

March 28, 1944.

H. W. NYLUND

2,345,066

GAIN CONTROL SYSTEM

Filed June 10, 1942

2 Sheets-Sheet 1

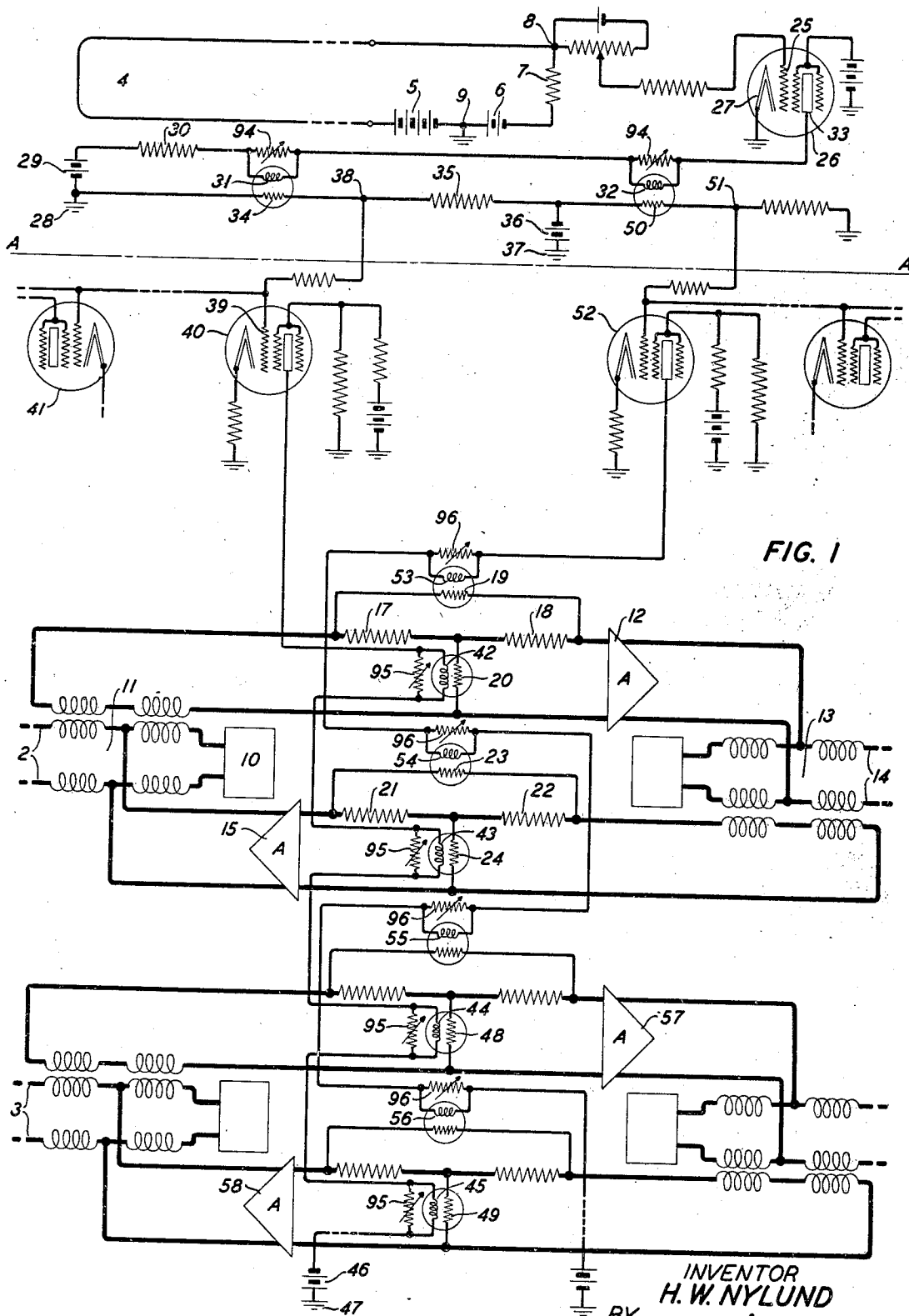


FIG. 1

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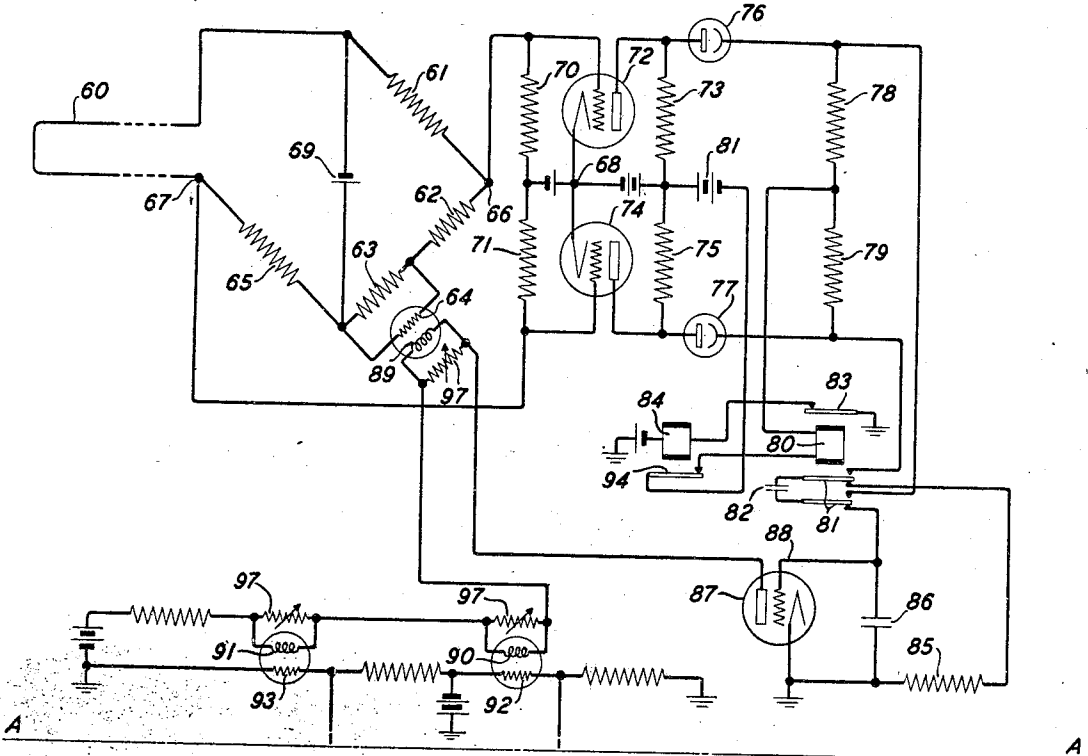
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FIG. 2



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GAIN CONTROL SYSTEM

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10 Claims. (Cl. 178-44)

This invention relates to signal transmission systems and particularly to gain regulating circuits controlled by currents transmitted over pilot wires or pilot channels.

An object of the invention is to provide a gain control system which shall be effective but sufficiently inexpensive to justify its use with systems which may provide only a few signaling channels.

Another object of the invention is to provide a gain control which may be applicable to existing systems without modification of the amplifying circuits.

An additional object of the invention is to provide a gain control system which may take advantage of the simplicity and economy of thermistors but will be free from the disadvantages occasioned by non-uniformity of their characteristics.

In accordance with the invention gain control at repeaters of a long communication or other electric wave transmission system is effected by varying the resistances of thermistors which constitute an attenuation pad inserted in the signal transmission channel in tandem with the repeater amplifier. Control of the resistance of the thermistors is had by employing as indirect heaters for the thermistors elements which are subjected to regulating currents derived from a pilot channel control circuit. This control circuit includes the pilot wire or pilot channel in such manner that the pilot wire resistance determines the regulating current output of the control circuit to the thermistors. The control circuit may be of the self-balancing bridge type, in which the resistance of the pilot wire is balanced against that of another element in the circuit, or it may be of the "forward acting" type not involving a balancing action. Thus any changes in the pilot wire resistance cause the regulating current, and thereby the thermistor resistance, to be altered so as to compensate for the attenuations experienced by the signal currents. Each thermistor is provided with a variable shunt to enable non-uniformities in the characteristics of the thermistors to be compensated.

Other features and aspects of the invention will be apparent upon a consideration of the annexed specification taken in connection with the accompanying drawings in which:

Fig. 1 illustrates a portion of a long distance cable communication system and in particular the gain control circuits at a repeater station of such a system; and

Fig. 2 illustrates a similar cable system with an alternative pilot channel control substituted for that portion of Fig. 1 above the line A—A.

