THEORY AND CHARACTERISTICS OF ELECTRONIC TELEGRAPH LOOPS

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1. GENERAL

1.01 This section discusses the theory and characteristics of electronic telegraph loop operation. Comparisons of this type of loop with relay-type telegraph loops are discussed in order to afford a better understanding of the fundamental differences involved between the two types of loop operation.

1.02 For convenience all figures are attached in the form of fold-out sheets.

1.03 Relay-type loops are used in most dc telegraph repeaters and older types of carrier telegraph terminals such as the 40-type carrier telegraph channel terminal.

1.04 In the electronic loop circuit, electron tubes instead of polar telegraph relays are employed for both the sending of signals into the loop toward the TTY station and the receiving of signals from the station loop.

1.05 Electronic loops offer maintenance advantages since there are no polar relays to maintain, and also afford certain transmission quality improvements over relay-type loops as described in detail later in this section.

1.06 In the analysis of signal transmission in electronic loops as compared to relay-type loops, it will become apparent that certain important and significant differences in transmission aspects exist, and a thorough understanding of these aspects is required for the proper treatment of electronic loops including transmission measurement techniques.

1.07 Electronic loop operation is employed currently in the 43A1 Carrier Telegraph Channel Terminal and in the 96A1 Electronic Loop Repeater associated with electronic hub circuits such as used with the No. 2 and No. 9B Service Boards.

2. RELAY-TYPE LOOP OPERATION

(A) General (Refer to Fig. 1)

2.01 The operating principles and transmission aspects of relay-type loops are reviewed briefly here to aid in the comparative analysis with electronic loops.

2.02 The central office end of the loop terminates in a telegraph repeater or carrier telegraph channel terminal as shown in Fig. 1. This type of loop circuit is sometimes referred to as a "balanced neutral loop."

2.03 With the receiving relay receiving a marking signal from the line, its armature is operated to its marking contact and a negative 130-volt grounded battery is applied to the midpoint connection, or apex, of the two windings of the sending relay. One winding of the sending relay is connected to one side of the station loop. The other side of the station loop is returned to a positive 130-volt grounded battery. 260 volts is therefore applied to the loop and the current is adjusted to 62.5 ma by a variable resistor R1. This current flows in the winding of the magnet or line relay at the TTY station resulting in a marking condition at the station, and flows through the loop winding of the sending relay at the central office in a direction which causes the polarized sending relay to be operated to its marking contact. The current flowing in the other winding (bias winding) of the sending relay has a spacing effect because the two windings are connected differentially. Assuming that resistor R in Fig. 1 is equal to the total resistance of the external loop, including resistor R1, and the two windings of the relay have an equal number of turns, the spacing current in the bias winding of the sending relay is one half the value of the marking current in the loop winding. The sending relay armature will, therefore, remain on its marking contact when the loop is in a closed or marking condition.

2.04 When the receiving relay at the central office receives a spacing signal from the line, its armature is operated to its spacing contact and positive 130-volt grounded battery is applied to the loop. Since the loop is returned to a positive 130-volt grounded battery, it is connected between equal-potential points and the loop current is reduced to zero, thus causing a spacing signal condition at the TTY station. The sending relay at the central office remains in a marking condition because the current in bias winding circuit is reversed and flowing in a direction to hold the polarized sending relay marking. It is important that the sending relay remains on its marking contact when signals are being received from the line in order to prevent the received signals being repeated back to the line. This feature or one similar to it is, therefore, essential in all types of loop operation.

(B) Kickoff Effect and Antikickoff Arrangements

2.05 If a cable loop of appreciable length is employed, the loop will be predominately capacitive. This capacitive characteristic causes a current wave shape similar to the one shown in Fig. 2(A) during the transmission of signals from the central office to the loop. It will be noted that the current in the loop winding of the sending relay decreases rapidly toward zero on a mark-to-space transition. The bias winding circuit of the sending relay is predominately inductive since there is little natural capacitance in the circuit, and the relay winding is inductive. The current in this winding, therefore, does not change as rapidly as the current in the loop winding during signal transitions. This can cause a momentary spacing operation of the sending relay, known as "kickoff," during a mark-to-space transition in signals sent to the loop from the armature of the receiving relay. This kickoff effect results from the fact that the two windings of the sending relay are differentially connected. When the current in the loop winding is decreasing toward zero on a mark-to-space transition, the current in the bias winding is changing from a "spacing effect" direction to a "marking effect" direction. If this change is not sufficiently rapid, the current in the loop winding may be reduced to a value low enough to cause a momentary spacing operation of the sending relay before the marking current in the bias winding is of a sufficient value to hold the armature of the relay on its marking contact. In order to prevent this condition, capacitance in the form of an "antikickoff" capacitor may be connected to the bias winding circuit. The addition of this capacitor produces a time constant in the bias winding circuit which is closer to that in the loop circuit. The current wave in the bias winding of the relay is thus made to resemble more closely the current in the loop winding.

2.06 In the case of 100-speed operation, the "antikickoff" capacitor treatment causes an objectionable amount of distortion in transmission from the station to the central office.

For "kickoff" prevention in 100-speed loops, it is recommended that an additional branch, consisting of a resistor and capacitor in series, be bridged around the balancing network resistor R. The values of the resistor and capacitor are chosen in accordance with the lengths and gauges in the loop.

(C) Transmission to the Station

2.07 As described above, marking and spacing signals are transmitted to the loop and station by the application of negative and positive voltages respectively from the contacts and armature of the receiving relay. These voltages aid or oppose the positive voltage to which the loop is returned resulting in current and no-current conditions in loop.

2.08 Since in this type of transmission the impedance at the signal sending end does not change, as would be the case in open-and-close sending in a loop, the current wave produced at the central office end of the loop, shown in Fig. 2(A), remains symmetrical when received at the station end of the loop as shown in Fig. 2(B). Assuming that the line relay at the station is biased with current equal to half the steady-state loop current, the relay operating points lie in a symmetrical manner just above and below this halfway position in the current wave. The marking and spacing time intervals of the station relay are therefore equal and no bias is introduced in the signals. This is sometimes referred to as "effective polar" operation because the transmission quality is about equal to that of polar transmission.

