Dec. 22, 1931. G. CRISSON ET AL 1,837,316

VOICE OPERATED CONTROL ARRANGEMENT FOR TELEPHONE CABLE SYSTEMS

Filed Sept. 10, 1929 2 Sheets-Sheet 1

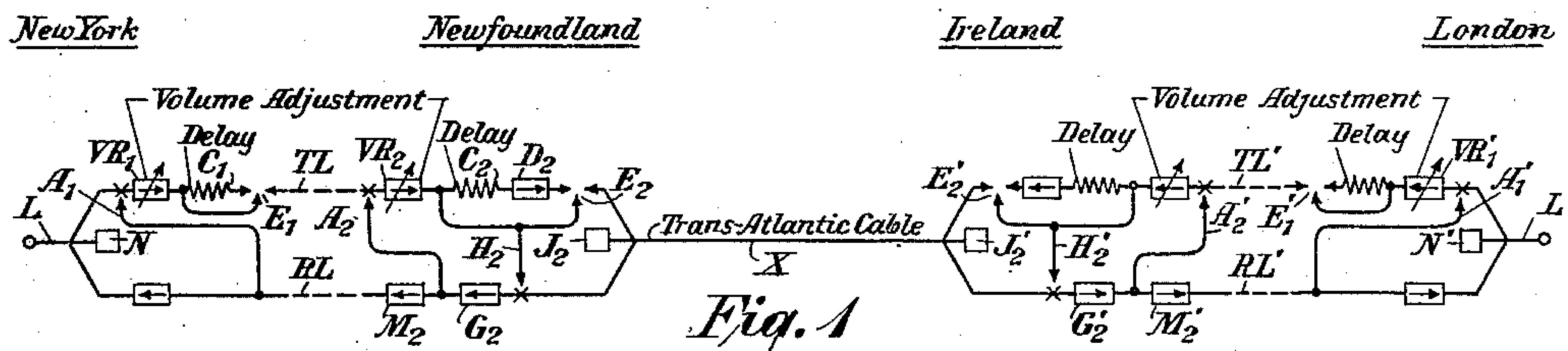

Fig. 1

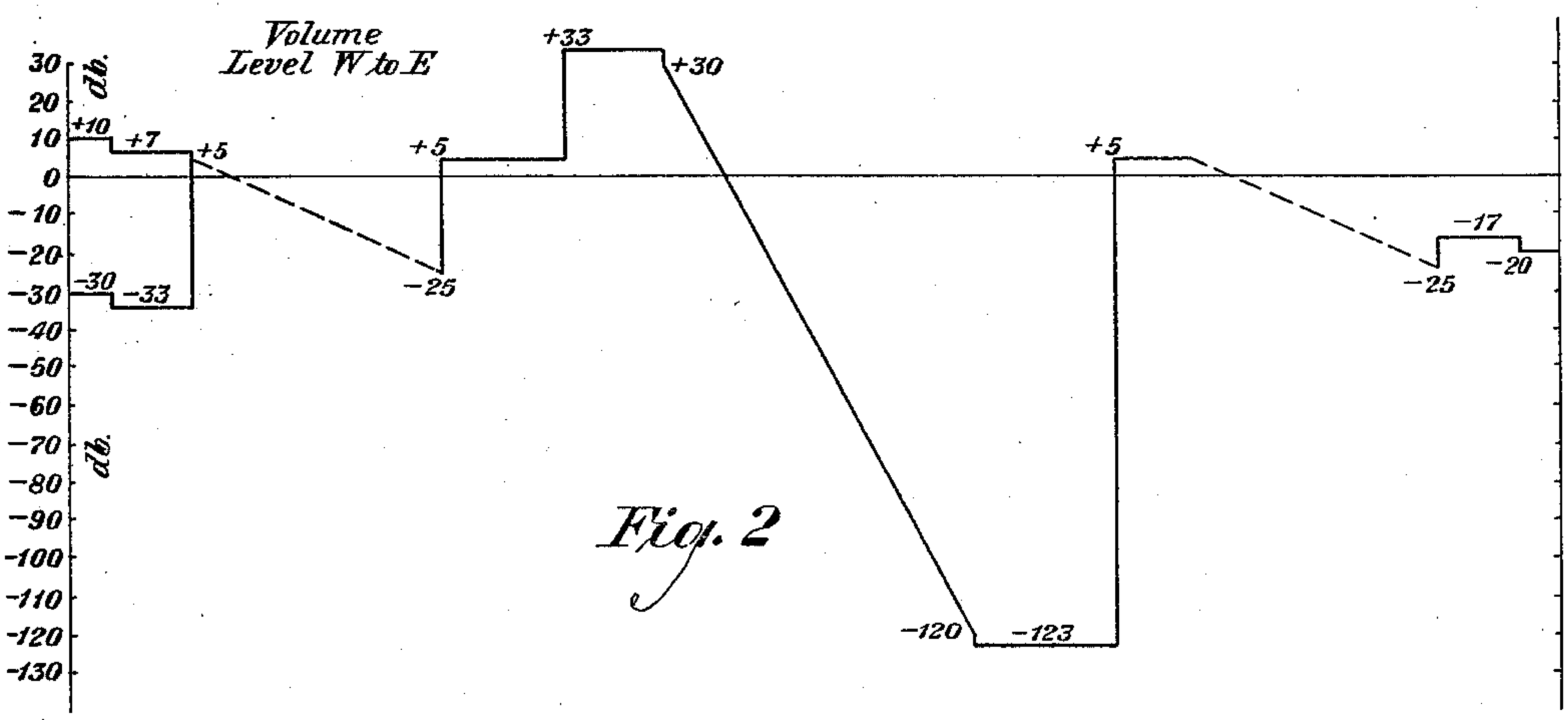

Fig. 2

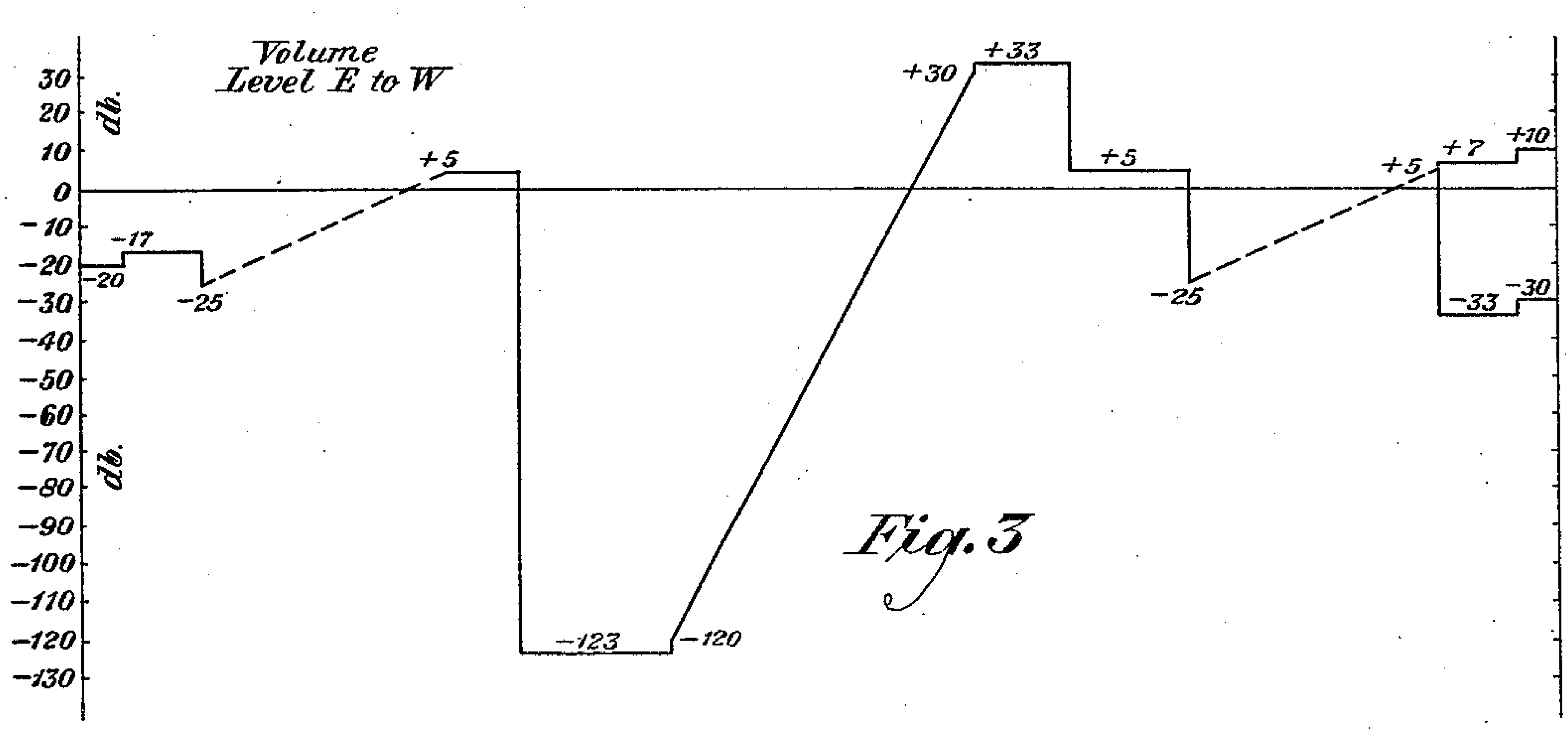

Fig. 3

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VOICE OPERATED CONTROL ARRANGEMENT FOR TELEPHONE CABLE SYSTEMS