Referring to Fig. 1, there is shown a portion of a telephone or similar system involving a large number of signal channels 2, 3. Each of the signal channels may consist of a pair of conductors associated with other pairs in a cable in well-known manner. Included in the cable so as to be subjected to the same ambient conditions and particularly to the same temperatures, is a pilot channel 4 preferably consisting of conductors of the same type as those constituting signal channels 2 and 3. The pilot channel comprising a loop of conductors directly connected at their remote terminals is connected in series with a steady current source 5, a second current source 6 and a local fixed resistance 7. Point 8, intermediate between resistance 7 and pilot channel 4, is connected through a biasing battery and potentiometer to the grid 25 of tube 26.

When conditions change so as to increase the attenuation over signal channel 2, for instance, it is desirable to compensate for the change. This is done in the system of Fig. 1 by means of variable impedance elements associated with the input terminals of repeater circuits which are introduced into the signal channels at intervals determined primarily by the frequency of the signal waves. For voice frequency telephone transmission systems employing cable conductors of 19 gauge these repeaters may be spaced at intervals of approximately 50 miles. Such repeaters are illustrated diagrammatically in Fig. 2 in connection with signal channels 2 and 3. Westbound currents arriving over channel 2 which terminates in a balancing network 10 are transferred over a hybrid coil 11 to the input terminals of an amplifier 12 preferably of the well-known electronic type and after amplification are impressed through hybrid coil 13 upon the outgoing section 14 of signal channel 2. In similar fashion eastbound reply signal currents arriving over section 14 are transferred over hybrid coil 13 to the eastbound amplifier 15 and after amplification are impressed over hybrid coil 11 upon the eastbound section of channel 2. This is the well-known 22 repeater arrangement.

The devices 12 and 15 may be straightforward amplifiers or they may be of the negative feedback type known as the Black amplifier and disclosed in more detail in United States patent to H. S. Black 2,102,671, December 21, 1937. Whenever type of amplifier is used there is an advan-

tage obtainable on circuits already designed or installed in using a gain control which does not require unnecessary additional range of gain over the minimum which will compensate for the varying attenuation to which the system is subject.

The gain regulation in the system of Fig. 1 is, as has been stated, effected by thermistors associated with the input terminals of the amplifiers. In the input circuit of amplifier 12, for example, there is a T-network consisting of fixed resistances 17, 18 and the thermistors 19 and 20, the former of which is in shunt to the series arrangement of resistors 17 and 18 and the latter of which is in shunt across the signal channel. It will be apparent that the signal volume may be increased by increasing the impedance of shunt thermistor 20 and decreasing the impedance of the thermistor 19 and that the signal volume may be diminished by a converse operation.

It will be understood that the amplifier 15 which functions to augment eastbound signals may be provided with a very similar input gain control pad consisting of series resistors 21, 22 and the thermistors 23 and 24. In the apparatus as illustrated the pilot channel 4 is made up of a series arrangement of conductors two of which extend east from the repeater and two of which extend west. Under those circumstances the control which it exercises is based upon conditions both east and west of the repeater station and an operation of the gain control to increase the level of westbound message currents will be accompanied by a like operation to increase the level of eastbound message currents. As an alternative which needs no illustration separate pilot channels may be provided, one extending east of the repeater and controlling westbound message currents at the input of amplifier 12 and the other extending west of the repeater and controlling eastbound currents at the input of amplifier 15.

The intermediate devices and circuits connecting the pilot channel to the gain control pad may readily be explained by tracing their operation. Suppose, for example, that after a period of normal condition the weather has suddenly become warmer, heating the cable and causing the resistance of channels 2 and 3 to start increasing with a consequent reduction in the level of the message currents. At the same time the resistance of pilot channel 4 increases. In consequence the potential of the point 8 will become more negative with respect to point 9. Consequently the grid 25 of electron discharge device 26 will become more negative with reference to its cathode 27 and the space current of device 26 by way of cathode 27, ground 28, space current source 29, fixed resistor 30 and thermistor heaters 31 and 32 to anode 33 will decrease. Lowering of temperature of heater 31 will increase the resistance of associated thermistor 34 thus decreasing the current therethrough by way of ground 28, thermistor 34, fixed resistor 35, battery 36 and ground 37. Decrease of current through resistor 35 will render less positive the potential of point 38 which is electrically connected to grid 39 of discharge device 40. In a large repeater station the incoming pairs of conductors may be arranged in quads in the cable and an electronic device such as 40 may be assigned to a small group of quads. Other electronic devices 41 similar in all respects and serving other groups of quads may have input circuits connected in parallel to that of device 40

in order to distribute the load since it would be entirely too heavy for device 40 to handle alone. Electronic device 40, as has been explained, experiences a fall in grid potential as the resistance of channels 2 and 3 begins to rise. The space current path of device 40 may be traced from the anode of the device through thermistor heaters 42, 43, 44, 45, in series, space current source 46 and ground 47 back to the cathode of the device. As the space current of device 40 decreases the temperatures of the series thermistor heaters fall and the resistances of the associated thermistors 20, 24, 48 and 49 rise.