(D) Transmission from the Station

2.09 Signal transmission from the station is effected on an open-and-close basis. The sending end impedance therefore varies from very low when the sending contacts are closed for the transmission of a marking signal to very high or infinite when the contacts are open for the transmission of a spacing signal. The charging and discharging times of the loop capacitance are therefore different as the capacitance discharge path is wholly at the receiving end through the winding of the sending relay at the central office. The current wave received through this winding is therefore not symmetrical like the current wave at the sending end as shown in Fig. 2(C), but resembles the wave shown in Fig. 2(D). The leading edges of the marking impulses received at the central office are steeper than the trailing edges. This results in marking bias being introduced in the received signals.

(E) Wave Shaping

2.10 The marking bias effect described in Paragraph 2.09 can be reduced or overcome by the application of wave shaping equipment at the station as shown in Fig. 1. Series resistance only may be used on shorter loop lengths. For longer cable loops, and some shorter loops where maximum reduction in signal bias is required, series inductance is used. These arrangements modify the sending end impedance during the marking condition for the transmission of signals from the station toward the central office to produce a current wave at the station similar to the one shown in Fig. 2(E). This wave form when affected by loop capacitance is similar to the one shown in Fig. 2(F) when received at the central office. It can be seen that this current wave is symmetrical and therefore little or no bias is present in these signals. The use of wave shaping at the station for relay-type loops has a negligible effect on transmission from the central office to the station.

3. ELECTRONIC LOOP OPERATION

(A) General (Refer to Fig. 3)

3.01 The first application of electronic loop operation was the 96A1 Loop Repeater which serves to connect telegraph loops to the hub circuits of the No. 2 and No. 9B Service Boards. Later this type of loop operation was provided for the 43A1 Carrier Telegraph Terminal. At the time the 96A1 Loop Repeater was designed it appeared necessary to retain the usual 62.5 ma operation of private line teletypewriter station equipment. Consequently the present electronic loop design originated from this requirement. As will be mentioned later this in part accounts for certain difficulties associated with 20 ma operation.

3.02 The electronic loop circuit employs a pentode type of power tube (V1 in Fig. 3) operating as an open-and-close switch to send neutral signals into the loop toward the station.

3.03 Tube V1 is operated from the output signals of a circuit ahead of this tube which are applied to its control grid. These signals develop grid-to-cathode voltages which are sufficiently positive during marking signals to cause plate current flow and are sufficiently negative during spacing signals to result in "cutoff" and consequently no plate current flow.

3.04 With ±130-volt operation as indicated in Fig. 3, the screen potential of the pentode tube V1 is adjusted with the LP CUR potentiometer so that an 80-volt plate-cathode voltage is obtained with 62.5 ma steady-state current flowing in an external loop of 2880 ohms. The loop circuit is always adjusted to have a resistance of 2880 ohms which includes a 120-ohm, +130-volt termination in the return side of the loop. A variable resistance loop pad is provided in the top side of the loop for this purpose. No series resistance is used at the customer station other than that inherent in the receiving relay or magnet.

3.05 In half-duplex operation, the 80-volt drop across tube V1 serves as the keying voltage applied to the control grid of tube V2 when receiving signals from the loop. It is important that the external loop resistance be built out to the 2880 ohms for ±130-volt operation. If the loop consists of less resistance and the current is adjusted by the LP CUR potentiometer to provide 62.5 ma of loop current, a voltage other than 80 volts will be developed across tube V1. Therefore, the signaling voltage applied to the grid of the input tube V2 when receiving from the loop will not be symmetrical around the bias voltage of the tube, and distortion will be introduced.

3.06 A resistor of high value (0.24 megohm) is connected between the plate and cathode of tube V1, thereby providing a high-resistance shunt path around the tube. When the station loop is opened for the transmission of a spacing signal from the station, the positive 130 volts is removed from the plate of tube V1 and the tube does not conduct. During these spacing signals, negative 130 volts at the cathode of tube V1 is connected to the grid of sending tube V2 through the shunting resistor. This permits tube V2 to be "cut off" and a spacing signal is transmitted to the carrier line. This arrangement also insures the transmission of clean breaks when receiving signals from the carrier line.

3.07 Since a tube (V1) of 30 ma capability was required in the design of the 96A1 loop repeater for sending signals into the hub circuit, two such tubes in parallel were chosen to control a 62.5 ma loop in order to avoid a new tube design.

(B) Transmission to the Station

3.08 The neutral signals sent into the loop are generated by an electron tube operating as an open-and-close switch as indicated by V1 in Fig. 3. A pentode type of power tube is used to obtain a relatively high dynamic resistance in the closed condition. The plate characteristic is shown in Fig. 4. This results in a nearly square-shaped current wave with symmetrical transitions at the central office end of the loop. The "constant current" property of the pentode is thus made use of. After the loop attenuates the higher frequency components of the wave it arrives at the subscriber station considerably rounded but still symmetrical. This prevents the signal bias at the subscriber from varying with loop length. Thus a fixed bias can be used on receiving relays and TTY selector mechanisms. The wave forms of these signals are illustrated in Figs. 5(A) and 5(B). It will be noted that signals sent to the loop and station from an electronic loop circuit can be analyzed on a current-wave basis in the same manner as signals toward the station from a relay-type loop circuit, since in both cases the signals operate a relay or magnet at the station on a current basis. The wave forms in both cases are also similar.

3.09 From another viewpoint, the symmetrical current wave form is the result of the constant impedance signal source provided by the pentode tube. This permits the closed loop condition to be high impedance so as to be more nearly like the open loop condition.

3.10 When sending into a cable loop the capacitance of the cable tends to keep the plate voltage of the pentode above the steady-state value for the initial portion of each marking interval. Since the pentode does not have infinite plate resistance the current wave has some overshoot at the space-to-mark transition which causes a small amount of marking bias at the extreme loop lengths. As indicated in Fig. 4 the amount of overshoot cannot exceed 12 ma. A steady-state plate voltage of 80 volts was chosen for the pentode. With ±130-volt operation this gives a 2880-ohm loop resistance. This allows operation to nearly 30 miles of 19-gauge cable. A value of 80 volts also places the quiescent point up on the flat portion of the characteristic and, as will appear later, gives an 80-volt swing when receiving from the subscriber. (See Fig. 4.)