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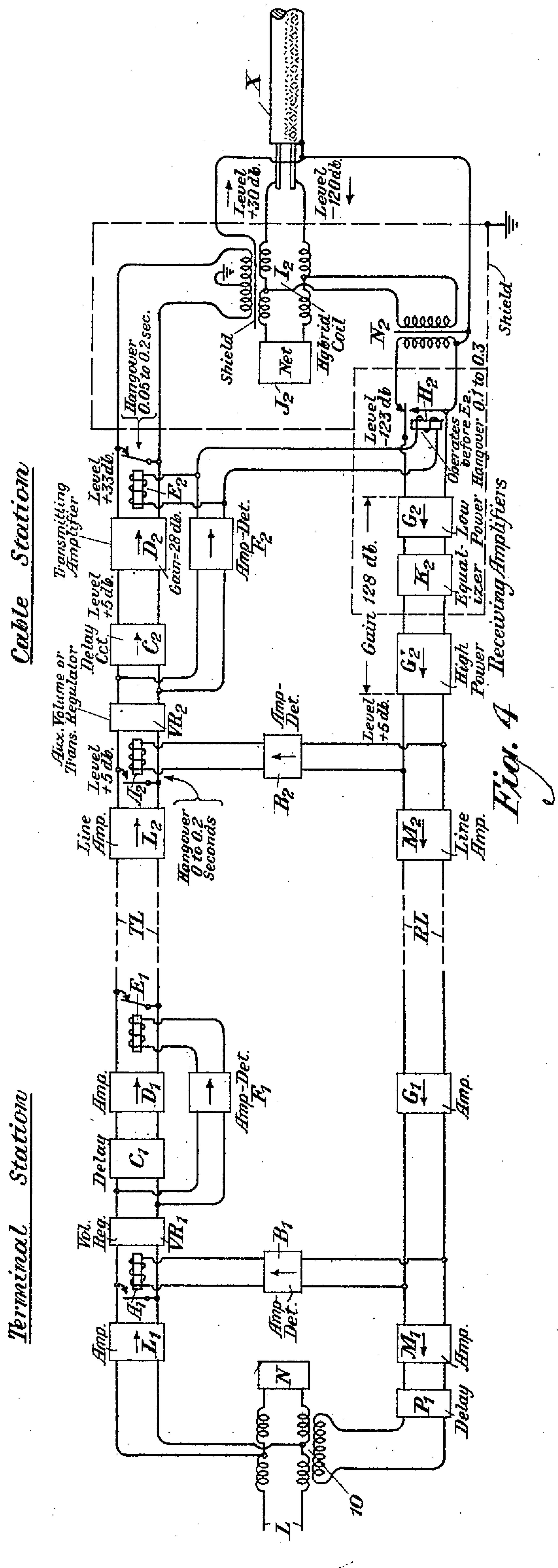

Fig. 4

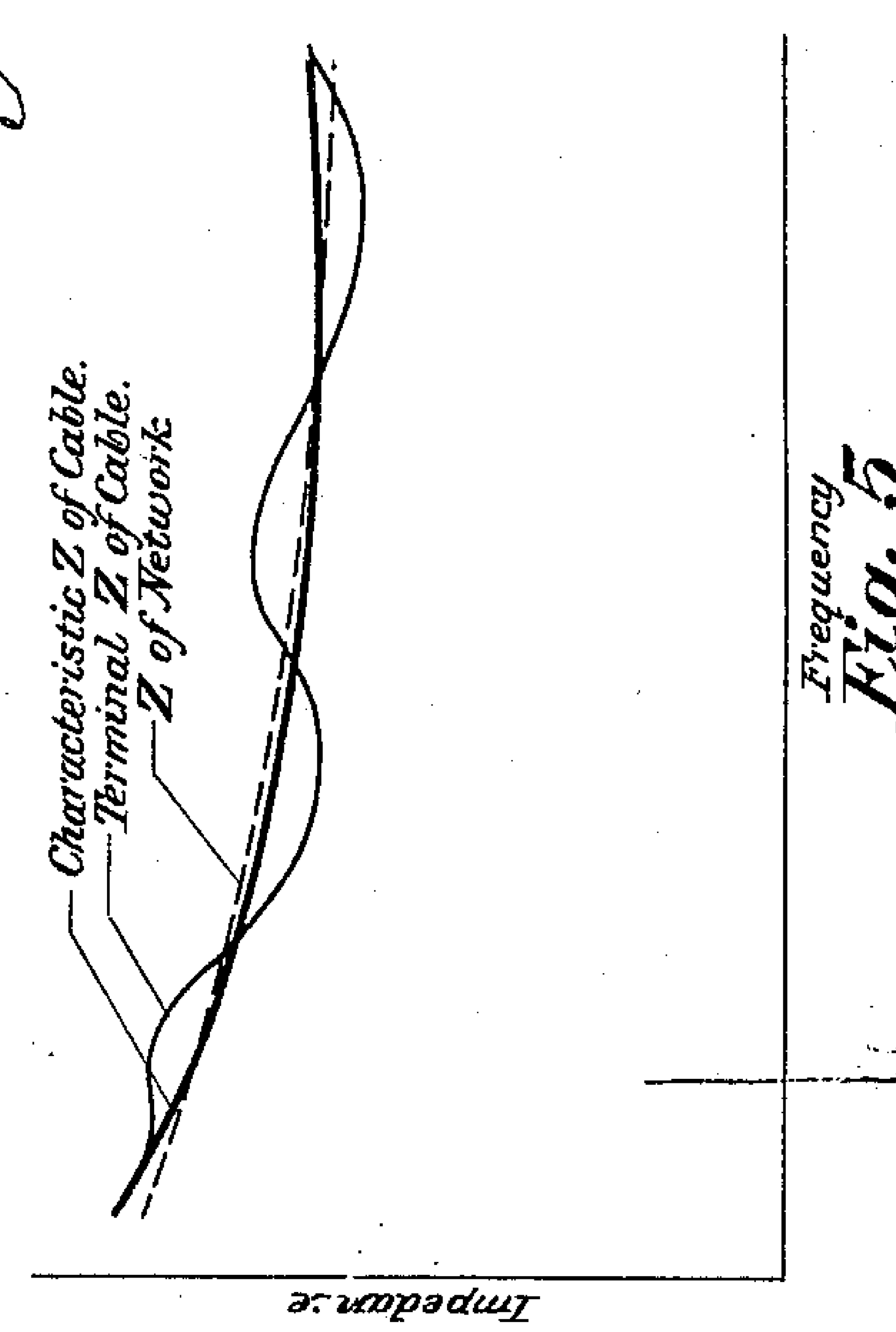

Fig. 5

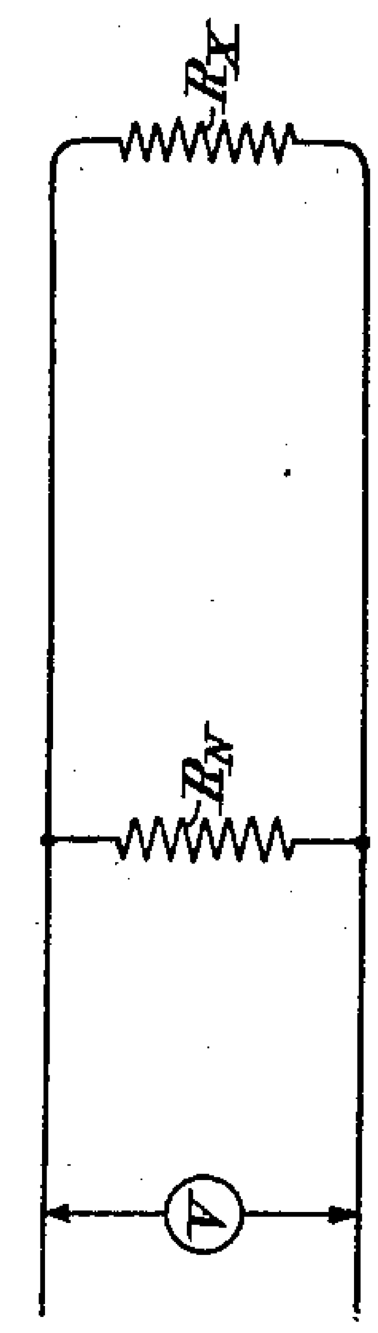

Fig. 6

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UNITED STATES PATENT OFFICE

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VOICE OPERATED CONTROL ARRANGEMENT FOR TELEPHONE CABLE SYSTEMS

Application filed September 10, 1929. Serial No. 391,598.