The raising of the temperature of the pilot channel 4 has been shown to increase the resistance of thermistor 34 and to consequently render less positive the potential of point 38. Simultaneously the resistance of thermistor 50 will also increase and the potential of point 51 will become more positive increasing the space current of electronic device 52 and the temperature of the thermistor heaters 53, 54, 55 and 56, the net result of the operation is that the resistances of the series arm thermistors decrease and the resistances of the shunt arm thermistors increase thus reducing the attenuation of the input circuit pads associated with amplifiers 12, 15, 57 and 58 to an amount sufficient to restore the level of the impressed input signal waves to its former magnitude.

Thermistors are described in an article by G. L. Pearson at page 106 of the Bell Laboratories Record for December 1940. These devices are small and stable and their use is attended with considerable economy over elaborate moving contact elements and auxiliary amplifiers of the prior art. It will be appreciated, however, that small variations which may occur in the manufacture of such devices may produce enormous changes in their resistance characteristics. For example, as indicated in Fig. 6 of the Pearson article a reduction of the heater current from 12.5 milliamperes to 10 milliamperes amounting to a decrease of 20 per cent in the heater current is attended with an increase in resistance of several hundredfold. Since the non-linearity of the resistance characteristics of thermistors is so very pronounced, the problem of using these inexpensive devices with their heating elements in series in the same regulating circuit may impose severe requirements upon their manufacture in order to attain the necessary uniformity in individual performance of the thermistors. Applicant has discovered, however, that the requirements with respect to uniformity may be met by the use of thermistors of the same general type by an expedient which in effect enables the characteristics of the thermistors to be shifted laterally so that they may be superposed. In other words the characteristics of two thermistors of the same general type may be made to appear substantially identical over an extensive useful working range by assigning to each the proper heating current. With this principle in mind the invention proceeds to utilize indirectly heated thermistors of considerably varying characteristics to serve interchangeably and to operate even in series arrangement by providing each thermistor heater with a variable resistance shunt which may be set to so divide the regulating current between the variable shunt and the thermistor heater as to cause the thermistor to operate with an effective characteristic substantially identical with that of each of the others. This expedient therefore makes prac-

licable the use on an extended scale of inexpensive regulating elements which can function with the same precision and effectiveness as are obtainable from thermistors of uniform characteristics which would otherwise be very much more costly to provide. In accordance with this principle the heaters 31 and 32 of thermistors 34 and 50 are provided with variable resistor shunts 94 which enable the two thermistors to be controlled in series by the space current of electronic device 26. In like manner the thermistor heaters 42 to 45, inclusive, are each shunted by a variable resistor 95 and the thermistor heaters 53 to 56, inclusive, are each shunted by a variable resistor 96. It is therefore possible to regulate a large number of circuits simultaneously with a precision which could be otherwise had only at large additional cost.

Fig. 2 illustrates an alternative system which differs from that of Fig. 1 only in the part above the broken line A—A. A pilot channel 60 constitutes one arm of a Wheatstone bridge of which the other three arms are, respectively, a fixed resistor 61, fixed resistors 62 and 63, the latter shunted by thermistor 64, and a fixed resistor 65. Under normal conditions the bridge is balanced and there is no potential difference between the conjugate points 66 and 67 across which the input path of a push-pull electronic amplifier 68 is connected. Upon variation of the temperature of pilot channel 60, its resistance changes and the bridge becomes unbalanced. Source 69 will therefore set up a difference of potential across points 66, 67 causing current to flow through the series resistors 70, 71 of the input circuit of amplifier circuit 68. Assuming that the change is in such direction as to cause the grid of electronic device 72 to become more negative with reference to its cathode, the space current of the device 72 will diminish as will also the potential difference across the resistor 73 in the output circuit of the tube 72. At the same time the grid of tube 74 will tend to become more positive with reference to its cathode the space current flowing through resistor 75 and the potential difference across that resistor will increase. Associated with the resistors 73 and 75 are gas discharge devices 76 and 77 which are connected through resistors 78 and 79, respectively, and the winding of relay 80 to a current source 81. Under normal conditions with the Wheatstone bridge balanced and with normal space current flowing through tubes 72 and 74, the potential drop across resistor 73 is substantially equal in magnitude to the electromotive force impressed by the opposing source 81 upon discharge device 76. Likewise, the potential difference across resistor 75 substantially balances the electromotive force impressed by the source 81 upon discharge device 77. Under these circumstances the devices 76 and 77 remain inactive. Assuming, however, as we previously have done, that the space current through resistor 73 has sufficiently decreased the effective potential impressed across the terminals of discharge device 76 by source 81 will rise to such a point that discharge takes place through device 76 energizing relay 80. Energization of the relay 80 causes operation of its armatures 81 to move from their fixed right-hand contacts into engagement with their left-hand contacts to cause condenser 82 to be charged in consequence of the difference of potential existing between the outer terminals of resistors 78 and 79. Simultaneously therewith the armature 83 of the relay 80 is actuated inter-