(C) Transmission from the Station

3.11 Since it is undesirable to locate any telegraph battery at the subscriber station, transmission toward the central office is on an open-and-close basis with the keyboard or transmitter-distributor contacts directly in series with the loop. When one side of the loop is terminated in the plate of a pentode, as is the case for half-duplex operation, the plate ***current*** wave in that side at the central office resulting from signaling at the subscriber station is found to be considerably different in shape from the current wave in the return side of the loop terminated in battery. When the loop is opened at the station the pentode maintains nearly the full marking plate current until the voltage on that side of the loop approaches the cathode potential. The ***current*** wave in the top side of the loop is therefore greatly distorted, and for this reason it is undesirable to receive from the station loop on a current basis as is the case of relay-type loops. The ***current*** wave in the battery return side is more symmetrical, except for the marking bias resulting from the loop capacitance (see Fig. 5(E)), but it is difficult to arrange electronic coupling to this point in the circuit, and it is also difficult to provide half-duplex operation with such an arrangement. Signaling, therefore, toward the central office with electronic loops is effected on a ***voltage*** basis by utilizing the voltage change across tube V1, occurring as a result of the closed and open loop conditions, and applying this voltage swing in a symmetrical manner around a properly biased grid of input tube V2.

3.12 The ***voltage*** wave at the pentode plate termination resulting from signaling at the station has a fairly symmetrical form. Also the duplexing feature is easily obtained without any balancing since the plate voltage swings positive for a space toward the station and negative for a space from the station. When the loop is opened at the station, the constant plate current characteristic of the pentode discharges the cable more rapidly than would be the case in a relay-type loop. The voltage at the pentode plate falls nearly linearly and it is not necessary to use wave shaping at the customer's station in order to obtain a nearly symmetrical ***voltage*** wave form at the pentode plate. The voltage swing at the pentode plate is large in amplitude and is ideally suited for dc coupling to other electron tubes such as the input tube (V2). The symmetry of the voltage wave at the plate does not change materially with the loop length and consequently no loop loading is required when receiving in such a manner. These wave forms are illustrated in Fig. 5. Zero bias signals from the loop can be received by tube V2 so biased as to operate near −90 volts, the midvalue of the −50 volts marking and −130 volts spacing voltage wave. (See Figs. 4 and 5(F).)

(D) Duplexing Arrangements (Refer to Fig. 6)

3.13 The 96A1 loop repeater always operates on a half-duplex basis. The 43A1 terminal sometimes operates on a full-duplex loop basis. Rather than provide another pair of pentodes to terminate the send loop, a 1280-ohm resistance termination is used. This causes the voltage wave from the loop to fall more slowly in the mark-to-space transition than with the pentode termination. Consequently, to prevent marking bias, tube V2 is arranged to operate at about the 75 per cent point on the loop voltage wave for full-duplex operation. This is accomplished by connecting the grid of tube V2 to a voltage divider consisting of a 1.96 megohm resistor and a 1 megohm resistor bridged across the 1280-ohm termination. Two-thirds of the voltage developed across the 1280-ohm resistor will, therefore, be applied to the grid of tube V2. When the loop voltage at the top of the 1280-ohm resistor passes through the −70-volt level, the voltage drop across the resistor to the −130-volt battery will be 60 volts. Two-thirds of this voltage, or 40 volts, which is −90 volts with respect to the −130-volt battery is applied to the grid of tube V2 which is still biased to operate at this point.

(E) Wave Shaping Considerations

3.14 As described in Paragraphs 3.11 and 3.12 the signals sent from the station operate the central office loop circuit on a voltage basis rather than on a current basis, as is the case with the relay-type loops. The voltage wave is symmetrical as indicated in Fig. 5(F). Wave shaping at the station is therefore not required in electronic loops. Also, the introduction of inductance into the loop which would result from the application of inductance wave shaping could cause a "kickoff" condition during the transmission of signals toward the station. ***Wave shaping at the station is therefore not only not required but is not desirable.*** This is discussed in more detail in Paragraph 4.08.

(F) Operation with Multiple Loops or Multiple Stations in the Same Loop

3.15 Two loops in series may be connected to an electronic terminal if the total length is restricted to about 7 miles of 19-gauge cable. Two stations may be operated in series at different locations in the same loop with perhaps a small increase in the total loop length over the 7-mile limit. In such cases communication from either station to the electronic terminal depends on the ***voltage*** wave, while communication between the two stations depends on the ***current*** wave. Signals received by either station from the other will be characterized by heavy marking bias. (See Fig. 5(E).) Transmission between the remote station and the electronic terminal will be quite good. Any attempt to employ wave shaping at either station to reduce the marking bias in the ***current*** wave will result in spacing bias in the ***voltage*** wave and the possibility of "kickoff." (See Paragraph 4.08.)

(G) 20 Ma Operation

3.16 The foregoing material applies mainly to ±130-volt, 62.5 ma operation. The 96A1 always operates under these conditions. Originally the 43A1 was visualized as also using ±130-volt, 62.5 ma loops when connecting to teletypewriter equipment via a cable loop. For a local loop on the customer's premises a 20 ma +130-volt loop was also provided. There has since been need to serve cable loops from locations not normally having −130-volt battery. Consequently there are now such loop conditions as: +130-volt/ground, 62.5 ma; +130-volt/ground, 20 ma and +130-volt, −48-volt, 20 ma. The last two conditions upset the relationship between the pentode tube and the loop parameters such that zero bias can no longer be maintained from the customer station with the same adjustment which fits all 62.5 ma loops. For this reason it is necessary to equip the 43A1 with a variable voltage divider for adjustment of sending bias at the channel terminal when operating 20 ma loops. This matter is under active study.

