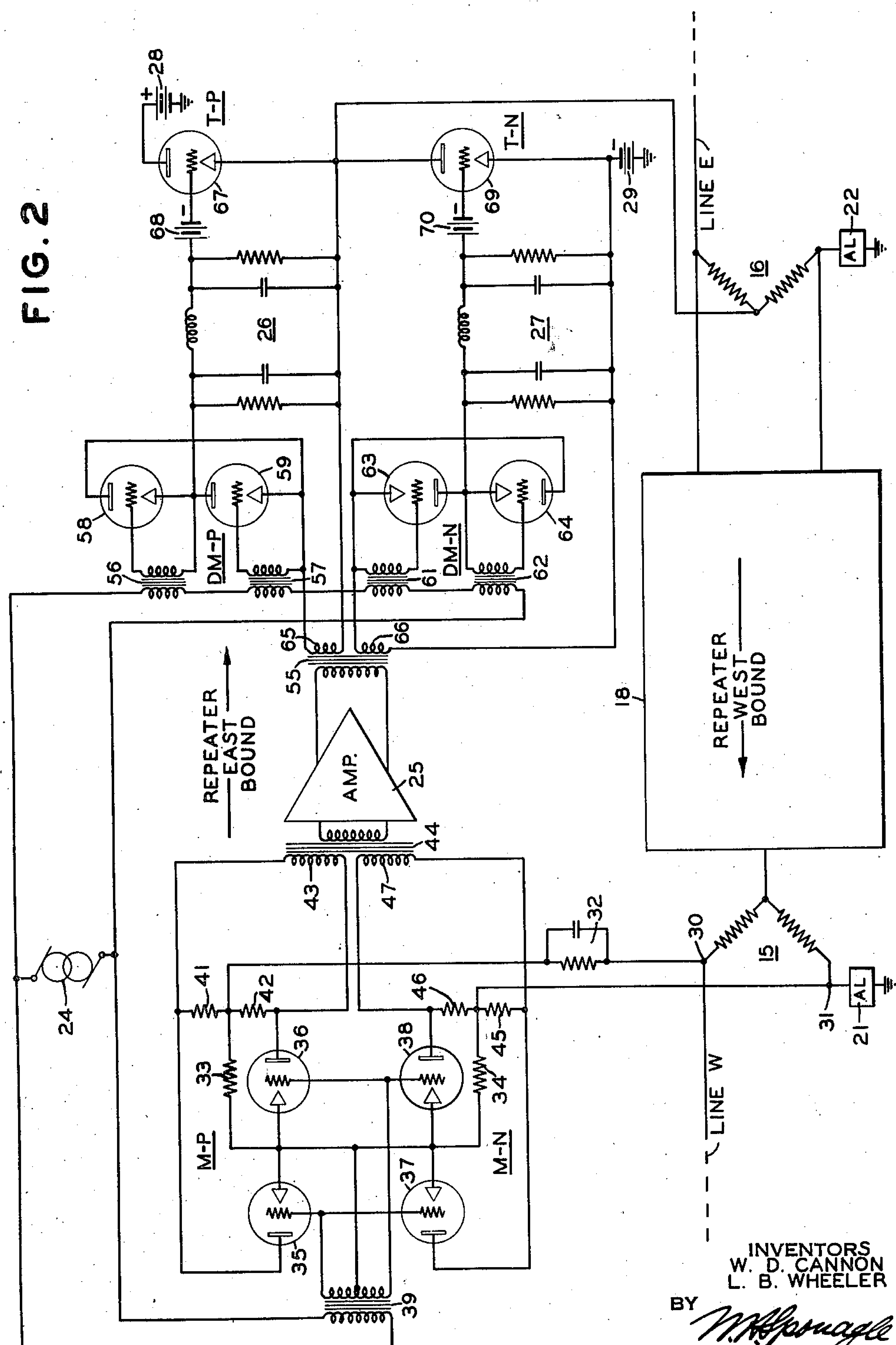

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FIG. 4

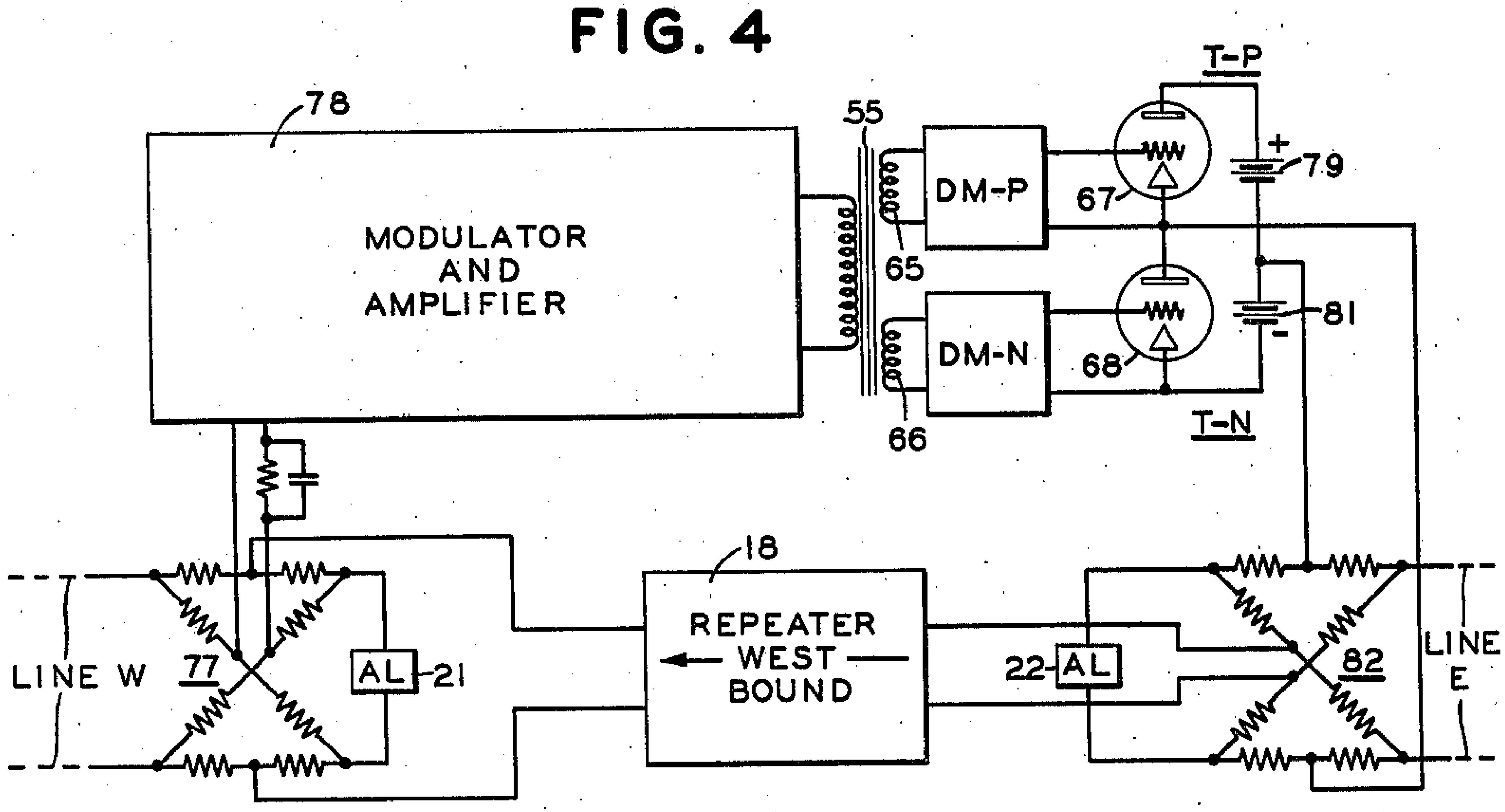
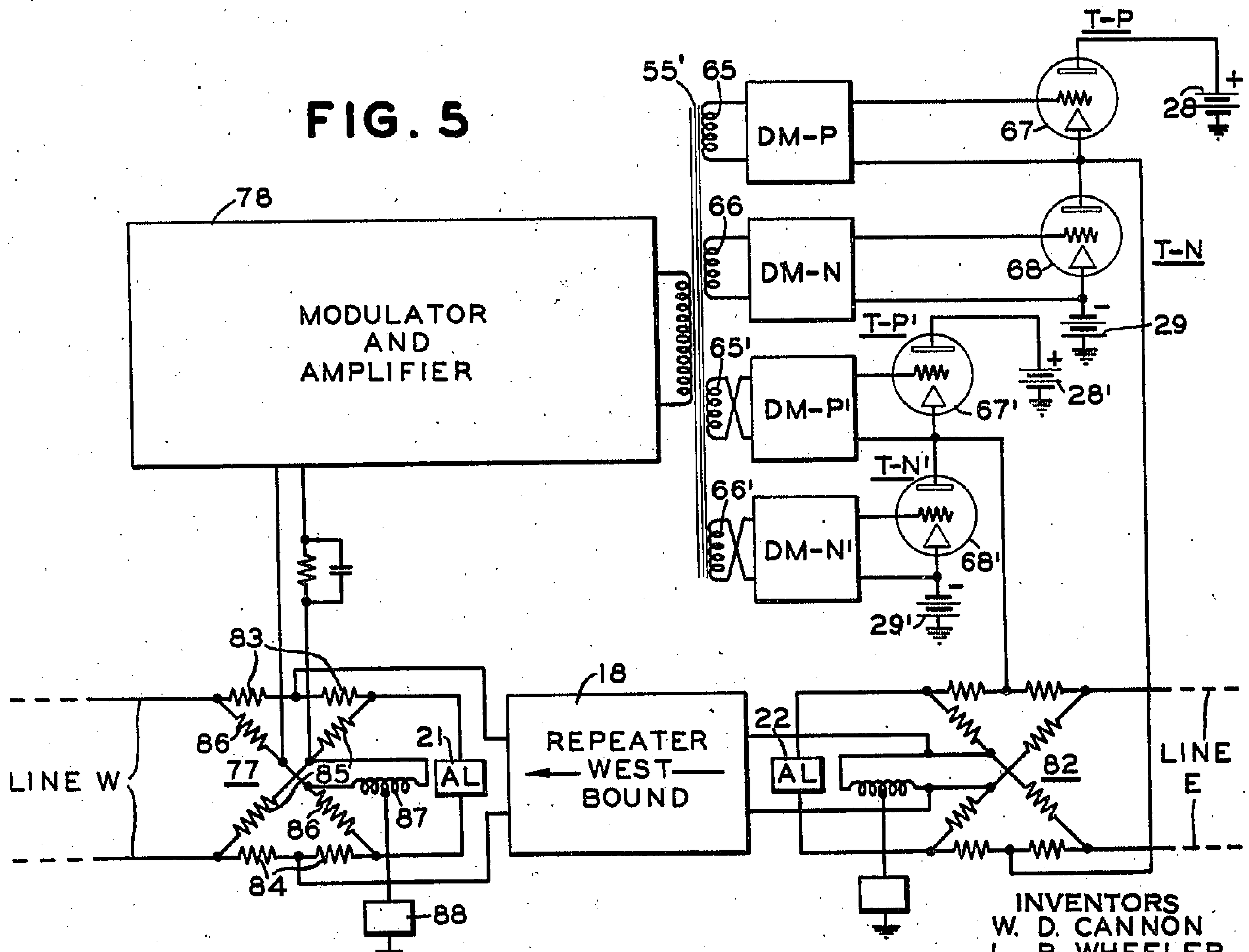


FIG. 5



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ELECTRONIC TELEGRAPH REPEATER

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Application August 12, 1941, Serial No. 406,454

22 Claims. (Cl. 178—60)

This invention relates to telegraphy and has particular reference to a duplex telegraph system embodying an electronic repeater particularly adapted for use at an unattended station.

Since the time that electronic repeating devices were first suggested as substitutes for electromagnetic relays for the repetition of telegraph signals, numerous electronic repeaters have been devised. However, all of these devices, while obviating certain deficiencies such as slowness of response inherent in relay repeaters, have in themselves introduced other limitations or deficiencies. These prior art electronic repeaters have not been readily adapted for use with the regular sources of grounded direct current potentials available in a telegraph office. Consequently, modifications in the telegraph battery supply for use with these repeaters have been required. Also, the prior art electronic repeaters have required relatively large quantities of power for their operation so that they are uneconomical for use in this respect. Another deficiency has been the limited power output of the prior art electronic repaters, thereby limiting their use to short lines or lines which do not require very large signal amplitudes to be transmitted from a repeater station in order that a signal of amplitude sufficient for proper reception may be received at a terminal station. Furthermore, because of the inherent characteristics of the electronic devices employed in the prior art repeaters and the manner in which the circuits employing such devices have been designed, these repeaters have tended to introduce a bias between the positive and regative signal impulses. This limitation also detracts from the efficiency of the system in which such a repeater is employed.

Where circuits are operated on a duplex basis, in each station at which a line section is terminated either for transmission and reception, or for repetition, an artificial line has been employed in a well known manner and adjusted so that the constants thereof simulate the constants of the real line. In any of the prior art repeaters, whether relay or electronic, an unbalance between the constants