This invention relates to telephone transmission systems, and more particularly to transmission systems involving a long section of submarine cable.

In order that wire telephone transmission may take place between points separated by a large body of water, as, for example, is the case in telephoning between New York, and London, it is necessary that at least one long section of submarine cable be incorporated in the transmission circuit. Because of the expense of constructing such a cable, it is impractical to provide two cables for four-wire operation, and therefore the one long section of submarine cable, for example, between Newfoundland and Ireland, must be used for two-way transmission. It is, however, quite feasible to operate on a four-wire basis those portions of the circuit which extend between the ends of the cable and the terminal switching stations at say New York and London, even though parts of the four-wire circuit must be carried in shorter sections of submarine cable as, for example, in the Irish Sea and in the short stretch of water between Nova Scotia and Newfoundland. These relatively short cables may be worked on the two-way plan or the transmission paths for opposite directions may be separated by using carrier transmission. In any case substantial echoes in the four-wire circuits may be caused by the intervening lengths of submarine cable.

With reference to the long section of submarine cable, which is operated on a two-way basis, however, the attenuation is at best enormous, and although such a cable is relatively free from external disturbing influences to cause noise, it will at least have a noise level determined by the resistance noise (or noise due to thermal agitation) of the cable. In order, therefore, that the currents received after transmission over the cable have sufficient volume to be above this noise level, the voice energy must be applied at the sending end of the cable at a very high volume level, so that the difference in level between the sending energy and the received energy at a given end of the cable is very much greater than is the case with any type of telephone system heretofore employed. This situation introduces transmission problems of an order never heretofore encountered.

With this great disparity between applied and received energy at the ends of a cable, it is obviously necessary that voice operated switching arrangements be provided for preventing singing in the four-wire circuit and for suppressing echoes. Furthermore, it is necessary to locate the voice operated arrangement adjacent the ends of the cable. This is for the reason that the receiving amplifier must be very sensitive in order to step the very weak attenuated currents incoming from the cable up to a normal volume for transmission over the receiving line of the four-wire circuit, and it is therefore necessary to protect such sensitive receiving apparatus from the relatively enormous echo currents coming in from the cable in response to transmission going into the cable from the other side of the four-wire circuit. It is also necessary to protect the receiver from the enormous transmitting currents which might enter the receiving circuit from the transmitting path of the four-wire circuit due to incomplete balance.

On the other hand, to locate, at the ends of the cable, all of the apparatus for suppressing singing and echoes in the four-wire circuit is inadvisable, as it is impracticable to maintain at the relatively isolated points at which the cable terminates the technical operating, supervisory and maintenance staff necessary to control apparatus for the various conditions obtained by different telephone extensions at the switching terminal. It is therefore proposed to arrange the main voice operated equipment for the suppression of singing at the terminal stations, for example, New York and London, and to so arrange the equipment at the cable terminals that the voice operated mechanisms at the cable terminals need not require continuous inspection and adjustment. For this reason the voice-operated devices at the cable ends will be referred to as "auxiliary" devices, even though they may consist of more complex circuits than the main devices. To accomplish this result, the voice operated equipment at the switching terminals is arranged so as to normally disable the transmitting side of the circuit to prevent singing, the disabling means being removed in response to the voice currents. Arrangements are also provided for disabling the transmission path at the switching terminal in response to voice currents received over the receiving side of the four-wire circuit. Since the transmitting side of the circuit is disabled except when used for talking, the voice-operated equipment at the cable terminal is protected from noise currents arising in the connecting circuits beyond the switching terminal, and, as the four-wire circuit to the cable terminal will be laid in telephone cable, the four-wire circuit itself should be relatively free from noise. By providing volume adjusting means at the switching terminal to keep the voice currents applied to the transmitting path at a normal level well above noise, the voice operated apparatus at the cable terminal may be made very sensitive and need not be carefully adjusted to discriminate between signals and noise.

By making the voice operated apparatus at the cable terminals highly sensitive, such apparatus will respond to the initial part of the voice wave before such wave approaches its peak value. Therefore, the delay circuit ordinarily used to prevent clipping, when the sensitivity is held to a lower value due to noise in the connections, may be made very small or even omitted. This is important from the standpoint of the time of transmission between the voice operated apparatus at one terminal of the cable and that at the other, as the delay circuit time is added to the time of transmission over the cable.

It is desirable to keep down the time of transmission between the two sets of echo suppressing apparatus which ultimately determine which subscriber has control of the circuit in order to reduce the possibility of a "lock-out". When two full echo suppressor equipments are associated with a circuit at the same point, the possibility of the subscribers mutually locking each other out is limited to the case where the voice currents, from both subscribers arrive at the echo suppressors at the same instant. If, however, the two full echo suppressor equipments are moved toward the terminals of the circuit so that a definite time is required for transmission between the two sets of equipment, mutual lock-out can take place when the voice currents of the two subscribers arrive at the corresponding echo suppressors within a period equal to the time of transmission between the two sets of suppressors.

In the case of the submarine cable, it is evident that the lock-out time cannot be reduced to a period less than the time of transmission over the cable, for the reason that the two sets of echo suppressor equipment cannot be closer together than the ends of the cable, and to the time of transmission over the cable the delay time of the delay circuits must be added in determining the lock-out time. Hence, the reduction of the delay due to the delay circuits is important.

As already stated, voice operated devices for the suppression of singing are to be located at the switching terminals. If these arrangements were so designed that the talking subscriber's voice currents in passing over the transmitting path of the four-wire circuit could disable the receiving path at the switching terminal, the lock-out time would be the time of transmission from one switching terminal to the other, and, as the four-wire circuits leading from the cable terminals to the switching terminals might be of considerable length, and noise conditions are such that delay circuits are necessary for proper operation of the transmitting relay, the increase in lock-out time might be so considerable as to make the circuit very unsatisfactory from the subscriber's standpoint. Accordingly, it is proposed to arrange the voice-operated apparatus at the switching terminals so that only the transmitting path of the four-wire circuit is controlled, and no means is provided at the switching terminals to disable the receiving path. This will give control of the circuit from the standpoint of lock-out to the voice-operated devices at the cable terminal and thus reduce the lock-out time accordingly.

Another factor which must be considered in the telephone system involving a long submarine cable is the so-called relaxing current. The characteristic impedance of the cable will involve a considerable reactance component. When voice currents of large energy are applied to one end of the circuit for transmission to the other end, energy is stored up in the reactance of the cable, and, when the voice potential ceases, a unidirectional gradually decaying current flows out of the cable because of the energy stored up in its reactance. Since the reactance is large, and the applied energy must necessarily be large, (because of the great attenuation of the cable), this relaxing current will, at the instant when the applied energy ceases, be large and may require a considerable time before it decays to a value small enough to cause no disturbance in the sensitive receiving apparatus associated with the cable at its terminal. This relaxing current may therefore be for a considerable period of time very much greater in magnitude than the signaling currents which are to be received over the cable, and, if nothing is done to reduce its effect, the voice-operated relays for disabling the receiving path of the four-wire circuit at the cable terminal might have to be provided with a hang-over much longer than that necessary to take care of the echoes returned from the cable. It is therefore proposed, in accordance with the present invention, to reduce the effect of the relaxing current. This may be accomplished by associating a hybrid coil with the ends of the cable and balancing the cable with a network whose impedance will have a reactance component simulating that of the cable. Consequently, similar relaxing currents will flow out of both the cable and its balancing network, and these relaxing currents will tend to cancel each other to the extent that the cable and network, balance each other, so that the resultant component of relaxing current in the receiving path will be accordingly reduced.