(H) Back-to-Back Operation of 43A1 Terminals

3.17 Many difficulties occur when electronic loop circuits are connected to relay-type loop circuits of repeaters or 40-type carrier terminals. This places certain restrictions on loops connected to a circuit where 43A1 neutral loop terminals are operated back-to-back.

3.18 For the back-to-back half-duplex case, relays are required between the 43A1 terminals in order that each loop circuit may be terminated in the required +130-volt battery. Two 13G1 repeaters will perform this function very well. If a loop is connected on one side of these repeaters to add an intermediate station to the circuit, transmission from the station to the circuit will be via the 13G1 repeaters for one direction and direct to a 43A1 terminal for the other. For the former case, transmission depends on the ***current*** wave while for the latter on the ***voltage*** wave. Since anything done to reduce the marking bias in the ***current*** wave will cause spacing bias in the ***voltage*** wave, loops operated in this manner are restricted to those which will not cause excessive bias in either wave. About 5 miles of cable with no wave shaping at the station appears to be the practicable maximum.

3.19 The limitation on the length of the intermediate loop mentioned in Paragraph 3.18 could be removed if two 2-relay repeaters or one 4-relay repeater were used to connect the 43A1 terminals back-to-back, and the intermediate loop was connected at the repeater midpoint. With such an arrangement transmission from the intermediate station toward either half of the circuit would depend on the current wave, and normal relay-type loop limits would apply. This method is uneconomical, however, since the only available repeaters which would be satisfactory are certain cord circuit models which incorporate unnecessary features and equipment.

3.20 In order to eliminate the problems caused by incompatibility of current-driven and voltage-driven loops which arise in the back-to-back connections described above, effort is presently being directed toward the development of a half-duplex quasi-hub circuit which will permit two 43A1 neutral loop channel terminals and a relay-driven loop to be connected together.

3.21 Present standard arrangements for connecting two 43A1 electronic loop circuits back-to-back on a full-duplex basis only are discussed in the BSP sections covering 43A1 systems.

4. COMPARISONS OF ELECTRONIC LOOPS WITH RELAY-TYPE LOOPS

(A) Noise Influence

4.01 For short loops the noise influence at the central office end sending toward the subscriber is about the same for an electronic loop as for a relay-type loop. This is because the current waves are similar. (Refer to Figs. 2(A) and 5(A).) For loops approaching 30 miles of 19-gauge cable, the relatively low impedance of relay-type loops causes considerable overshoot of the current wave into the cable so that the noise influence becomes as much as 10 db greater than that from an electronic loop repeater.

4.02 When sending from the subscriber the noise is about the same for the two types of loops for short loop lengths. For longer loop lengths where inductive wave shaping is used with relay-type repeaters the noise becomes less for these repeaters than with electronic repeaters.

4.03 The telegraph noise suppression circuit per SD-70338 cannot be used with 96A1 loop repeaters because of a "kickoff" effect described later in Paragraph 4.08.

(B) Wave Form at Station

4.04 Since no current overshoot of any significance occurs when sending toward the subscriber with the electronic repeater, the wave at the subscriber is more rounded than would be the case with a relay-type repeater. This leads to somewhat more characteristic distortion but the total distortion at 100 wpm is less than 10 per cent for 30 miles of 19-gauge cable.

4.05 The more rounded wave form also tends to cause more marking bias in the operation of holding magnet teletypewriters. In this respect the electronic repeater compares favorably with relay-type repeaters up to 20 miles of 19-gauge cable.

(C) Sensitivity to Crossfire

4.06 The electronic loop is somewhat more sensitive to crossfire than a relay repeater loop for transmission toward the station. This again is the result of a more rounded wave form. For transmission toward the central office the electronic loop is the less susceptible since the pentode termination together with no inductive loading gives a squarer wave form.

(D) Effects of Leakage

4.07 An electronic loop is more affected by leakage than a relay-type loop but not appreciably so except at extreme loop lengths.

(E) Kickoff Effect in Inductive Loops

4.08 Normally when sending toward the subscriber in ±130-volt loops, the pentode plate voltage swings between −50 volts for mark and +130 volts for space. For a capacitive loop the loop load never appears greater than 2880 ohms so that at no time does the plate voltage swing more negative than −50 volts. However, when the loop is inductive the loop load may momentarily appear high enough in impedance to cause the plate voltage to swing toward −130 volts on a space-to-mark transition. If severe enough this will appear as a momentary space from the subscriber. A short loop containing more than one holding magnet selector may produce this effect. The 96A1 repeater is particularly sensitive to this type of "kickoff" since it can transmit very short spaces to the hub. Standard arrangements are provided for applying capacitance across the loop at the loop pad position to prevent "kickoff". In the case of the 43A1 a very short space cannot pass through the narrow band channel filter and open the distant loop. Consequently in this case the use of capacitance across inductive loops is not required. See the wave form Fig. 5(D).

(F) Montioring and Transmission Measurements

4.09 As discussed previously transmission in both directions in a relay-type loop is on a ***current*** basis. It is therefore possible to connect a monitoring teletypewriter or transmission measuring set in series with the loop at either end and monitor or measure signal transmission in either direction of transmission in the conventional manner.

4.10 In the case of the electronic loop this current wave type of monitoring or measuring at the central office end of the loop can be used properly only for transmission toward the station. This is because the signals from the station are received as a ***voltage*** wave. Any attempt to measure transmission in this direction by the insertion of monitoring teletypewriter or current-type measuring set in the usual series manner in either side of the loop would result in measuring a current wave and would therefore lead to erroneous results.

4.11 Since the 96A1 loop repeater is associated with a No. 2 electronic hub circuit, monitoring or measuring of inward signals can be readily accomplished on the hub side, rather than on the loop side, of the repeater. Also, a loop repeater test set is provided to check the loop repeater itself.