of the artificial line and the real line caused for any reason such as, for example, changing atmospheric conditions to which the real line is exposed, produces a distinctive distortion of the signals received from such a line. This type of distinction is produced by the signals which are transmitted over the unbalanced line in the reverse direction to that from which other signals are being received. These distorted received signals when passed through any of the prior art repeaters are retransmitted as substantially square-topped signals, and the effect of the unbalance disturbance upon such signals is a change effected in the length thereof, if the disturbance occurs near the beginning or end of a signal. Of course, if it occurs during the middle of a signal, there is apt to be no deleterious effect upon the signal. As is well known, there are numerous other interference effects to which the telegraph line is exposed which also tend to change the length of the signals. Consequently, at the station where such lengthened or shortened signals are received, there is no way of determining which signals have been distorted by reason of an unbalanced condition existing at a repeater station through which the signals have passed and those which have been distorted by other forms of interference. There fore, in the past there has been no way of correcting or compensating at a terminal or repeater station for unbalance disturbance introduced at other stations into the signals received at that station for the reason that the unbalance disturbances are no longer distinguishable as such.

Hence, it is an important object of the invention to provide an improved electronic repeater obviating the foregoing deficiencies of prior art repeaters and which is suitable for use at unattended stations of a duplex telegraph system.

Another object of the instant invention is to provide a method of operating a duplex telegraph circuit whereby unbalance disturbances occurring at an intermediate repeater point are transmitted to another station of the system at which is effected compensation for the disturbances.

Still another object of the invention is the provision of a method and means for operating a duplex telegraph circuit whereby the effect upon the signals arising from an unbalanced condition between the real and artificial lines is accurately reflected in the signals transmitted from the station at which said unbalance exists and a compensating adjustment in the artificial line values at a station receiving such signals is effected.