Other features of the invention will be clear from the following detailed description thereof when read in connection with the accompanying drawings, in which Figure 1 is a symbolic diagram showing the general layout of a telephone system employing as one link long submarine cable; Figs. 2 and 3 are curves showing the volume levels at the various points of the circuit in the two directions of transmission, respectively; Fig. 4 is a schematic diagram of the apparatus at the switching terminal and at the cable terminal, respectively; Fig. 5 shows a series of curves illustrating certain features of the invention, and Fig. 6 is a simplified circuit for explaining the effect of resistance noise in the circuit.

The general layout of a typical system in accordance with the invention is shown in Fig. 1. In interpreting this figure, it should be borne in mind that transmission paths comprising two wires, one acting as a return for the other, or one wire with a ground return, are symbolically represented by a single line and that amplifiers are represented by rectangles with arrows to indicate the direction of transmission. The echo suppressing devices are symbolically represented by a line attached directly to the voice circuit which operates the echo suppressor, with an arrow at the other end adjacent the circuit which is to be controlled. The open or closed condition of the contacts in the controlled circuit is indicated by separated arrowheads in the case of a normally disabled circuit, and by arrowheads which touch in the case of a normally operative circuit condition. Delay circuits associated with the voice operated devices are represented by zigzag lines.

In order to simplify the description, the circuit will be described for a hypothetical case of a telephone system having its switching terminals at New York and London, with a submarine cable between Newfoundland and Ireland, and with the terminals of the submarine cable connected to the switching terminals by four-wire circuits each comprising a one-way transmitting circuit for talking in the one direction and a one-way receiving circuit for talking in the opposite direction. The principal unit of the system is the transatlantic submarine cable indicated at X in Fig. 1. Each end of the cable is balanced by networks symbolically indicated at J_2 and J'_2, and the ends of the cable are also connected to the four-wire circuits comprising paths TL and RL extending from Newfoundland to New York, and paths TL′ and RL′ extending from Ireland to London. The dotted lines used in the four-wire circuits indicate that the conductors are of the land line type, of standard form equipped with repeaters and all necessary apparatus although it will be understood that parts of the four-wire circuit will pass through undersea cables in order to span the Irish Sea and that portion of the Atlantic Ocean lying between Nova Scotia and Newfoundland. It should also be understood that the layout of Fig. 1 merely typifies the general principle and that the particular locations of apparatus will in practice be varied according to the submarine conditions that exist between the two switching terminals of any given circuit.

At the New York switching terminal, the transmitting line TL is normally disabled at E_1 and a voice operated mechanism operating in response to voice currents applied to the circuit from the terminal line L defeats the disabling means so that the transmission line TL becomes operative. A delay circuit C_1 is provided to enable the voice operated device E_1 to operate before the voice currents arrive at the disabling points. A voice operated device A_1 is associated with the receiving line RL and operates in response to voice currents received over the line RL to disable the transmitting path. A volume regulator VR_1 is also provided at the New York terminal to bring the speech currents to a definite strength for transmission over the system. The apparatus at the London terminal is similar to that at New York, corresponding elements being designated by the same reference characters primed. It will be noted that no voice operated device is provided at either terminal for disabling the receiving path thereat.

Similar voice operated devices are provided at the Newfoundland and Ireland terminals of the submarine cable X. At Newfoundland, the transmitting line TL of the transmitting circuit is normally disabled and a voice operated device E_2 is associated with the transmitting path to make the circuit operative in response to transmitted voice currents. Another voice operated device H_2 controlled from the transmitting path is arranged to disable the receiving path RL. A delay circuit C_2 is provided to enable the devices E_2 and H_2 to perform their functions before the voice currents arrive at the point where the transmitting line TL is disabled.

Another voice operated device A_2 is associated with the receiving path RL for disabling the transmitting path TL in response to the voice currents received over the submarine cable. An amplifier D_2 is associated with the transmitting line TL for bringing the voice currents up to a very high volume before applying them to the cable, whose attenuation is very great. The voice currents received over the cable are, of course, greatly attenuated during transmission and are stepped up to a desired level by means of an amplifier G_2 in order to operate the voice operated device A_2. An additional amplifier M_2 may be provided where desired. The apparatus at the Ireland end of the cable is similar to that at Newfoundland.

Figure 2 is a volume level diagram to indicate the volume levels at the different points of the circuit in transmitting from New York to London, while Fig. 3 shows a similar volume level diagram for transmission in the opposite direction. Since volume control arrangements VR_1 and VR'_1 are used at the New York and London terminals, so that the transmitting volume applied to the system is always substantially constant, the diagrams of Figs. 2 and 3 are so drawn as to show the voice volume, referred to zero reference volume, at each point of the system. In considering Figs. 2 and 3, it should be borne in mind that the zero reference volume does not represent zero energy, but, on the contrary, represents an arbitrarily chosen volume level which may be roughly described as the average amount of electrical energy produced by the average subscriber in talking over a long distance circuit into an ordinary telephone system using a standard transmitter. The unit of volume used in plotting the diagram is the decibel, and the number of decibels indicated at any point in the diagram is a function of the ratio of the voice energy at the point indicated to the amount of energy arbitrarily chosen as the zero level. Suppose, for example, a current I_t is applied to a circuit, and a current I_r is received at the receiving end, the number of decibels representing the gain in transmission over such circuit will be equal to 20 $\log_{10}$

$$\frac{I_t}{I_r}.$$

If, therefore, the ratio of the received current to the applied current is unity, so that there is no change in energy, the change in transmission will be zero decibels. If the received current is ten times as great as the applied current, the gain in transmission will be 20 decibels. If, on the other hand, the received current is $\frac{1}{10}$ of the applied current, the change in transmission will be -20 decibels. The following table gives the number of decibels corresponding to certain current ratios, the current ratios being given in the first column:

Current ratio	Decibels	Energy ratio
10^2	40	10^4
10	20	10^2
3.16	10	10
2	6	4
$\sqrt{2}$	3	2
1	0	1
$\frac{1}{\sqrt{2}}=.71$	-3	$\frac{1}{2}$
$\frac{1}{2}$	-6	$\frac{1}{4}$
.316	-10	10^{-1}
10^{-1}	-20	10^{-2}
10^{-2}	-40	10^{-4}

The corresponding energy ratios are given in the third column. It will be noted that the energy ratio corresponding to any number of decibels will be the square of the corresponding current ratio. From this table it will be seen that doubling the energy represents a gain of 3 decibels, while reducing the received energy by one-half represents a loss of 3 decibels. Doubling the current, on the other hand, represents a gain of 6 decibels, while halving the current, represents a loss of 6 decibels. These particular values should be noted, as they are of some importance in understanding the effect of the hybrid coils and balancing networks, as will be described later.

Owing to the necessary use of voice operated switching apparatus, the system is arranged to deliver a substantially constant volume of speech to the connecting line at either end, regardless of the volume impressed upon the other end of the system. This is accomplished by providing the volume regulating apparatus at the switching terminals so that, regardless of the loudness of the speech applied to the system from the connecting line, the volume applied to the transmitting line of the four-wire circuit will be constant. As will be seen from the curves of Figs. 2 and 3, the volume delivered at the receiving end of the system is 20 db. weaker than the zero or reference volume. Under normal conditions with reference volume applied to either end of the system, and -20 db. delivered at the other end, the transmission loss between terminal offices is 20 db. When stronger or weaker volumes are applied at either end of the system, the gain will be adjusted by the volume regulator at the switching terminals, and, if necessary, by the volume regulator at the cable terminal, to bring the volume to the normal value at the voice operated apparatus, in the submarine cable, and at the far end of the system. The range of applied volume to be provided for is from $+10$ to -30 db. with respect to reference volume at the switching terminal. This is shown, for example, by the two branches of the volume level curves at the extreme left in Fig. 2 and at the extreme right in Fig. 3. The system will give an over-all loss of 30 db. in the direction of transmission when +10 db. is applied at the sending end, and a gain of 10 db. if −30 db. is applied.

Referring more particularly to the curve of Fig. 2, it will be seen that when +10 db. is applied to the system, the volume level drops to +7 db. upon passing through the hybrid coil, and, similarly when −30 db. is applied to the system, it drops to −33 db. upon passing through the hybrid coil. This is because the applied energy divides at the hybrid coil between the transmitting line and the receiving line, due to the conjugate arrangement of the connection, and only half of the energy is ultimately delivered to the transmitting line. In the table above given, halving the energy resulted in a loss of 3 decibels, which accounts for the condition just described.

By means of the volume regulator VR_1, the volume level finally applied to the transmitting line at the switching terminal may be reduced (or raised) to +5 db. This value is chosen as the maximum constant volume which may be transmitted over the system without producing excessive cross-talk in adjacent land lines.