4.12 With 43A1 carrier telegraph terminals, the loop transmission toward the station can be checked in the conventional manner. The only accurate method at present for checking transmission from the station is with the 43A carrier TMS circuit incorporated in the modified 164C1 telegraph transmission measuring set. This method permits measurements to be made at the modulator of the 43A1 terminal for signals received from the loop, and the measurements reflect the combined distortion effect of the sending station and loop plus the response of the modulator circuit. There are obvious disadvantages in this method since the measuring set must be patched directly to pin jacks on the carrier terminal. Consideration is being given to the development of a circuit for use at testboards which will permit this type of monitoring and transmission measuring.

Attached:
Figs. 1, 2, 3, 4, 5, and 6

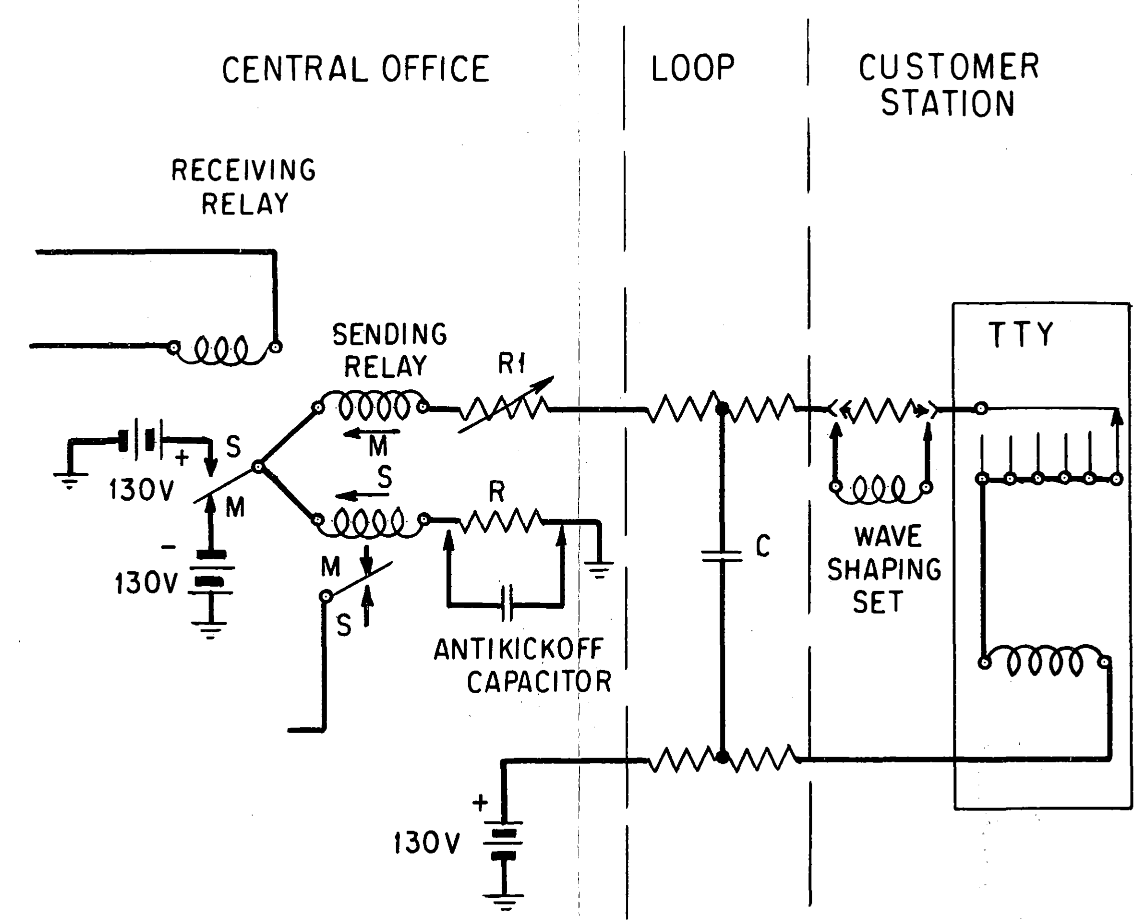

Fig. 1—Typical Relay-Type Telegraph Loop

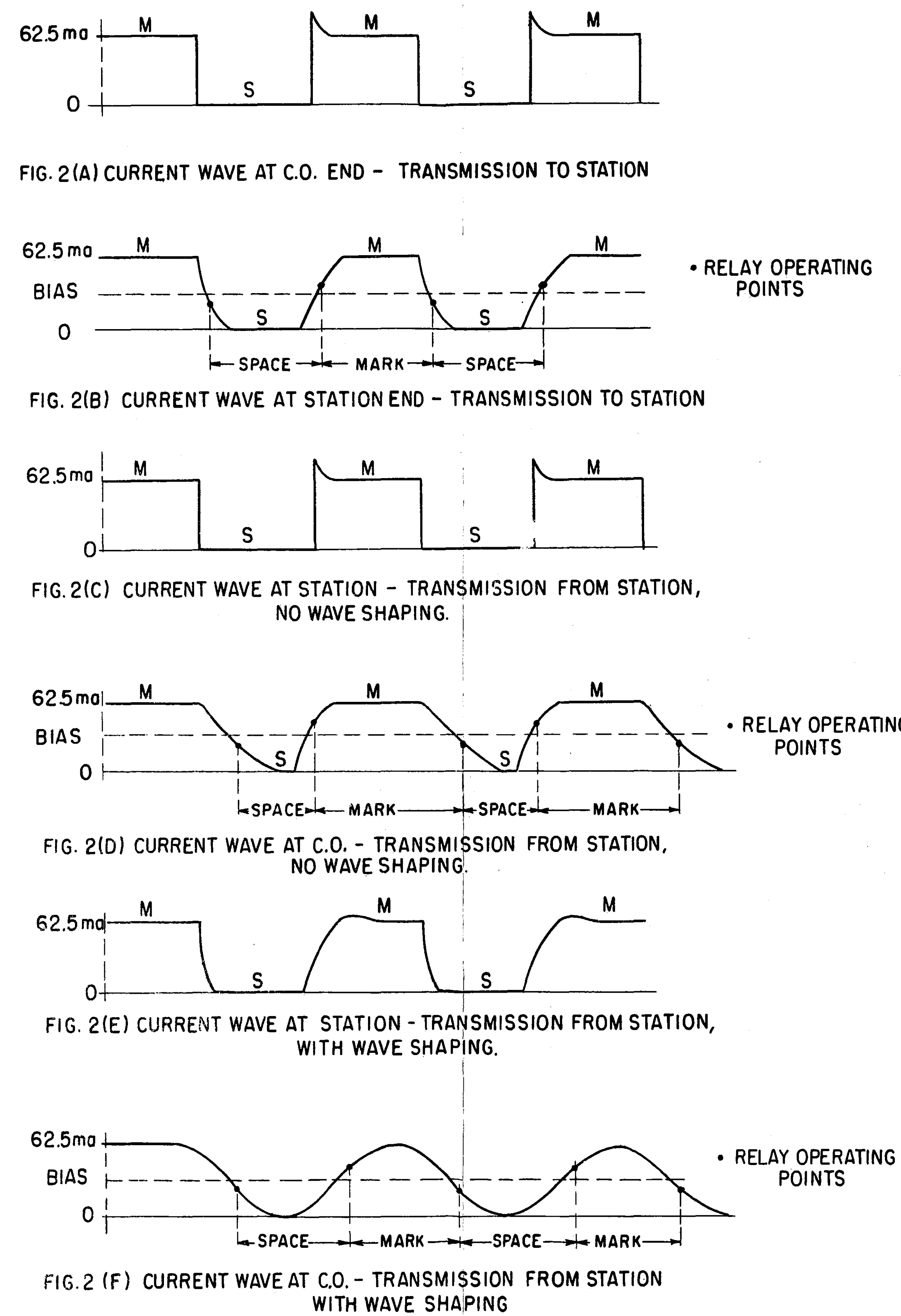

Fig. 2—Typical Current Waves in Relay-Type Telegraph Loops