Another object of the invention is to provide in a signaling system a translation device employing a carrier current of which one characteristic is modified in accordance with signal amplitude and another characteristic is modified in accordance with signal polarity.

Still another object of the invention is to provide a signaling system in which a carrier current is phase-modulated in accordance with marking and spacing signals and subsequently synchronously demodulated whereby the signals are reproduced in a novel manner.

An additional object of this invention is the provision of a novel organization of instrumentalities whereby a carrier current which is phase-modulated in accordance with marking and spacing signals is synchronously demodulated to translate the signals into opposing direct current components having polarities representative of said signals.

A further object of the present invention is the provision of means for transmitting telegraph signals in which is employed a carrier current modulated in amplitude according to the signal amplitude and in phase according to the signal polarity and also means including a phase discriminating demodulator for translating said modulated carrier into direct current signals of positive and negative polarity.

A still further object of the invention is to provide for each direction in a telegraph repeater a single electronic amplifier upon which is impressed phase-modulated alternating currents having substantially the same magnitude for both marking and spacing signals whereby both signals are amplified alike so that bias of said signals cannot occur due to any unequal amplification of the marking and spacing signals.

The attainment of these and other more specific objects of the instant invention is effected by the apparatus disclosed herein by way of illustrating one form of the invention and which is described in conjunction with the accompanying drawings, of which:

Fig. 1 is a block diagram of a typical duplex telegraph circuit, into which may be incorporated the novel repeater;

Fig. 2 shows in greater detail the apparatus comprising the repeater;

Fig. 3 is a series of curves representing typical wave forms found in various portions of the repeater;

Fig. 4 illustrates an arrangement for utilizing the novel repeater in a full metallic circuit requiring the use of metallic transmitting batteries; and

Fig. 5 illustrates the manner in which the novel repeater may be employed in a full metallic circuit in a case where it is desired to use grounded transmitting batteries.

Referring to Fig. 1 of the drawings, there is shown a duplex telegraph system comprising two repeater sections linking two remote terminal stations A and C. Each of the repeater sections includes a line wire designated respectively as line W, extending between station A and an intermediate repeater station B, and line E, extending between the repeater station B and the terminal station C. It will be understood that where the stations A and C, for the sake of simplicity, are referred to as terminal stations, one or both may be additional repeater stations through which the circuit is extended to still other stations. At station A is provided transmitting equipment 11 by means of which positive and negative signals are transmitted over the line W to the repeater station B. Station A is also provided with a receiving device which, in this instance, is shown as a polarized relay 12 having two similar windings connected differentially in the well known manner for differential duplex operation. One winding of the relay 12 is connected to the line W, and the other to an artificial line. The constants of the artificial line are adjusted to simulate the constants of the real line W so that the receiving relay 12 is unresponsive to signals transmitted from the transmitting device 11 and at the same time responds to positive and negative signals received at station A over line W.

Station C is also provided with a similar polar signal transmitter 13, an artificial line and a polarized receiving relay 14 which are connected to the line E.

Lines W and E terminate at the repeater station B respectively in impedance bridges 15 and 16. Each of these bridges also is connected to its individual artificial line in the well known manner. To the receiving terminals of the bridge 15 is connected the input side of the eastbound repeater 17, the output side of which is connected to the transmitting terminal of the bridge 16. Similarly, the receiving terminals of the bridge 16 are connected to the input side of the westbound repeater 18, the output side of which is connected to the transmitting terminal of the bridge 15.

In the case where stations A, B and C are provided with attendants who maintain and operate the equipment located at their respective stations, the artificial lines at all stations are kept as nearly as possible in such adjustment that good balances with the associated real lines are maintained. However, atmospheric conditions may change somewhere along line W, which then necessitates a readjustment of the artificial lines 19 and 21 of stations A and B, respectively. Likewise, there may be times when a readjustment of the artificial lines 22 and 23 of stations B and C, respectively, will be necessary to maintain the proper balance with the line E. Such a procedure is the usual method of operating duplex telegraph circuits.

However, consider the case where the artificial line 21 at repeater station B does not provide the proper balance for the impedance bridge 15 with respect to line W. Because of the unbalanced condition between the two arms of the bridge 15, the signals which are impressed upon the transmitting terminal of the bridge by the westbound repeater 18 will produce disturbing unbalance potentials at the receiving terminals of the bridge. The usual character of one of these latter potentials is a critically damped oscillatory transient which is superimposed on the signals received from station A. Since there is no time relation existing between the transmission of signals from station A and the transmission of signals from station C, these spurious potentials caused by the unbalance of bridge 15 may occur at any time with respect to the signals which are received from station A. If they are not received in the middle of a received signal, not much damage is done. It is chiefly in the case where these unbalance disturbances are superimposed upon the received signals at or about the time of reversal of polarity between signals that the signals are seriously distorted.

In the prior art repeaters, particularly those employing relays, the receiving device which responds to the potentials appearing across the receiving terminals of the bridge 15 is operated at or shortly after the reversal of potential. If the super-position of an unbalance disturbance upon a received signal occurs just as it is about to reverse in polarity, the actual time of reversal is either hastened or delayed depending upon the shape of the unbalance transient. Consequently, one signal is in effect lengthened and the other signal is correspondingly shortened. Thus, when a prior art repeating device which is responding to such a mutilated signal retransmits a regenerated signal, this signal is either longer or shorter than a perfect signal. When such a signal is received at station C, the only thing that can be determined there is that it is longer or shorter than a perfect signal, but since all transmission lines are exposed to a large number of other types of interference effects which produce similar effects upon the signals, this information is of little value in correcting or compensating for unbalance distortion. It will be observed, therefore, that the unbalance distortion of a signal goes undetected because the manifestations of such distortion are indistinguishable from other types of distortion. Even if it were possible to determine at station C that the cause of the signal length distortion is due to an unbalanced artificial line at station B, it is not possible with prior art repeaters to effect at station C a uniform compensation for such distortion for the reason that there is received not the distorted wave form of the signal but only the resulting length distorted signal.

If the repeaters 17 and 18 are of the improved type in accordance with the instant invention, any distortion of a signal received from line W at station B caused by the unbalance of artificial line 21 is accurately repeated in its original form so that it may be received in such form at the terminal station C. It should be clear then that, if the wave form of signals appearing at the receiving terminals of the bridge 15, distorted in form by an unbalance of the bridge, are transmitted accurately so that they appear at the receiving terminals of the receiving relay 14 of station C, they will have the same effect upon the signals received at station C as if they were actually produced by an unbalance of the artificial line 23. Consequently, it is a relatively simple matter for the attendant at station C to readjust his artificial line 23 to produce at the receiving terminals of the relay 14 transient effects which are substantially equal in magnitude and opposite in sense to the disturbances present in the received signals. The readjusted artificial line now no longer provides a perfect balance for its associated line, but the new condition does provide a substantially perfect compensation for any unbalance existing at the nearby unattended repeater. Thus, it is obvious that there is an effective compensation made at station C for a duplex unbalance existing at station B whereby the relay 14 will respond to the received signals in precisely the same manner as it would if these signals were undistorted.

The importance and value of such a system is that a repeater may be installed at an intermediate point such as station B in accordance with the teachings of the instant invention and may be left completely unattended. In such a case the artificial lines 21 and 22 are adjusted to some values approximating line conditions which are the average between extremely wet conditions and extremely dry conditions. As the atmospheric conditions surrounding the lines W and E vary from time to time, the degree of unbalance between these real lines and the corresponding artificial lines will be changing. However, since both repeaters 17 and 18 are capable of faithfully and accurately retransmitting to the respective terminal stations any amplitude distortion of the signals as received at the repeater station caused by unbalance between real and artificial lines at the repeater station, compensation may be made at stations A and/or C by adjusting the artificial lines 19 and/or 23, respectively, in the manner outlined.