The volume level at the cable terminal, for example, at Newfoundland, is again brought up to +5 db. by means of the line repeaters at that point, the volume adjuster VR_2 being operated, if necessary, to correct for any deviation from the desired level. The volume level actually impressed upon the submarine cable should be made as high as possible with due regard to the limitations imposed by the loading material, in order that the cost of the cable may be kept down by designing it for a large transmission loss without permitting the received signal to fall too near the noise level in the cable. Accordingly, the amplifier D_2 may raise the level to +33 db. The energy, upon passing the hybrid coil at the terminal of the cable, loses 3 decibels because only half of the energy goes to the cable, the other half being distributed to the balancing network J. Accordingly, 30 decibels are applied to the cable. Assuming that the attenuation of the cable is such as to reduce the applied energy 150 decibels, it will be received at the opposite terminals of the cable at a level of −120 db. and will be reduced 3 db. further by reason of the hybrid coil arrangement at the other end of the cable. The extremely low volume thus received is again raised to +5 db. by the repeaters M'_2 and G'_2 and then transmitted over the receiving path RL′ of the four-wire circuit to the London switching terminal. The transmission in the opposite direction, as shown by the curve of Fig. 3, will be similar to that described. It will be understood, of course, that the values of volume level above given are merely illustrative and that in any practical design the volume levels may be changed very considerably from those described.

The volume regulating apparatus at the switching terminals may merely consist of a potentiometer associated with a repeater which is adjusted by a technical operator who is guided by a volume indicator; but, if desired, it may be an automatic arrangement. In any event, its function is to keep the volume of speech at all parts of the four-wire circuit at a normal value except for minor variations so that sufficient energy will be available to operate the voice operated apparatus at the cable terminals. While the lines of the four-wire circuit will be provided with pilot wire transmission regulation, there may be some residual variations in the transmission loss of the four-wire circuit. Such variations may be taken care of by the volume regulating apparatus, such as VR_2 at the cable terminal. The variation to be expected at this point will be a slow variation with changes in the transmission efficiency of the four-wire circuit, and consequently the volume adjustment at the cable terminal need not be fairly continuous as is necessary at the switching terminal, where differences between the loudness with which different subscribers speak, and the effective distances of the subscribers from the terminal, must be taken care of. The transmission loss of the submarine cable is, of course, enormous, but since the cable is exposed to very constant temperature conditions, it should not be necessary to make provision for automatic or quick adjustment of the gains of the receiving amplifiers associated with the cable. If any serious changes occur, they are likely to take place slowly and can be compensated for by adjustments made at the time of the lining-up tests of the circuit. Of course automatic devices might be used here if found necessary.

As has been previously stated, the great transmission loss of the submarine cable and the desirability of reducing the inherent lock-out and breaking difficulties of the system to the lowest possible degree make it necessary to have auxiliary voice operated anti-singing and an echo suppressing apparatus at the ends of the cable itsef. Certain advantages are secured, however, by locating the principal anti-singing voice operated devices and delay circuits at the switching terminals (New York and London), as compared to having the main voice operated devices at the ends of the cable, with the primary control of volume levels also exercised at the switching terminals. This enables the auxiliary voice operated devices at the cable terminals to be operated at relatively high sensitivity. The receiving voice operated relay at the cable terminal need have a hangover only long enough to take care of echoes due to unbalances between the control station and the end of the cable. Echoes from the connected circuits are suppressed by the suppressor A_1 at the terminal office whose hangover can be adjusted as required. As no transmitting echo suppressing relay is included at the switching terminals to control the receiving side of the circuit, incoming speech from the transatlantic cable takes control of the circuit even though outgoing speech is actually traveling through the land cable. Consequently, while the over-all delay of the circuit is slightly increased by the use of the additional voice operated devices, smaller delay circuits are required in connection with the auxiliary voice operated devices at the cable terminals, and, as lockouts occur between the apparatus at the cable terminals, the probability of mutual lock-out is substantially limited to that due to the time of transmission through the cable. By locating the principal anti-singing voice operated devices at the switching terminals, the technical operators at those terminals will be immediately aware of the necessity for adjustment in relay sensitivity necessitated by clipping or excessive land line noise, and are in a position to make decisions and issue instructions to the switching operators in case troubles are caused by faulty connecting circuits.

With this general idea of the operation of the system in mind, the details of the apparatus at the switching terminal and the cable terminal, as shown in Fig. 4 may be readily understood.

It may be assumed that Fig. 4 shows the apparatus at New York and Newfoundland, the corresponding Landon and Ireland installations being in all respects similar.

Referring to Fig. 4, the connecting line L at the switching terminal is balanced by a network N and is associated by means of a hybrid coil 10 with the transmitting line TL and receiving line RL of the four-wire circuit. The transmitting line includes a line amplifier L_1 of ordinary construction, a volume regulator VR_1 which may be simply an amplifier with an adjustable potentiometer operated either manually or automatically, and a second line amplifier D_1. The volume regulator VR_1 is for the purpose of maintaining the volume level of voice currents in the transmitting line TL at a substantially constant value so that variations in the loudness with which a given speaker talks, or differences between the loudness with which different speakers talk, will be compensated for. The line TL will be normally disabled by means of a relay E_1 which is controlled by an amplifier-detector set F_1 bridged across the line TL ahead of a delay circuit C_1 for the purpose of enabling the relay E_1 to cut through the line TL before the voice currents which operate the amplifier-detector arrive at the point where the line TL is disabled.

The receiving line RL includes amplifiers G_1 and M_1, and is provided with a voice operated arrangement comprising an amplifier-detector B_1 and control relay A_1 for disabling the transmitting line TL when voice currents are received from the line RL. If necessary, a delay circuit P_1 may be provided to enable the relay A_1 to operate before echoes from the received voice currents pass through the hybrid coil 10 into the transmitting circuit. The relay A_1 should control the transmitting line TL ahead of the volume regulator VR_1, so that if it is automatically operated, it will not be adjusted by echoes passing from the receiving circuit through the hybrid coil into the transmitting circuit.

At the cable terminal, the cable X is balanced by a network J_2, and, by means of a hybrid coil I_2 is associated with the transmitting line TL and the receiving line RL of the four-wire circuit. Owing to the enormous difference in transmission level between the sending energy from the transmitting circuit and the receiving energy transferred from the cable to the receiving line, shielding is provided to protect the low level parts of the receiving circuit from high level transmitting apparatus. This is indicated by the dotted line rectangles in the figure, which surround certain portions of the transmitting and receiving equipment, respectively.

The transmitting line includes a line amplifier L_2, an auxiliary volume or transmission regulator VR_2 and a transmitting amplifier D_2 for bringing the final volume to be applied to the cable up to the desired level indicated by the diagram of Fig. 2. Normally, the transmitting line is disabled just ahead of the hybrid coil by means of a relay E_2 which is controlled by an amplifier-detector arrangement F_2 bridged across the transmitting line ahead of a delay circuit C_2 which may be provided for the purpose of enabling the relay E_2 to operate before the voice currents arrive at the point where the circuit is disabled. Since the amplifier-detector F_2 may be made very sensitive, due to the fact that noise currents are kept off of the transmitting line at the switching terminal, except when voice currents are being transmitted, the delay circuit C_2 may be made very small and indeed may be omitted entirely without causing undue clipping.

It will be noted that the contacts of the relay E_2 are bridged across the output circuit of the amplifier D_2 rather than across the input circuit, so that any noise arising within the amplifier will be prevented from reaching the cable and the receiving side of the system.

The amplifier-detector F_2 also controls a relay H_2 by means of which the receiving line RL may be disabled. Normally, the receiving circuit is operatively connected over the back contact of the relay H_2, but when the relay operates, the circuit of the line RL is broken as soon as the armature leaves its back contact. The receiving line includes a low power amplifier G_2 and a high power amplifier G'_2 for bringing the very weak received currents in the cable up to a desired value for transmission over the receiving line RL. An attenuation equalizer K_2 may be connected between the two amplifiers for equalizing the attenuation of the currents transmitted over the cable, the cable, of course, having the effect of attenuating the high frequencies to a much greater extent than the low frequencies. An amplifier-detector arrangement B_2 is associated with the receiving line and controls a relay A_2 for disabling the transmitting line TL. The contact controlled by the relay A_2 is preferably associated with the line TL ahead of the volume regulator VR_2 in order that where an automatically adjusted volume regulator is used, it will not be adjusted by echo currents.