rupting the local circuit of slow release relay 84. After a short period determined by the characteristics of slow release relay 84 the normally actuated armature 94 of the relay 84 is released, thus interrupting the energizing circuit of the relay 80 and the discharge of the gas discharge device 76. The deenergization of relay 80 permits armatures 81 and 83 to fall back to their initial positions as shown in Fig. 2. The transfer of the armatures 81 from engagement with their left-hand contacts to their right-hand contacts connects the charged condenser 82 through a series resistance element 85 to a charge integrating capacitor 86 connected across grid cathode circuit of a triode 87. As soon as the armature 83 closes the circuit of the slow release relay 84 and the armature 94 of the latter is moved into engagement with its contact the potential across the discharge device 76 is again built up and another discharge takes place during which the condenser 82 is again connected across the terminals of resistors 78 and 79 receiving another charge. This process continues, the condenser 82 transferring the charge to the condenser 86 step by step while the potential of the charged condenser 86 builds up. As the charge of the condenser 86 increases the potential of the grid 88 of the triode 87 changes in such manner that the space current of the triode 87 passing in series through the thermistor heaters 89, 90 and 91 changes the temperature and consequently the resistances of the associated thermistors. Finally a point is reached at which the resistance of thermistor 64 is so changed that the Wheatstone bridge including the pilot channel 60 is again balanced. When that point is reached the bridge remains balanced, the difference of potential condition across tube 76 ceases, and the intermittent charging and discharging of the tube 76 stops. The rebalancing of the bridge 60 by the change of resistance of the thermistor resistor 64 is accompanied by a simultaneous and similar change in the resistances of the thermistors 92 and 93, the heaters 90 and 91 of which are in series with the heater 89. The thermistors 92 and 93 correspond respectively to thermistors 50 and 34 of Fig. 1 and their effect upon the remaining gain control apparatus of the system will be readily understood without further explanation.

In the event that the temperature of the pilot channel 60 changes in the opposite direction from that which has just been described, the Wheatstone bridge will become unbalanced in an opposite manner to cause the grid of tube 74 to become more negative with reference to its cathode and to initiate an intermittent discharging operation of the gas discharge device 77. Under these circumstances the condenser 82 will be charged as before by connection across the outer terminals of resistors 78 and 79, but the charge will be of opposite polarity. The space current of the triode 87 will accordingly change in a direction opposite to that previously described and so likewise will the magnitude of the resistance of thermistor 64. When the Wheatstone bridge is finally balanced the discharging operation through gas tube 77 ceases. The remaining elements of the gain control system will be identical with those below line A—A of Fig. 1 and their operation will therefore be understood without additional explanation.

As in the circuits of Fig. 1 the heaters of thermistors 64, 90 and 91 are each shunted by a variable resistor 97.

What is claimed is:

1. In combination, a plurality of circuits each including an individual thermistor of an indirectly heated type, a heating circuit in which are connected electrically in series heaters for each of the thermistors and means for adjusting the characteristics of the thermistors to impart substantially identical response characteristics to each whereby current of given magnitude in the heating circuit will give rise to substantially equal changes in the resistances of the thermistors of the plurality of circuits.

2. A transmission system comprising a repeater station, a number of channels having conductors which follow a given route to the repeater station and are subject to variations in impedance, a pilot channel associated with the conductors and subject to similar variations in impedance, a circuit electrically separated from the pilot channel and including a thermistor, a heater for said thermistor electrically connected to the pilot channel so that the heating current supplied to the heater and the thermistor impedance varies with variations in the pilot channel impedance, a plurality of amplifiers each serving an individual group of conductor pairs, means under the control of the thermistor for varying the gain of each amplifier and an individual thermistor connected to the plate circuit of the respective conductor group control amplifier for each controlled pair of the group of conductor pairs.