The novel repeater employed in the improved telegraph system will be described in detail by having reference to Fig. 2 which discloses more specifically the apparatus included within the dotted lines of Fig. 1. This portion includes a novel organization of apparatus for receiving the signals of positive and negative polarity from the bridge 15, amplifying them and retransmitting them into the apex of the bridge 16. Only the eastbound portion of the repeater is illustrated in detail. The westbound portion, which is a duplicate, is indicated in block form in this figure. In this and the other figures of the drawings, the same reference characters are used to designate the same apparatus. Apparatus designated by reference characters with primes is similar to corresponding apparatus designated by the same reference characters without primes.

The illustrative embodiment of the invention comprises a full duplex electronic repeater in each portion of which polar signals are received from one line and employed to modulate a carrier current. One characteristic of the carrier current, such as the amplitude for example, is modulated according to the signal amplitude. Another characteristic of the carrier current, such as either the phase or frequency for example, is modulated according to the signal polarity. After amplification this doubly modulated carrier current is suitably demodulated to produce distinctive direct currents which are utilized to control the transmission of polar signals into a second line.

The signals which are received from the line W are employed to modulate a carrier current derived from any suitable source, such as the generator 24. The frequency of the carrier current is appreciably greater than that of the telegraph signals. Two modulators which are controlled by the received telegraph signals are used to modulate the carrier current. The modulator M—P is employed to modulate the carrier current in response to positive signals, and the modulator M—N is employed to modulate the carrier in accordance with negative signals. In the form of the invention which at present is preferred, the carrier current is modulated in amplitude in accordance with the amplitude of the received telegraph signals and also in phase in accordance with the polarity of these signals. The modulated carrier currents are then amplified by means of an amplifier 25, and the amplified alternating currents are impressed upon a pair of demodulators DM—P for positive signals and DM—N for negative signals. The products of these demodulation processes are applied to impedance networks constituting smoothing filters. The filter 26 is used in conjunction with the positive demodulator DM—P and the filter 27 is used in conjunction with the negative demodulator DM—N. The direct currents so derived are applied simultaneously to the input circuits of a pair of transmitting devices T—P for positive potentials and T—N for negative potentials. The output circuits of these devices are connected to suitable sources of direct current potential, such as the positive battery 28 and the negative battery 29, and also to the transmitting terminal of the bridge 16 associated with the line E.

Similarly, the signals which are received from line E at the receiving terminals of the bridge 16 are passed through the westbound repeater 18 which is a duplicate of the eastbound repeater. The signals regenerated by this device are then applied to the transmitting terminal of the bridge 15, which is associated with the line W.

For a more detailed description of the mode of operation of the eastbound repeater consideration will be given first to the repetition of a positive signal received from the line W. This signal appears across the bridge 15 as a difference of potential, the point 30 being positive with respect to the point 31. This difference of potential is applied through a shaping network 32 to a voltage divider comprising the two similar resistances 33 and 34. The shaping network 32 serves to emphasize the higher frequency components of the telegraph signal and to steepen its rising slope. The voltage drop across the resistance 33 is impressed between the cathodes and the anodes of the tubes 35 and 36 comprising the positive signal modulator M—P. Also, the voltage drop across the resistance 34 is applied across the cathodes and anodes of the tubes 37 and 38 comprising the negative signal modulator M—N. It is evident that the anodes of the tubes 35 and 36 are positive with respect to their associated cathodes and also that the anodes of the tubes 37 and 38 are negative with respect to their associated cathodes. Consequently, irrespective of the condition of the input circuits of the modulator M—N, this device will not respond to a positive received telegraph signal.

The source of carrier current 24 is coupled by means of a transformer 39 to the input circuits of both positive and negative modulators in such a manner that one tube of each is conditioned for operation insofar as the input circuits are concerned. Consider the condition where the grids of tubes 35 and 37 are rendered positive with respect to their associated cathodes. At this time the grids of the tubes 36 and 38 are rendered negative with respect to their associated cathodes, and therefore can produce no response. Also, the tube 37 is rendered completely inoperative by reason of the negative anode to cathode potential previously referred to. The tube 35, however, becomes conductive so that current is permitted to flow through two parallel paths as follows: One of these parallel paths may be traced from the right hand terminal of the resistance 33, through the resistance 41 and the space discharge path of the tube 35, to the left hand terminal of the resistance 33. The other parallel path may be traced from the right hand terminal of resistance 33 through the resistance 42, upward through primary winding 43 of the coupling transformer 44 and through the space discharge path of the tube 35 to the left hand terminal of resistance 33.

Upon reversal of the carrier current the tubes 35 and 37 are rendered inoperative, and the input circuits of tubes 36 and 38 are operatively conditioned. The anode to cathode potentials of the modulator tubes remain as before so that the tube 36 is rendered conducting and completes two parallel paths similar to those previously traced including the resistances 41 and 42 and the transformer primary winding 43, but in this case it is to be noted that the flow of current in the transformer primary winding is downward, thus effecting a current reversal in this winding.

This cyclic operation of the tubes comprising the positive modulator M—P continues for the duration of the positive received telegraph signal. The optimum performance by the modulators has been attained by employing an exciting carrier voltage of such magnitude that the tops of the half cycles in the modulator output are cut off to produce square topped waves. These tubes then have negligible resistance substantially continuously throughout the excitation period. It then follows that the output of the tubes is a direct function of the signal voltage which is applied to the anodes of these tubes and the alternating current half cycles derived from the carrier appears sharply cut off as it follows the envelope of the applied signal. It has been found that by following such a practice the output levels of the modulators are not materially affected by fluctuations in the level of the exciting source which in this instance is the generator 24. As a further benefit more energy is transmitted through the modulators within the limits of the telegraph signal voltage applied to the space path. The modulator tubes may be of conventional three electrode or other suitable types, although preferably they should have relatively high amplification factors. It is obvious that while the tubes 35 and 36 and also the tubes 37 and 38 are shown as individual tubes, it may be desirable to employ tubes containing in the same envelope the elements of both tubes 35 and 36 and also of the tubes 37 and 38.

Before continuing with the description covering the repetition of a positive telegraph signal, a better understanding of the invention may be obtained by considering the action of the carrier modulator in response to a negative telegraph signal. When such a signal is received at the repeater station, it also appears across the bridge 15 as a difference of potential, in this case the point 30 being negative with respect to the point 31. When such a potential is applied across the resistances 33 and 34, the positive modulator tubes 35 and 36 are rendered inoperative by reason of the negative potential applied to the anodes thereof with respect to their associated cathodes. At the same time the anodes of the negative modulator tubes 37 and 38 are rendered positive with respect to their associated cathodes, thereby conditioning these tubes for alternate operation under the control of the exciting carrier currents. When a positive half cycle of the carrier current is applied to the modulator tubes, the negative signal modulator tube 37 is rendered conducting, thereby completing a pair of parallel paths for the flow of current derived from the received signal. One of these paths may be traced from the right hand terminal of resistance 34, through the resistance 45 and the space discharge path of the tube 37, to the left hand terminal of resistance 34. The other of these paths may be traced from the right hand terminal of resistance 34 through the resistance 46, downward through the primary winding 47 of the coupling transformer 44 and through the space discharge path of the tube 37 to the left hand terminal of resistance 34. Upon reversal of the carrier current the negative modulator tube 38 becomes conducting to permit a flow of current upward through transformer winding 47. This cyclic operation of the tubes 37 and 38 of the negative modulator M—N continues during receipt of the negative telegraph signal.