The operation will now be described briefly. Waves originating at a subscriber's telephone come in over the connecting line L of Fig. 4 and are raised to the proper volume at the terminal office and operate the anti-singing relay E_1 at that point, so that they may be passed through the delay circuit C_1 and thence over the line TL to the cable terminal. Upon arriving at the cable terminal office, they operate the amplifier-detector F_2 and the relays E_2 and H_2 and then pass through the amplifier D_2 to the cable. The delay apparatus C_2 gives the relay E_2 time to operate before the wave reaches its contacts, thus avoiding initial clipping. This voice operated apparatus obviously must operate on all voice waves, since failure of the relay E_2 to operate would prevent the transmission of speech, while failure of the relay H_2 to operate would permit powerful echoes to pass into the receiving line and operate the relay A_2, thus interrupting the outgoing speech.

The anti-singing relay E_1 at the terminal office insures that noise from the subscriber's telephone and any terminal connecting circuits will not reach the amplifier-detector F_2 except when voice waves are passing. Since the volume regulator VR_1 will be substantially continuously adjusted to maintain the volume transmitted over the circuit TL constant, the amplifier-detector F_2 will always have maximum voice volume applied to its terminals and will have to discriminate only against the noise in the transmitting side of the four-wire circuit, which, being in a telephone cable, should be relatively quiet. For this reason, the amplifier-detector F_2 may be made as much as 20 db. more sensitive than would be the case if the anti-singing relay E_1 were not used at the terminal office. Furthermore, the delay introduced at C_2 may be made very small, or, in fact, the delay circuit may be omitted entirely, as the amplifier-detector, being very sensitive, will respond to the initial weak part of a telephone wave before it approaches its peak, so that the relay E_2 will be operated before any important part of the telephone wave is cut off.

The auxiliary volume regulator VR_2 is provided to take care of the residual variations of the transmission loss of the line TL between the switching terminal and the cable terminal. This may be used to correct the volume of the speech waves to +5 db. before they reach the input terminals of the amplifier D_2. Since the voice volume is regulated at the terminal office, VR_2 need not necessarily be a volume regulator, but may be a transmission regulator controlled by a pilot current transmitted from the terminal office when speech is not passing.

When waves come in over the cable X, they pass, without hindrance, through the receiving amplifier G_2, an equalizer K_2 and high power amplifier G'_2 toward the terminal office, provided the relay H_2 is not operated. In passing, these waves operate the amplifier-detector B_2 and the relay A_2, which latter short circuits the transmitting side of the circuit and so prevents operation of the anti-singing relay E_2 and the echo suppressor relay H_2 either by voice or by echoes during the passage of incoming waves. Later, the waves reach the terminals of the amplifier-detector B_1 and operate the relay A_1 which short-circuits the transmitting circuits and prevents operation of the anti-singing relay E_1. These waves finally pass to the connecting line L.

It is not essential that the relay A_2 operate in response to very weak received speech waves, provided the transmission loss from the receiving to the transmitting side of the four-wire circuit through the unbalance of the hybrid coil at the switching terminal is great enough to prevent the operation of the relay E_1 by the echoes of waves that are too weak to operate the relay A_2 and that the transmission loss through any intermediate unbalances is great enough to prevent the operation of the relays E_2 and H_2 by such echoes. Relay E_2 will be very sensitive, however, as pointed out above, so that if intermediate unbalances exist it will be necessary for relay A_2 to be correspondingly sensitive. If no intermediate unbalances occur, it will be sufficient to make A_2 sensitive enough so that it will respond to waves the echoes of which will operate relay E_1 since E_2 and H_2 will not operate until E_1 has operated.

The relay A_2 is completely protected from land line and terminal noise when speech is not being received over the cable. The line amplifier M_2 prevents noise coming back from the receiving line RL to operate the relay A_2, while at the distant end of the cable the anti-singing relay corresponding to E_2 prevents any noise from entering the cable at that terminal when speech is not passing, and consequently the only noise coming from that direction to which the relay A_2 is subjected is that arising in the submarine cable itself and in the apparatus such as the amplifier G_2, equalizer K_2, etc. This noise will be due principally to thermal agitation, and, after passing through the equalizer K_2, will be much stronger at high frequencies than at low frequencies. The amplifier-detector B_2 should therefore be most sensitive to the important voice frequencies and should be quite insensitive to the higher voice frequencies, thus reducing the liability of the relay A_2 being operated by thermal agitation to a considerable extent.

In order to ensure full operation of relay A_2, it is desirable for the speech waves in the receiving side RL of the four-wire circuit to be of the order of 30 db. stronger than the noise which exists when no speech is being received. This noise, of course, includes thermal agitation in the network and office apparatus and in the cable, as well as interference picked up by the cable itself. However, the interference picked up by the cable should be very small, as there are no power lines or other sources of interference in the ocean, and this type of interference would therefore be limited to points near the ends of the cable.

The line amplifiers L_2 and M_2 are ordinary one-way repeaters which serve as terminal repeaters for connecting the four-wire circuit to the voice apparatus. The repeater L_2 in the transmitting side serves to raise the level of the transmission from whatever the line delivers to +5 db. (or other desired level) which is suitable for operating the apparatus associated with the transmitting side of the system. The amplifier M_2 performs a similar function for the receiving side, changing the level from whatever level is furnished by the receiving amplifier G'_2 to +5 db. or such other level as it is desired to impress upon the receiving side of the four-wire circuit. Since the amplifier G'_2 should be normally adjusted to provide this level at its output, the function of the repeater M_2 is essentially to provide a one-way device to prevent the amplifier-detector B_2 from operation by echoes or noise coming back over the line RL from the direction of the switching terminal. This is particularly important if there are no other one-way repeaters in the receiving side of the four-wire circuit between the nearest hybrid coil and the voice operated apparatus B_2. In such a case, voice waves from the switching terminal could reach the input terminals of the amplifier-detector B_2 if the amplifier M_2 were not used.

Owing to the large transmission loss of the submarine cable, which may be assumed to be in the neighborhood of 150 db. at the upper end of the voice range (about 3000 cycles), certain precautions must be taken that ordinarily are not necessary. As has been previously pointed out, the amplifier D_2 will supply, in its output circuit, speech waves at about 33 db. above reference volume, of which 30 db. is impressed upon the cable while 3 db. is lost in the hybrid coil due to the fact that half of the energy flows into the balancing network J_2. On the other hand, the incoming waves from the submarine cable will reach the amplifier G_2 at about 123 db. below reference volume −120 db. being received from the cable and 3 db. lost in the hybrid coil due to the fact that half of the energy is transmitted into the transmitting circuit where it is wasted. The total difference of level is therefore about 156 db. at high frequencies. Consequently, if the circuit from the output of the amplifier D_2 to the hybrid coil I_2 is not perfectly balanced longitudinally, an unbalanced or longitudinal voltage will act through the system and transfer noise to the cable even when the circuit is short-circuited by the relay E_2. This will take place regardless of the loss to normal transmission caused by the relay E_2, the longitudinal current flowing in effect through the capacity between the windings of the hybrid coil. This longitudinal effect can be greatly reduced by placing a shield grounded to the cable sheath between the line and drop windings of the hybrid coil. A similar shield, connected to the office ground, should also be provided between the windings of the output transformer (not shown) of the amplifier D_2. The effect of these shields is to shunt to ground the displacement current which tends to pass through the capacity of the windings. Also, it is desirable that the secondary winding of the output transformer of the amplifier D_2 and the drop winding of the hybrid coil be made in two closely balanced and closely coupled parts with grounds at the midpoints. The series resistances of the conductors connecting the amplifier AD_2 to the hybrid coil should also be accurately balanced.

In order that the relay H_2 may disable the receiving circuit as quickly as possible, it is arranged to open the receiving circuit as soon as its armature leaves its back contact. In order to prevent transmission through the capacity between its armature and back contact, it is provided with a front contact so connected as to short-circuit the input of the amplifier G_2. It is undesirable to open both sides of the receiving circuit at the contacts of the relay H_2, as a momentary unbalance would occur if the two contacts did not open simultaneously, and this might produce enough disturbance to cause false operation of the relay A_2, thereby clipping speech outgoing from the transmission line TL to the cable X. In order to make possible the use of this unsymmetrical arrangement of the relay H_2, the transformer N_2 is provided, the transformer also serving to insulate the cable conductor from the input circuit of the amplifier G_2 and to shield said amplifier from the longitudinal voltages on the conductors.