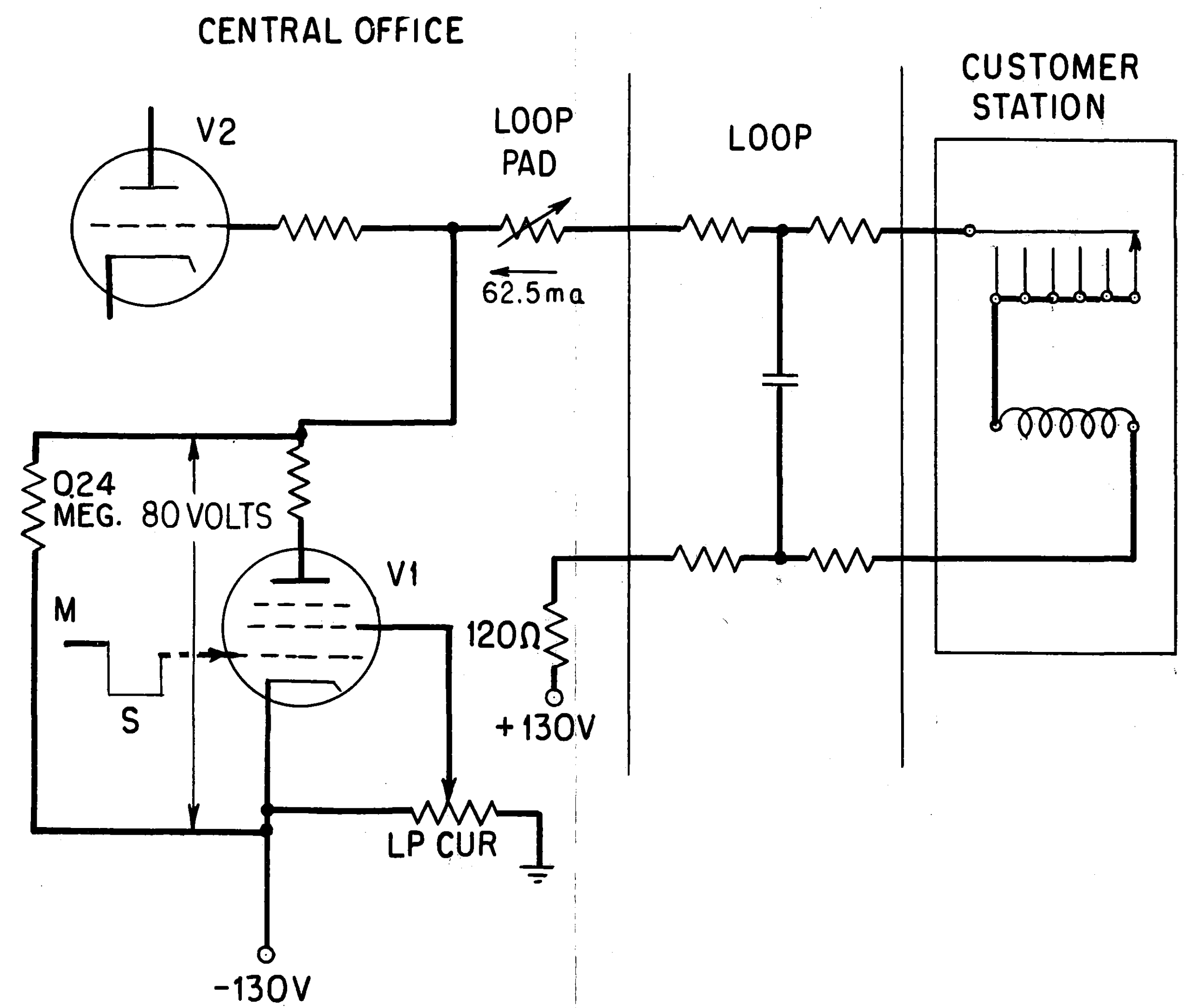

Fig. 3—Typical Half-Duplex Electronic Telegraph Loop

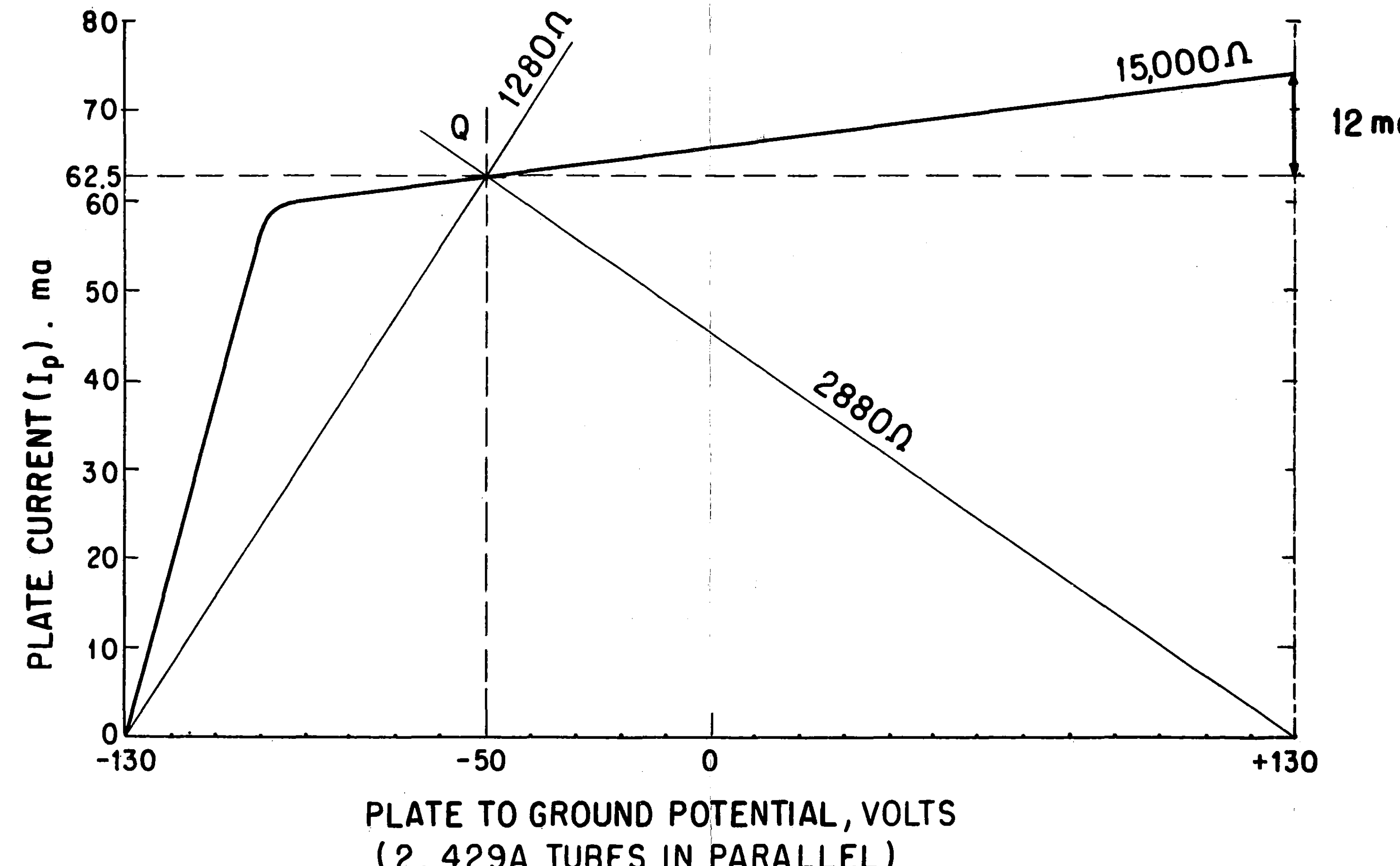

Fig. 4—Plate Characteristics of Two Pentode Power Tubes in Parrallel

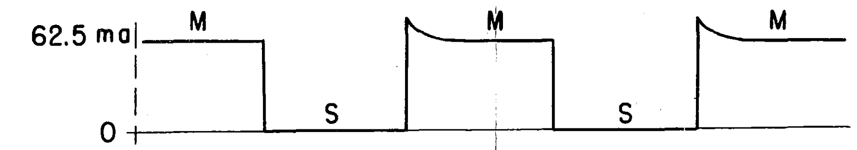

FIG. 5(A) CURRENT WAVE AT C.O. END - TRANSMISSION TO STATION

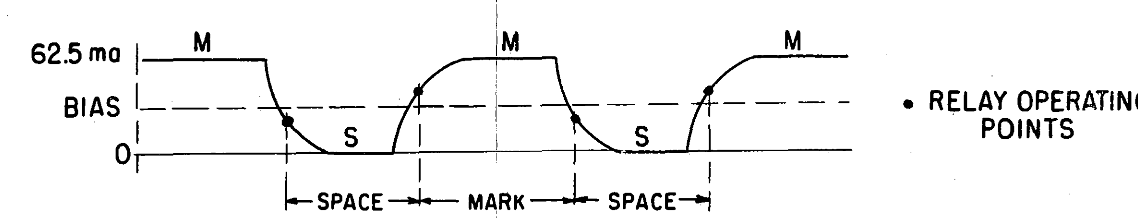

FIG.5(B) CURRENT WAVE AT STATION END - TRANSMISSION TO STATION

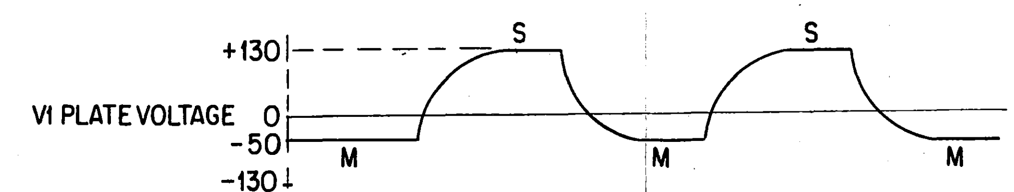

FIG. 5(C) VOLTAGE WAVE AT C.O. END - TRANSMISSION TO STATION WITH CAPACATIVE LOOP.