It will be remembered that in modulating the carrier current in response to a received positive signal during the time when the modulator tubes were excited by positive half cycles of the carrier current, an upward flow in transformer primary winding 43 was effected. This is the reverse of the current flow through the transformer primary winding 47 during the modulation of corresponding half cycles of the carrier current in response to negative received telegraph signals.

Thus it is seen that the action of the positive and negative signal modulators responding respectively to positive and negative received telegraph signals produces a phase reversal in the secondary winding of the transformer 44 to distinguish between these two types of signals. Also, where the positive and negative telegraph signals as received have identical wave shapes, the amplitude modulation of the carrier current in conforming to these wave shapes will be the same for positive signals as it is for negative signals. As a consequence of this arrangement, there is applied to the amplifier 25 alternating currents of varying amplitude in accordance with the received signal wave shape, but there is no distinction made as to amplitude between positive and negative signals. A distinction between these two types of signals is made on the basis of phase so that these signals may be separately recovered in a manner to be presently described. The importance of the lack of distinction as to amplitude between positive and negative signals is that it obviates any possibility of a bias between these two signals being introduced in the amplifier by reason of unequal amplification of the two types of signals.

It will also be observed that one amplifier is used for the amplification of both positive and negative signals, thereby eliminating the further possibility of the introduction of bias into these signals which is always present where separate amplifiers are employed for the amplification of the respective signals. In this case, the amplifier 25 may be any conventional type of amplifier, such as a common resistance coupled type, so long as it has ample power capacity to render it substantially distortionless with regard to signal amplitude. Numerous amplifiers meeting these requirements are so well known to those skilled in the art that it is believed unnecessary to elaborate further upon this element of the repeater.

At this point in the description it may be well to refer briefly to some of the curves of Fig. 3. The curve 48 represents a typical wave form of two received signals, the left hand portion representing a positive signal and the right hand portion a negative signal. The curve 49 represents a carrier current of a frequency higher than the telegraph signaling frequency. It has been found that for the repetition of telegraph signals having a frequency of approximately 60 cycles per second a carrier frequency of approximately 1500 cycles per second is satisfactory. These figures are included by way of example, since obviously it is not contemplated that the invention be limited thereto, since other values, preferably of higher frequency, will produce the desired results, as well understood by those skilled in the art. In this figure, the frequency of the carrier current represented by the curve 49 is illustrated as being substantially less than 1500 cycles. The purpose of this is to better illustrate the principles underlying the operation of the novel repeater.

Another curve of this figure illustrates the results obtained by modulating the carrier current by the received signals in the manner described. The amplitude modulation of the carrier current in response to the positive received signal is illustrated by the curve 51, while the curve 52 illustrates the modulation of the carrier current in response to a negative signal. The carrier current curves 51 and 52 are drawn to a larger scale than that of curve 49 and may be considered as representing the output as well as the input of the amplifier 25. It will be noted that positive half cycles shown in the shaded areas above the axis are sharply cut off and confined within an envelope 53 which corresponds to the shape of the positive portion of the curve 48 after the addition of some beneficial shaping at the beginning of the signal. Also, the modulation of the negative half cycles of the carrier current in response to a positive received signal is illustrated by the shaded portions appearing below the axis and encompassed within the dotted line 54 which is the exact reverse of the curve 53.

Bearing in mind that these curves under discussion are representations of the current supplied to the input side of the amplifier, it will be noted that under the enveloping curve 53 positive half cycles of the alternating current correspond in time to positive half cycles of the carrier current represented by the curve 49. However, when this carrier current is modulated in response to a negative received signal, the envelope of the alternating current is an exact duplicate of the envelope of the alternating current produced by modulating the carrier in response to a positive received signal, but in this case there has been a reversal in phase as indicated previously. This is demonstrated by a comparison of the curves 51 and 52 with the curve 49, where it is seen that for positive signals 51, the phase of the carrier is unchanged but for negative signals 52, the phase is reversed with respect to curve 49. Also, it will be noted that the common amplifier 25 functions to transmit at all times a modulated carrier current having symmetrical positive and negative envelopes of equal magnitude. This symmetrical loading serves to prevent the occurrence of distortion due to rectification effects.

Referring again to Fig. 2, it is seen that after amplification by the amplifier 25 these amplitude- and phase-modulated alternating currents are applied to the primary winding of a transformer 55 coupling the amplifier with the demodulators DM—P and DM—N. These demodulators are excited by a carrier current having the same frequency and phase as the initially modulated carrier current which preferably is derived from the carrier current generator 24, although obviously it may be derived from other sources maintained in synchronism with the generator 24 by any of a number of well known means. Consider the operation of the demodulators during receipt of a positive telegraph signal and while the carrier current half cycle is also positive. By means of transformers 56 and 57 the respective grids of the positive demodulator tubes 58 and 59 are rendered positive at this time with respect to their associated cathodes. At the same time by means of transformers 61 and 62 the respective grids of the negative demodulator tubes 63 and 64 are rendered negative with respect to their associated cathodes. Therefore, the negative demodulator tubes cannot function at this time, but both of the positive demodulator tubes are rendered receptive by the input circuit exciting voltages. At this particular instant a positive half cycle of the modulated carrier current is induced simultaneously in the secondary windings 65 and 66 of the transformer 55. The potential induced in the winding 65 is applied to the positive signal demodulator DM—P, while the potential induced in the secondary winding 66 is impressed upon the negative signal demodulator DM—N. The latter potential can have no effect at this time, since both of the tubes 63 and 64 are inoperatively conditioned as described. However, the positive demodulator tube 58 is rendered conducting to complete a circuit which may be traced from the upper terminal of the secondary winding 65, through the space discharge path of the tube 58 and downward through the filter network 26 to the lower terminal of the winding 65. Since the upper and lower terminals of the filter 26 are connected respectively to the grid and cathode of the tube 67 forming part of the positive signal transmitter T—P, the positive potential appearing at the upper terminal of the filter is sufficient to overcome the negative bias potential applied to the grid of the tube 67 by the battery 68 and to render the grid of this tube positive with respect to its associated cathode, thereby greatly increasing conduction in the tube 67. Thus, an increase in the positive current flowing from the battery 28 to the transmitting terminal of the bridge 16 is effected to increase the magnitude of the positive current flowing to the line E.

When the carrier current reverses in polarity, the tubes 58 and 59 are inoperatively conditioned, and the tubes 63 and 64 are rendered receptive. Thus, irrespective of the potential apearing across the winding 65 of the transformer 55, the positive signal demodulator DM—P cannot respond. When a negative half cycle of the modulated alternating current appears across the secondary windings 65 and 66, there is completed a path for current flow which may be traced from the lower terminal of the winding 66, upward through the network of filter 27 and through the space discharge path of the tube 63 to the upper terminal of the winding 66. The terminals of the network 27 are in turn connected to the grid and cathode respectively of a tube 69 forming part of the negative signal transmitter T—N. In this case it is noted, however, that the potential applied to the grid is negative with respect to the cathode, thereby adding to the biasing action of the battery 70 to further decrease conduction in the tube 69. There is, therefore, effected a reduction in the negative current flowing from the battery 29 to the line E. It will be noted that, since positive and negative half cycles of the carrier current are correspondingly modulated in amplitude, the increase in the positive current transmitted to flow to line E is exactly the same as the decrease in the negative current permitted to flow to this line.