The hybrid coil I_2 performs its usual function of separating the outgoing signals from the incoming signals. In the case of the submarine cable, however, it performs an even more important function in that it assists in reducing the relaxing current from the cable. The loaded submarine cable has a characteristic impedance which is not a pure resistance but involves a very considerable reactive component. As has been previously stated, the voice currents are applied to the cable from the line TL at a very high volume level, and the voice potentials thus store up in the reactance of the cable a very large volume of energy, with the result that when the applied voice potential ceases, the energy stored up in the reactance causes a gradually decaying uni-directional current to flow out of the cable. This current, at the moment of cessation of voice waves, is so large in magnitude that it might produce very serious disturbing effects in the receiving circuit. Unless some means were provided to reduce its effect, the relaxing current from the cable might require a longer hang-over time for the relay H_2 than would be required by the echoes from irregularities in the cable. By providing a balancing network J_2 having a characteristic impedance similar to that of the cable, a relaxing current will flow out of the network at the same time that the relaxing current flows out of the cable, and both relaxing currents will decay at substantially the same rate, so that they tend to annul each other with respect to any effect in the receiving circuit RL. Assuming that the balance between the cable and the network is 40 db., that is, that the unbalance current is 40 db. weaker than the current entering the network, not counting losses due to the division of energy by the hybrid coil, the relaxing current from the network should balance that from the cable to at least this degree. Hence, the unbalanced relaxing current would be so small that excess hang-over above that necessary to take care of echoes many not be required. In fact, the reduction of relaxing current should be even greater than this because the balance between the network and the characteristic impedance of the line upon which the relaxing current depends would be greater than 40 db.

In order to understand this, let us refer to the curves of Fig. 5. Assume we have a cable, the resistance component of whose characteristic impedance varies with frequency as shown by the heavy unbroken curve. A network might be designed whose characteristic impedance would fairly closely simulate that of the cable, the resistance component of the characteristic impedance of the network being shown by the dotted curve of Fig. 5. Now, the actual input impedance of a circuit from the standpoint of the transmission of signals is not the same as its characteristic impedance, because some of the transmitted energy is reflected back due to irregularities in the cable, with the result that the current measured at the input at any frequency may be greater or less than should be expected from the characteristic impedance, depending upon whether the reflected current is in phase or not. The result is that the sending end impedance, while in a general way following the characteristic impedance, will have humps or undulations. The resistance component of the sending end impedance would be as shown by the thin line of Fig. 5. The degree of balance between the cable and the network at any frequency is determined by the difference at that frequency between the dotted curve of Fig. 5 and the fine line curve of said figure and the corresponding differences between the reactance curves (not shown). Such unbalances include the effect of echoes reflected from irregularities in the cable. The balance, with respect to relaxing currents, however, is not affected by reflected currents, and it depends upon the reactance component of the characteristic impedance. For practical reasons, it is difficult, if not impossible, to design a network which would closely simulate the terminal impedance of the cable as indicated by the fine line of Fig. 5, and, for that reason, the network is designed to simulate the characteristic impedance, since the irregularities in the terminal impedance deviate about equally in both directions above and below the characteristic impedance. Consequently, due to the closer simulation between the impedance of the network and the characteristic impedance of the cable, than that which exists between the impedance of the network and the terminal impedance of the cable, the balance will be considerably better from the standpoint of the relaxing current than in the case of echo currents.

The use of the hybrid coil I_2 (Fig. 4) of course, involves certain penalties. One of these is that the transmitting amplifier D_2 must raise the power level by 3 db., that is, it must supply twice the power which would be required if the amplifier were connected directly with a submarine cable. This is for the reason that one-half the signaling energy is wasted in the balancing network. Another penalty is that the margin between the voice waves coming from the cable and the noise due to thermal agitation in the cable, in the network, and in the associated apparatus at the input terminals of the amplifier G_2, is reduced by 3 db. With respect to any thermal noise arising in the receiving circuit beyond the bridge connection to the hybrid coil, it is evident that this reduction in margin occurs since such thermal noise is not affected by the hybrid coil, while half of the signal energy coming from the cable is wasted by being transmitted into the transmitting channel. While at first thought it would seem that the hybrid coil should produce no change so far as the margin between the signal and the thermal noise in the cable is concerned, actually the margin is effectively reduced in this case, also. That this is so, will be apparent when it is remembered that while the presence of the hybrid coil reduces the thermal noise of the cable by one-half, the network J_2, which would not be present if the hybrid coil were omitted, adds an equivalent amount of thermal noise, so that in effect the total amount of noise due to thermal agitation remains unchanged as a result of the introduction of the hybrid coil, but the received signal is reduced by 3 decibels. Since the thermal noise, after passing the equalizer K_2, is strongest at high frequencies, this margin could be restored to some extent by reducing the upper limit of the frequency band which is received and utilized.

As has been previously stated, the matter of shielding is of considerable importance, since the hybrid coil and associated apparatus sometimes work at a high volume level and sometimes at a low volume level. Owing to the very low level at the input of the receiving amplifier G_2, this amplifier and its associated wiring should be shielded from the high level parts of the circuit. Accordingly, this amplifier, together with the equalizer K_2 and the input wiring of the amplifier, are enclosed within a grounded shield indicated schematically in dotted lines in Fig. 4. Similarly, the high level parts of the circuit, including the wiring leading from the output of the transmitting amplifier D_2 to the hybrid coil, the hybrid coil itself, and the network J_2, are included within another grounded shield schematically represented in dotted lines in the figure. The high power amplifier G'_2 need not be shielded if it is not located too close to the output of the transmitting amplifier D_2.

There will generally be an appreciable difference in potential between ground at the cable terminal station and the armor of the submarine cable which is in effect grounded through the sea water. It is therefore desirable that shields between the windings of the hybrid coil I_2 and the transmitter N_2 be connected to the armor of the submarine cable in order that the potential difference between the shield and the windings connected to the cable conductors be as small as possible. On the other hand, there should be no connection between the office ground and the cable armor, as this would disturb the potential of the armor with respect to the cable conductors and tend to increase the cable noise. One end of the secondary winding of the transformer N_2 must necessarily be connected to the filament of the first vacuum tube of the amplifier G_2. It is also essential that the shield associated with the transformer N_2 be connected to this point because any potential difference between the shield and filament would cause noise in the input circuit of the receiving amplifier G_2. Therefore, at least the first stage of this amplifier, and preferably all stages of the amplifier, should be provided with isolated and shielded batteries for the vacuum tubes of these stages, so that they need not be connected to the office ground. This will reduce the potential difference between the low level circuits of the amplifier G_2 and the cable conductors to the lowest possible value and so reduce the possibility of trouble due to stray capacity around the shield.

Due to the extremely low level of the signal currents received from the cable, precautions must be taken to keep thermal noise in the system to a minimum. Mention has already been made of the effect of the hybrid coil and network in reducing the margin between incoming speech waves and the noise due to thermal agitation in the cable, the network and input circuits of the amplifier G_2. The thermal noise in the cable itself is determined by the design of the cable, and, so far as the present problem is concerned, must be treated as unavoidable. Certain precautions may be taken in laying out the input arrangements and early stages of the receiving amplifier G to avoid unnecessary thermal noise.

In ordinary telephone repeater circuits, it is necessary that the circuit provide a fairly good termination for the line with which it works, in order to avoid reflected waves, and consequently the bridged terminals of the hybrid coil, in the case of a 22-type repeater, are connected to a resistance which gives the desired termination, and the drop across this resistance is applied through the transformer to the grid of the first stage vacuum tube. For example, in a 22-type repeater system, the input transformer corresponding to N_2 of Fig. 4 would have a resistance bridged across its primary winding. If this resistance is eliminated as it is in the arrangement disclosed in Fig. 4, the voltage due to the voice wave impressed upon the grid of the first vacuum tube would be doubled. Referring to the chart previously given, it will be seen that this doubling of the applied voltage, and consequently of the output current of the amplifier G_2, has the effect of increasing the output level of the amplifier G_2 by 6 db. The voltage due to thermal agitation, on the other hand, would only increase by

$$\sqrt{2},$$

and hence the amplified thermal noise in the output of the amplifier G_2 will only be increased 3 db.

In order to understand this, let us refer to the diagram of Fig. 6, in which R_N may be taken to be the resistance bridged across the primary winding of the transformer N_2 and R_X the equivalent resistance component of the impedance of the network J_2, hybrid coil I_2 and cable X. In accordance with the practice in repeater design, R_N would be made equal to R_X.

Now, the thermal noise voltage is a random varying voltage whose effective value is the same for all frequencies and is a function of the temperature and resistance. It may be expressed by formula

$$KT^{\frac{1}{2}}R^{\frac{1}{2}},$$

where T is the temperature, R the resistance and K a constant. At absolute zero temperature, there is no thermal noise.