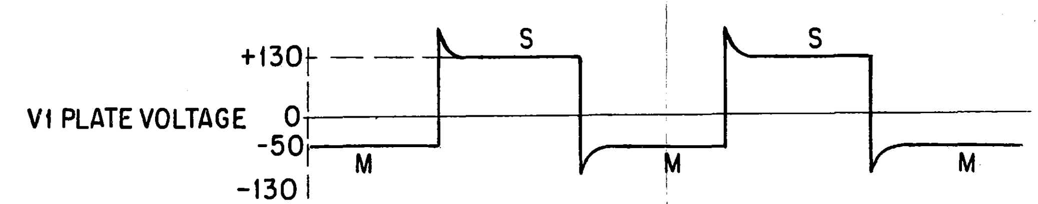

FIG. 5(D) VOLTAGE WAVE AT C.O. END - TRANSMISSION TO STATION WITH INDUCTIVE LOOP.

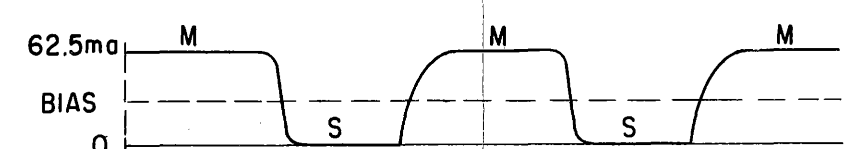

FIG. 5(E) CURRENT WAVE AT C.O. END - TRANSMISSION FROM STATION

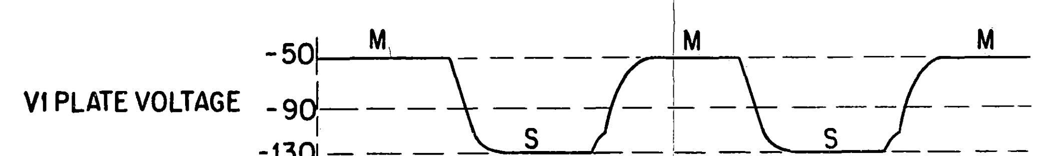

FIG.5 (F) VOLTAGE WAVE AT C.O. END - TRANSMISSION FROM STATION

Fig. 5—Typical Current and Voltage Waves in Electronic Telegraph Loops

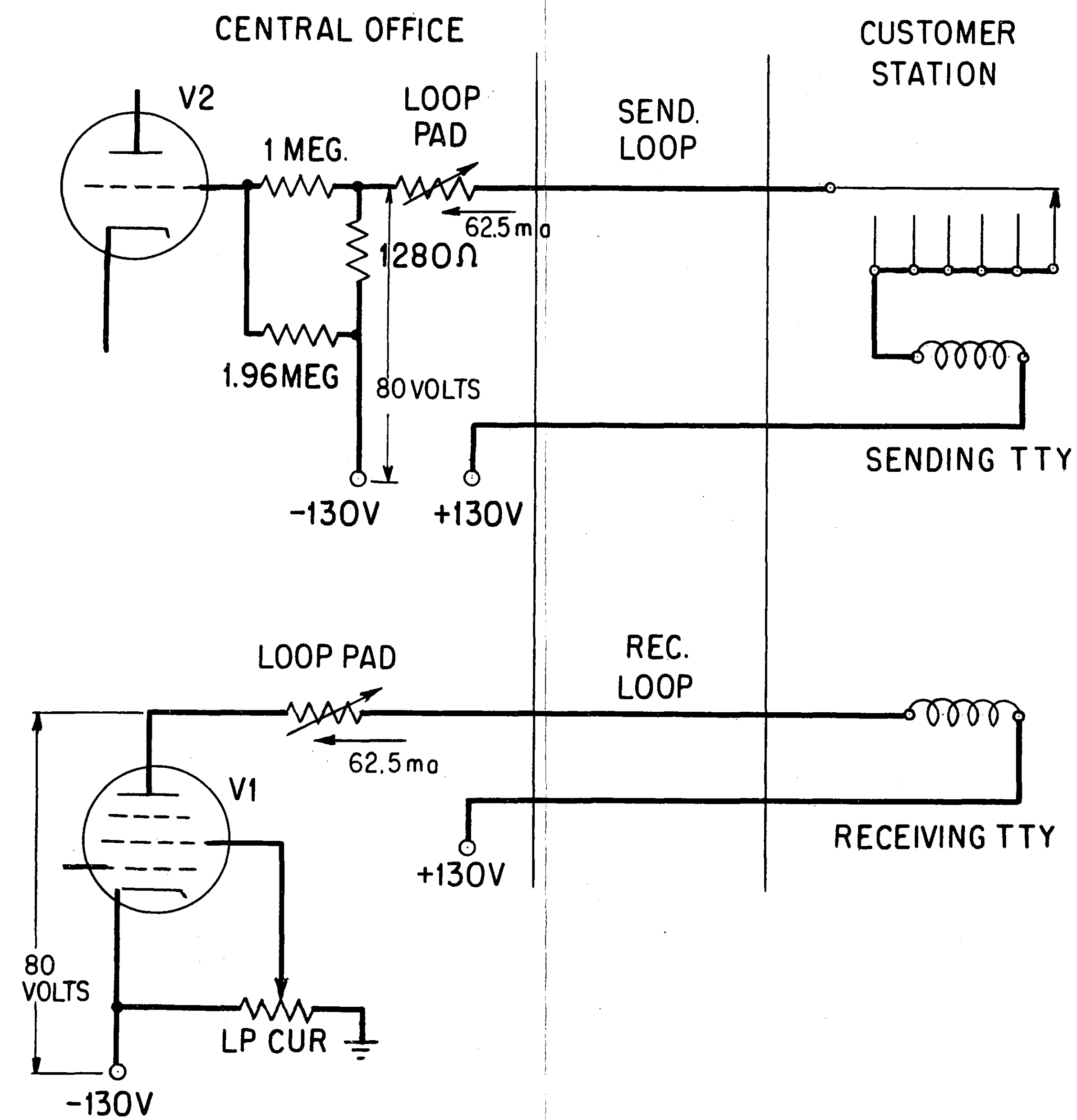

Fig. 6—Typical Full-Duplex Electronic Telegraph Loop