The alternate operation of the demodulators DM—P and DM—N for successive half cycles continues in the manner described for the entire time required for the transmission of a positive signal.

It is by this time apparent that the two transmitting tubes 67 and 69 operate simultaneously but in opposite sense to control in complementary relation the flow of current from the batteries 28 and 29 into the duplex bridge 16 of the line E. Since both tubes operate on the linear portion of their grid-plate characteristics distortionless amplification results. Further, since ample reserve power is available in these tubes, the unbalance transients are faithfully transmitted even when they are superimposed upon a signal of full amplitude.

A graphical indication of the operation of the demodulators may be obtained by referring again to Fig. 3. The output of the positive demodulator DM—P is indicated by the positive half cycles enveloped by the curve 71. This portion of the curve illustrates the positive direct current potential applied to the grid of the transmitting device T—P whereby conduction in this tube is increased in the manner described. Similarly, the negative half cycles enveloped by the curve 72 indicate the output of the negative demodulator DM—N and is the negative direct current potential applied to the grid of the negative transmitting device T—N whereby conduction in this tube is decreased in the manner described. The combined action of these two transmitting devices effects the transmission of a positive signal to the line E having substantially the same wave form as the positive signal received from line W with the addition of some beneficial shaping added to the beginning of the signal and is represented by the curve 73.

The functioning of the demodulating devices (see Fig. 2) in response to a negative telegraph signal is the reverse of that described in response to a positive signal. In this case when the carrier current derived from the source 24 is positive to operatively condition the tubes of the positive demodulator DM—P and to inoperatively condition the tubes of the negative demodulator DM—N, the potentials appearing in the transformer secondaries 65 and 66 are negative in contrast to the positive potentials appearing in these windings at the corresponding point in the repetition of a positive signal. This, of course, is the result of the phase-modulation of the carrier in response to received signals of opposite polarities. In this case a circuit is completed from the lower terminal of the winding 65, upward through the filter network 26 and through the space discharge path of the tube 59 to the upper terminal of the winding 65. Thus, it is seen that a negative potential is now applied to the grid of the transmitting tube 67 to decrease conduction in this tube and to thereby decrease the flow of positive current from the battery 28 to the line E.

Similarly, in response to the following negative half cycle of the carrier current the tubes of the negative demodulator DM—N are operatively conditioned and the tubes of the positive demodulator DM—P are inoperatively conditioned. At this time the potentials appearing in the transformer secondary windings 65 and 66 are positive. There is then completed a path for the flow of current from the upper terminal of winding 66, through the space discharge path of tube 64 and downward through the network of filter 27 to the lower terminal of winding 66. Now it is seen that a positive potential is applied to the grid of the transmitting tube 69, thereby increasing conduction in this tube and therefore increasing the flow of negative current from the battery 29 to the line E.

The operation of the demodulators DM—P and DM—N continues alternately in the manner described for the entire time required for the transmission of a negative signal.

A graphical representation of this operation is given in Fig. 3. Here, the output of the positive demodulator DM—P in responding to negative half cycles of the modulated carrier is represented by the curve 74 which, as described, is a direct current potential of negative polarity. Similarly, the output of the negative demodulator DM—N is represented by the curve 75 which is a direct current potential of positive polarity. The combined action of the transmitting devices in responding to the respective potentials applied to the input circuits thereof is represented by the curve 76 which represents the signal transmitted to line E and is of negative polarity with a wave form substantially similar to that of the received negative signal.

With regard to the types of tubes used for the demodulators, the invention may be carried into practice with any one of several different types of tubes although preferably they should have relatively high amplification factors. Also, each of the tubes of each demodulator may be a single triode as shown or the two tubes of each demodulator may be combined in a single envelope thereby forming a twin triode. Also, for the transmitting devices T—P and T—N a relatively wide range of types of tubes may be employed either singly as shown or in groups with the elements multipled together in a well known manner to increase the combined power output of the combination. The requirement for a tube used in this portion of the repeater is that it have a relatively low impedance and a relatively large power output, and if necessary two or more tubes may be used in parallel.

The frequency range of the repeating system is such that it will handle all essential components of the telegraph signals. The upper limit of this range is controlled by the operation of the low pass filters 26 and 27 as an additional function to that of smoothing out the demodulated carrier currents into the form of the signal envelope.

The signals which are received from line E appearing as potential differences between the receiving terminals of the bridge 16 are passed through the westbound repeater 18 which comprises elements similar to those shown in detail for the eastbound repeater. These regenerated signals are then transmitted over the line W in precisely the same manner as the signals traversing the eastbound repeater.

Having described the operation of the novel electronic repeater for accurately repeating the signals received from line W into line E, it may readily be seen that due to its large power capacity and linear frequency characteristics, such a repeater will accurately transmit into the line E along with the signals received from line W any unbalance transients caused by an unbalance condition of the artificial line 21. Reception of such distorted signals at the distant station connected to the other terminal of line E will have the same effect upon the receiving apparatus at this station as if the unbalance condition actually existed at this station. Consequently, an attendant there may make the proper adjustment of the artificial line whereby such a disturbance is compensated for in the manner previously described.

A feature of importance of the repeater system of Fig. 2 is that with the exception of the grid biasing batteries 68 and 70, all power supplies may have one terminal grounded. The repeater is thus readily adaptable for use with the regular grounded batteries commonly found in telegraph offices. However, other sources of supply may be used, in fact one useful embodiment of the repeater is as a unitary assembly provided with individual rectifier equipments to furnish power from the alternating current power mains.

By referring to Fig. 4 it may be seen that the novel repeater is readily adapted for use with metallic circuits utilizing metallic batteries. The two conductors comprising the line W are terminated at the repeater station in an impedance bridge 77, the receiving terminals of which are connected to apparatus 78 comprising the eastbound modulator and amplifier. As in the previously described embodiment, the amplified modulated carrier current is synchronously demodulated by means of the demodulators DM—P and DM—N to produce the positive and negative direct current potentials by which the transmitting devices T—P and T—N are controlled. In this case there are associated with these repective devices ungrounded or metallic batteries 79 and 81. These batteries together with the tubes 67 and 68 are connected to form a closed series circuit from which connections are made, as shown, to the transmitting terminals of the impedance bridge 82 in which the two conductors comprising the line E are terminated.

When the tubes 67 and 68 are equally and oppositely excited by the demodulator output potentials, the current flowing from one of the batteries to one line conductor is increased and the current flowing from the other battery to the other line conductor is decreased in a like amount. For example, for the transmission of a positive signal, the tube 67 is rendered more conducting and the tube 68 less conducting. There is then an increase in the positive current from the battery 79 to the lower conductor of the line pair accompanied by a like decrease in the negative current from the battery 81 to the upper conductor of the pair.

It frequently happens that where metallic operation is desired, a station in which the novel repeater is to be located does not have available metallic batteries, but only the usual telegraph grounded batteries. By referring to Fig. 5 the apparatus for adapting such a repeater for use under these conditions is illustrated. In this case the coupling transformer 55′ between the amplifier and the demodulating device is provided with a second pair of secondary windings 65′ and 66′. Also, two additional demodulators DM—P′ and DM—N′ together with their associated transmitting devices T—P′ and T—N′ are required. The transmitting devices T—P and T—N are each provided with positive and negative grounded batteries 28 and 29 respectively. These transmitting devices are connected to the lower conductor of the metallic pair in the same manner as the corresponding connection to the line conductor of Fig. 2. Likewise the added transmitting devices T—P′ and T—N′ are provided with grounded positive and negative batteries 28′ and 29′ respectively for transmission into the upper conductor of the metallic pair.