Suppose that with R_N disconnected the voltage due to the resistance noise of R_X as measured at V is e. Now, if a resistance equal to R_X but having zero temperature (and hence no noise voltage) is bridged across the circuit at R_N, the voltage drop at V due to resistance noise from R_X will be

$$\frac{e}{2}.$$

Likewise, if R_N is at ordinary temperature and a resistance equal to R_X at zero temperature is substituted for R_X, the voltage drop at V due to the resistance noise from R_N will be

$$\frac{e}{2}.$$

Now, if both R_N and R_X are in circuit and are at normal temperature, the voltages combine, but as they are random varying voltages they do not combine additively but as the square root of the sum of their squares. Hence, the terminal voltage at V will be

$$\sqrt{\left(\frac{e}{2}\right)^2+\left(\frac{e}{2}\right)^2}=\frac{e}{\sqrt{2}}.$$

Hence, since the voltage is e with R_N removed, it follows that the current will increase by the ratio

$$\sqrt{2}$$

when the resistance R_N is removed, which, as already stated, corresponds to a gain of 3 db.

If, on the other hand, we consider a sound wave voltage produced in R_X, the terminal voltage at V with R_N removed may be expressed by the value e. When the resistance R_N is bridged across the circuit, however, the terminal voltage at V will be reduced to

$$\frac{e}{2}.$$

Hence, removing the resistance R_N will increase the telephone current by a ratio of 2 which corresponds to a gain of 6 db.

In the case of a very long submarine cable, it is not necessary that the receiving terminal apparatus should provide a good termination for the cable. In the first place, the large transmission loss in the cable insures that any reflection from the terminal will have been so attenuated by the time it reaches the other end that it is negligible. Furthermore, the provision of the voice operated apparatus at the terminal insures that the wave reflected from the receiving apparatus would have no appreciable effect upon the transmission. Consequently, the resistance across the primary winding of the transformer N_2 should be omitted, thereby increasing the differential between voice currents and resistance noise by 3 db.

The attenuation equalizer K_2 will, of course, include resistance elements which would add some thermal noise to the circuit. It is necessary to provide this equalizer to compensate for the attenuation frequency curve of the cable, but the effect of its thermal noise may be decreased by connecting it beyond the amplifier G_2. By doing this, the incoming voice waves will be raised to a relatively high level before passing through the equalizer, and the thermal noise due to the equalizer will therefore be relatively insignificant.

The windings of the hybrid coil I_2 and of the input transformer N_2 should be so designed as to introduce as little resistance as possible in order to keep their contribution of thermal noise within the smallest possible limits.

The amplifier-detector B—2 and the relay A_2 constitute one-half of an ordinary echo suppressor. It is sufficient that the relay A_2 operate before any echoes arising in the four-wire circuit reach its contacts. Its hangover should be long enough to catch the slowest echo. Owing to the use of equipment B_1—A_1 at the switching terminal, which takes care of any echoes from connecting circuits, it should not be necessary for relay A_2 to hang over longer than the round trip time to the switching terminal office and back.

The relay H_2 must operate as fast as possible and slightly before any waves passing the contacts of the relay E_2 can reach those of the relay H_2. This will prevent the high power wave from the amplifier D_2 from reaching the amplifier G_2. It may not be necessary for the relay H_2 to complete its travel and short circuit the input of the amplifier G_2 before the relay E_2 operates.

The relay E_2 should operate as fast as possible in order to avoid initial clipping with little or no artificial delay in the delay circuit C_2, but its operation should not be so fast that the relay H_2 cannot stop all waves passing the contacts of E_2. The relay E_2 should also hang over long enough to avoid terminal clipping. The relay H_2, on the other hand, must hang over long enough so that echoes coming back from the cable, due to outgoing speech and noise from the transmitting line TL, will have ceased, and for the relaxing current from the cable to fall to a low enough value to prevent false operation of the relay A_2.

It will be obvious that the general principles herein disclosed may be embodied in many other organizations widely different from those illustrated without departing from the spirit of the invention as defined in the following claims.

What is claimed is:

1. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations. means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

2. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, when at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

3. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise due to external sources, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmitting medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

4. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

5. In a telephone system, a pair of terminal switching stations, a four-wide circuit comprising a transmitting line and a receiv-

ing line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

6. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise from external sources, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

7. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

8. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

9. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise from external sources, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when

voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

10. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

11. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

12. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

13. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish

connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

14. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line at the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

15. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise due to external sources, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

16. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

17. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said

transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

18. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise from external sources, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said submarine cable, said last mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said submarine cable.

19. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

20. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting line for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

21. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, the lines of said four-wire circuits being laid in cable so as to be relatively free from noise from ex-

ternal sources, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said submarine cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said submarine cable.

22. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said able, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

23. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

24. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to normally disable said transmitting lines, thereby preventing the transmission of noise thereover from

connecting lines, voice-operated means associated with said transmitting lines for rendering them operative, means associated with the receiving line at each terminal switching station to disable the corresponding transmitting line when voice currents are being received, means associated with said transmitting lines at each auxiliary station to disable the associated receiving line when the transmitting line is transmitting voice currents to said cable, said last-mentioned means being sensitive to the weak initial portions of a voice wave before it approaches its peak value, means at each terminal switching station to transform the voice current volume received from a connecting line to a substantially constant predetermined volume so that the voice currents will arrive over the transmitting lines at the auxiliary stations with substantially constant volume, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said cable.

25. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, said cable having an impedance which includes a substantially reactance component so that a relaxing current will be discharged by the cable upon the cessation of applied signaling energy, said cable also being of such dimensions that its attenuation will be so great that received signaling currents transmitted over the cable will be small as compared with said relaxing current, means at each auxiliary station to connect the terminals of said cable to said four-wire circuit so as to receive signaling currents from the transmitting line and transmit signaling currents to the receiving line, and means associated with said submarine cable to reduce the effect of the relaxing current in the receiving line of each four-wire circuit.

26. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, said cable having an impedance which includes a substantial reactance component so that a relaxing current will be discharged by the cable upon the cessation of applied signaling energy, said cable also being of such dimensions that its attenuation will be so great that received signaling currents transmitted over the cable will be small as compared with said relaxing current, a hybrid coil at each auxiliary station to connect the terminals of said cable to said four-wire circuit so as to receive signaling currents from the transmitting line and transmit signaling currents to the receiving line, and a balancing network so associated with said submarine cable and the hybrid coil as to reduce the effect of the relaxing current from the submarine cable in the receiving line of each four-wire circuit.

27. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, said cable having an impedance which includes a substantial reactance component so that a relaxing current will be discharged by the cable upon the cessation of applied signaling energy, said cable also being of such dimensions that its attenuation will be so great that received signaling currents transmitted over the cable will be small as compared with said relaxing current, a hybrid coil at each auxiliary station to connect the terminals of said cable to said four-wire circuit so as to receive signaling currents from the transmitting line and transmit signaling currents to the receiving line, and a balancing network associated with said hybrid coil and said submarine cable at each auxiliary station, said balancing network having such impedance as to produce a relaxing current of substantially the same initial value and having the same decrement as the relaxing current of the submarine cable whereby the effective relaxing current in the receiving line of each four-wire circuit will be small.

28. In a transmission system including an intermediate section connected at each end with connecting sections, means at each end of said intermediate section to block the transmission of waves in either direction while waves are passing in the opposite direction, and means at points of the connecting sections away from the end of said intermediate section to block the transmission of waves toward the intermediate section while waves are passing in the opposite direction, said connecting sections being so arranged as to permit at all times the passage of waves past the points where said last mentioned means are located in a direction away from the intermediate section.

29. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a transmission medium between said auxiliary stations, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmis-

sion of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means normally blocking the transmitting lines at the auxiliary stations, means associated with each transmitting line at each auxiliary station to clear the transmitting line for transmission and to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

30. In a telephone system, a pair of terminal switching stations, a four-wire circuit comprising a transmitting line and a receiving line extending between each terminal station and an auxiliary station, a two-way submarine telephone cable extending between said auxiliary stations, means to connect said submarine cable to receive voice currents from the transmitting line of the four-wire circuit at each auxiliary station, means to connect said submarine cable to transmit voice currents to the receiving line of the four-wire circuit at each auxiliary station, means at said terminal switching stations to establish connections between the system and connecting lines, means at said terminal switching stations to prevent the transmission of noise from connecting lines over the transmitting lines to said auxiliary stations at all times when said transmitting lines are not being used for voice transmission, means normally blocking the transmitting lines at the auxiliary stations, means associated with each transmitting line at each auxiliary station to clear the transmitting line for transmission and to disable the associated receiving line when the transmitting line is transmitting voice currents to said transmission medium, and means associated with the receiving line at each auxiliary station to disable the associated transmitting line when telephone currents are being received from said transmission medium.

In testimony whereof, we have signed our names to this specification this 3rd day of September, 1929.

GEORGE CRISSON.
SUMNER B. WRIGHT.