It will be noted in this arrangement that the connections between the secondary windings 65′ and 66′ and their respective demodulating devices are reversed in phase to the corresponding connections between the secondary windings 65 and 66 and their associated demodulating devices. The effect of these connections is that when the demodulator DM—P is producing a positive direct current potential, the demodulator DM—P' is producing a negative direct current potential. Similarly, the demodulators DM—N and DM—N' operate in phase opposition. Consequently, when a positive signal is to be transmitted, the transmitting tubes 67 and 68' are rendered more conducting while the transmitting tubes 68 and 67' are rendered less conducting. It is apparent then that there is an increase in the current flowing through the circuit which may be traced from the positive battery 28, through the space discharge path of the tube 67, to the bridge 82, and through the line E and return to the space discharge path of the tube 68' to negative battery 29'. At the same time there is a decrease in the current flowing through the path which can be traced from the positive battery 28', through the space discharge path of the tube 67', through the bridge 82, line E and the space discharge path of the tube 68 to the negative battery 29. Thus, it is seen that the effect upon the line conductors is the same in this case as it is in the arrangement illustrated in Fig. 4. Obviously, for the transmission of a negative signal the above described conditions for the various circuits are reversed.

The metallic circuit repeaters of Figs. 4 and 5 are possessed of the same unique advantages as the grounded circuit repeater of Fig. 2 and for this type of line perform the same kind of service.

The foregoing description of an illustrative embodiment of the invention is confined to the operation of a repeater for telegraph signals. As is common with telegraph sets of this type, some of the apparatus herein disclosed is susceptible of use as a terminal set without departing from the spirit of the invention. For example, the transmitting devices T—P and T—N instead of being connected to a line circuit may be connected to a receiving device for reproducing signals received from the line W by anyone skilled in the art. In this case then the apparatus functions as a receiving terminal set. Also, the signal input conductors of the modulators of the westbound repeater corresponding to modulators M—P and M—N may be connected to suitable keying devices whereby signals originating at the station at which the apparatus is located may be transmitted to an outgoing line. In this case the apparatus functions as a transmitting terminal set.

In describing the important functioning of the novel repeater to accurately retransmit unbalance disturbances appearing in the signals received at the repeater by reason of other signals being repeated in the opposite direction when the artificial line is out of balance with the line from which the signals are being received, it has been assumed that the delay in retransmitting the unbalance disturbances to the terminal station is insufficient to prevent satisfactory compensation therefor at the terminal station. Since the signals which are causing the unbalance originate at the terminal station, there is a transmission path equal in length to twice the repeater section intervening between the terminal station and the repeater station. In general, the phase lag between the transmission of the signal causing the distortion and the reception of the disturbance caused will be small because of the relatively low frequencies usually employed in telegraph systems of this charter. However, the fact that there is a phase lag will tend to limit the number of such unattended repeaters which may be located successively along a circuit between attended stations. In practice it has been found that, in the circuits in common use, two such intermediate repeaters may be employed and yet derive the benefits of terminal compensation for repeater unbalance distortion. In some cases where circuit conditions are more favorable than the average, a greater number of such repeaters may be used.

The bridges 77 and 82 are particularly useful in mitigating the effects of certain types of interference, particularly those characterized by currents flowing in the same direction in both line conductors. Two intermediate tapped impedance elements 83 and 84 are connected with one terminal of each to the respective line conductors of the line W and the other terminal of each to the artificial line 21. Dissimilar terminals of the impedances 83 and 84 are cross-connected by intermediate tapped impedance elements 85 and 86. Signaling currents flowing in opposite directions in the two line conductors produce potential differences between the intermediate taps of the impedances 85 and 86 and it is to these points that the input circuit of the eastbound repeater is connected. Any interference currents flowing in the same direction in both line conductors do not produce potential differences between these intermediate taps and accordingly are rendered ineffective. The output circuit of the westbound repeater is connected to the intermediate taps of the impedances 83 and 84 in conjugate relation to the input circuit connection of the eastbound repeater and hence has no effect upon the received signals.

This type of bridge makes it possible to employ the line conductors of the line W for a phantom circuit in a manner similar to that disclosed in Patent No. 1,758,900 to Morgenstern. A center tapped impedance element 87 is connected in parallel with the input circuit of the eastbound repeater. The phantom circuit telegraph apparatus 88 is connected between the midpoint of impedance 87 and ground. Such a phantom circuit may be operated with a ground return as shown in a well known manner or, by means of similar connections to a second pair of conductors arranged similarly to the line W, it may furnish a third metallic circuit.

The nature of the invention may be ascertained from the foregoing description of an illustrative embodiment thereof, it being understood that modifications of the specific apparatus and arrangement thereof disclosed may be made without departing from the spirit of the invention and the scope of the appended claims.

What is claimed is:

1. The method of operating a duplex telegraph circuit including two repeater sections linked together by an intermediate repeater and extending between two remote stations which comprises reflecting a disturbance caused by an unbalance between the real and artificial lines at said repeater in the signals transmitted to one or said remote stations from said repeater, and compensating for said unbalance disturbance at said one remote station.

2. The method of operating a duplex telegraph circuit including a plurality of repeater sections linked together by intermediate repeaters and extending between two remote stations which comprises reflecting a disturbance caused by an unbalance between the real and artificial lines at one of said intermediate repeaters in the signals transmitted to one of said remote stations

from said one repeater, and adjusting the artificial line values at said one remote station to compensate for said unbalance disturbance.

3. The method of operating a duplex telegraph circuit including two line sections connected together by a substantially distortionless repeater and extending between two remote stations which comprises causing the distortion of signals occasioned by an unbalance between the real and artificial line constants at said repeater to be accurately repeated to one of said remote stations, and introducing into said repeated signals at said remote station a distortion equal in magnitude and opposite in sense to said repeated distortion.

4. The method of operating a duplex telegraph circuit including two line sections connected together by a distortionless repeater and extending between two remote stations which comprises setting the artificial line constants of said repeater at values to simulate the real line constants in atmospheric conditions which are the average between dry and wet conditions, causing the amplitude distortion of signals occasioned by an unbalance between the real and artificial line constants at said repeater to be accurately repeated to one of said remote stations, and adjusting the artificial line constants at said remote station to create an unbalance thereat equal in magnitude and opposite in sense to said repeater unbalance.

5. In a signaling system employing positive and negative polarities, a source of carrier current, means for modulating said carrier in amplitude in accordance with the signal amplitude and in phase in accordance with the signal polarity, means for amplifying said modulated carrier, and a demodulator having phase discriminating means for translating said amplified carrier current to direct current signals of positive and negative polarity.

6. In a signaling system, a source of positive and negative signals, a source of carrier current, means employing said signals for modulating said carrier current in amplitude according to the signal amplitude and in phase according to the signal polarity, and means controlled by said carrier current for demodulating said modulated carrier current to reproduce said positive and negative signals.

7. In a signaling system employing signals of positive and negative polarity, a source of carrier current of a higher frequency than that of said signals, a modulator excited by said carrier current, means including said modulator for phase-modulating said carrier current in accordance with the signal polarity, a demodulator including a plurality of electronic devices excited by alternating current corresponding in frequency and phase to said carrier current, and means including said demodulator for converting said modulated carrier current into direct current potentials corresponding in polarity to said signals.

8. In a telegraph system employing a carrier current modulated in amplitude in accordance with signal amplitude and in phase in accordance with signal polarity, a utilization circuit, two pairs of electronic devices, a repeating device associated with each of said pairs of electronic devices, said repeating devices being arranged to impress upon said utilization circuit opposite polarities of direct current potentials, means including said carrier for operatively conditioning one device of each of said pairs of electronic devices in response to a modulated carrier current of one phase to equally and oppositely control the functioning of said associated repeating devices whereby the effects of said direct current potentials upon said utilization circuit are oppositely controlled, and means employing said carrier for operatively conditioning the other devices of said two pairs of electronic devices in response to a modulated carrier current of opposite phase to equally and oppositely control the functioning of said repeating devices in the reverse manner to that previously specified whereby the effects of the direct current potentials upon the utilization circuit are also reversed.

9. In a telegraph system employing marking and spacing signals, a distortionless electronic repeater comprising an amplifier having input and output circuits, means for impressing upon the input circuit of said amplifier an alternating current modulated in amplitude in accordance with the wave shape of said signals, said marking and spacing signals being represented by opposite phases of said alternating circuit, means coupled to the output of said amplifier for separately recovering from said modulated alternating current direct currents representative of said marking and spacing signals respectively, individual marking and spacing transmitting devices, and means employing said marking and spacing direct currents for controlling said marking and spacing transmitting devices respectively.

10. In a telegraph system employing marking and spacing signals, a distortionless repeater comprising an amplifier having input and output circuits, means for impressing upon the input circuit of said amplifier an amplitude-modulated alternating current having symmetrical positive and negative envelopes corresponding to the wave shape of one of said signals, means coupled to the output of said amplifier for separately recovering direct currents corresponding to said positive and negative envelopes respectively, marking and spacing signal transmitting devices, and means employing said direct currents for increasing the effectiveness of one of said transmitting devices and decreasing the effectiveness of the other of said transmitting devices according to the marking and spacing character of said one signal.

11. In a telegraph system employing positive and negative signals, a repeater comprising a modulator for positive signals, a modulator for negative signals, a source of carrier current, means including said modulators for modulating said carrier current, the envelope of said modulated carrier current corresponding to the wave shape of said signals, the phase of said negative signal modulated carrier current being opposite to the phase of the positive signal modulated carrier current, an amplifier for amplifying said modulated carrier current, a positive signal demodulator, a negative signal demodulator, a positive signal transmitting device associated with said positive signal demodulator, a negative signal transmitting device associated with said negative signal demodulator, and means including said demodulators for recovering from said amplified carrier current direct currents equal in magnitude and opposite in polarity to control the associated transmitting devices whereby in response to a positive signal the output of said positive transmitting device is increased while the output of said negative transmitting device is decreased in like amount and in response to a negative signal the output of said negative transmitting device is increased while the output of

the positive transmitting device is decreased in like amount.

12. In a telegraph system, a carrier current modulated to represent marking and spacing signals, first and second demodulators, a marking signal transmitting device actuated by the output of said first demodulator, a spacing signal transmitting device actuated by the output of said second demodulator, and means including said carrier current for controlling the operation of said demodulators to increase the output of one of said transmitting devices and concurrently to decrease the output of the other of said devices to the same degree.

13. In a signaling system employing marking and spacing signals, means for producing an alternating current of one phase representative of said marking signals, means for producing an alternating current of a different phase representative of said spacing signals, and means including a single amplifier for amplifying both of said alternating currents without discrimination as to the phase thereof.

14. In a signaling system, a source of carrier current, means for phase-modulating said carrier current according to marking and spacing signals and for amplitude-modulating said carrier current according to the wave form of said signals, and means for synchronously demodulating said double-modulated carrier current to produce direct current potentials having opposing polarities representative of said marking and spacing signals, said polarities having wave forms corresponding to the wave forms of said signals.

15. In a telegraph system, a carrier current modulated to represent positive and negative signals, a positive signal transmitter, a negative signal transmitter, said transmitters being operable to increase their respective outputs in response to positive applied potentials and to decrease their respective outputs in response to negative applied potentials, means for rectifying said modulated carrier current, means including said carrier current for controlling said rectifying means to produce simultaneously in response to said signals equal positive and negative direct current potentials, means responsive to a positive signal for applying said positive and negative potentials respectively to said positive and negative signal transmitters, and means responsive to a negative signal for applying said positive and negative potentials respectively to said negative and positive signal transmitters.

16. In a telegraph system, a signaling circuit, a duplex terminal station connected to one end of said circuit, a repeater station connected at an intermediate point of said circuit, means including an artificial line at said repeater station for repeating signals without substantial distortion to said terminal station, said artificial line being adjusted so that it may provide at times an imperfect balance for its associated real line, and means at said terminal station for compensating for said imperfect balance.

17. In a signaling system, a line circuit, a duplex terminal station connected to one end of said circuit, an intermediate station connected to the other end of said circuit, substantially distortionless duplex repeating apparatus including an artificial line located at said intermediate station, said artificial line providing at times an imperfect balance for its associated real line, and means employing signals traversing said line circuit for correcting at said terminal station for said imperfect balance.

18. In a telegraph system for positive and negative signals, a transmission medium, a positive signal transmitter, a negative signal transmitter, said transmitters being coupled so said transmission medium and conditioned in the absence of signals to transmit equal positive and negative signals having a net effect upon said transmission medium of a no-signal condition, means responding to a positive signal for controlling said positive signal transmitter to increase the magnitude of the transmitted positive signal and for controlling concurrently said negative signal transmitter to decrease in like amount the magnitude of the transmitted negative signal to produce a net effect upon said transmission medium of a positive signal, and means responding to a negative signal for controlling said positive signal transmitter to decrease the magnitude of the transmitted positive signal and for controlling concurrently said negative signal transmitter to increase in like amount the magnitude of the transmitted negative signal to produce a net effect upon said transmission medium of a negative signal.

19. In a duplex telegraph system, a pair of line conductors, an artificial line, a first pair of similar impedances each connected respectively between said line conductors and said artificial line, a second pair of similar impedances each cross-connected respectively between the line conductor terminal of one of said first pair of impedances and the artificial line terminal of the other of said first pair of impedances, a transmitting circuit connected to corresponding intermediate points of said first pair of impedances, and a receiving circuit connected to corresponding intermediate points of said second pair of impedances conjugate to the intermediate points of said first pair of impedances.

20. The invention in accordance with claim 19 further characterized by a phantom circuit impedance connected in multiple with said receiving circuit, and signaling apparatus connected to said phantom circuit impedance at a point intermediate the terminals thereof.

21. The method of operating a duplex telegraph circuit including a plurality of repeater sections linked together by intermediate repeaters and extending between two remote stations which comprises, setting the constants of an artificial line at one of said intermediate repeaters at fixed values, causing a disturbance produced by an unbalance between the real and artificial lines at said one repeater to be reflected as a distortion of the signals received at one of said remote stations from said one repeater, and adjusting the artificial line values at said one remote station to compensate for said unbalance disturbance.

22. In a telegraph system, a carrier current modulated to represent marking and spacing signals, a marking signal transmitter, a spacing signal transmitter, demodulating means for rectifying said modulated carrier current, means including said carrier current for controlling said demodulating means to produce simultaneously for each signal two direct currents of equal magnitude and opposite polarity, and means for utilizing said direct currents to increase the output of one of said transmitters and concurrently to decrease the output of the other of said transmitters to the same degree.

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