3. A plurality of communication channels each including an amplifier and each subject to variations in attenuation in accordance with ambient atmospheric conditions, an individual variable attenuator including a temperature responsive device connected to each channel, a common control circuit for heating each of said devices to control the attenuations of the various channels in accordance with ambient atmospheric conditions and means for adjusting the temperature-responsive devices whereby their characteristics may be made substantially identical.

4. Means for regulating transmission levels at the repeater of a communication system comprising a relatively long communication line, an attenuation pad connected thereto having series and shunt arms each including thermistors, means for varying the temperature of each thermistor in accordance with variations in the impedance of the line and individual shunt variable impedances connected across the terminals of the thermistors to equalize the irregularities of the thermistors.

5. A transmission line having variable attenuation characteristics, a variable attenuator connected thereto, a control pilot conductor extending in the region of the transmission line so as to be subject to the same ambient conditions as the line, two sources of electromotive forces and a relatively invariable resistance element all in series with the pilot conductor whereby the series current is controlled by the resistance of the pilot conductor and that of the resistance element and means connected between the junction of the two sources of electromotive force and a point on the resistance element and responsive to the potential between the junction and the point to vary the attenuation of the variable attenuator in such manner as to compensate for variable attenuation of the transmission line.

6. A communication system comprising a signaling channel extending to a repeater station, a pilot conductor likewise extending to the repeater station, an electron discharge device hav-

ing its input terminals connected across a resistance in series with the pilot conductor and its output terminals connected in series circuit with the heater elements of a pair of thermistors, a local source of current, two parallel paths connected to said source and each including one of the heaters of said pair and an individual resistance element, the resistance element of one path being electrically adjacent one terminal of the source and that of the other path being electrically adjacent the other terminal of the source, a pair of electron discharge devices having control elements respectively connected to the parallel paths at the junction point between the resistance and the heated thermistor whereby when the potential of one of said junction points rises that of the other falls, a second pair of thermistors having heaters connected respectively in the space current paths of said pair of electron discharge devices and having variable resistance thermistor elements heated thereby connected respectively in series with the signaling channel and in shunt to the signaling channel.

7. A Wheatstone bridge, an extended pilot channel subject to resistance variations in consequence of varying ambient conditions constituting one of the arms of the bridge, a thermistor connected to a second arm of the bridge, two resistance elements in series connected across one pair of diagonally opposite terminals of the bridge, a gas-filled tube connected across each resistance element, a source of electromotive force connected across the conjugate pair of diagonally opposite terminals of the bridge, the circuits of the tubes and the magnitudes of the resistances being so related that when the bridge is balanced with respect to the source of electromotive force the tubes are in non-discharging condition and when the bridge is unbalanced one of said tubes will discharge and means controlled by the discharge of either tube for varying the heating energy supplied to the thermistor to tend to rebalance the bridge.

8. In combination, a plurality of signal channels, a pilot conductor extending in the same region whereby its resistance is subject to the same ambient conditions as affect the signal channels, a Wheatstone bridge of which the pilot channel constitutes one arm, a thermistor connected to a second arm of the bridge, two series resistance elements connected across a pair of diagonally opposite terminals of the bridge, a source of electromotive force connected across the conjugate pair of diagonally opposite terminals, a gas-filled tube connected across each resistance element, the circuits of the tubes and the magnitudes of the resistances being so related that when the bridge is balanced with respect to the source of electromotive force the tubes are in non-discharging condition and when the bridge is unbalanced one of said tubes will discharge and means controlled by the discharge of either tube to simultaneously vary the heating energy supplied to the bridge thermistor and the attenuation of each signal channel.

9. A plurality of signaling channels extending through the same region and experiencing similar attenuations, a pilot channel extending through the region, an electron discharge device having an input circuit connected to the pilot channel and an output circuit connected to two thermistor heaters in series, a circuit including the corresponding variable thermistor elements controlled by the heaters each in series with a relatively fixed resistor and a source of electro-

motive force, a pair of electron discharge devices each having an input electrode connected to a point between one of the fixed resistors and the respectively associated thermistor, series impedance elements connected in each of said signaling channels, shunt impedance elements connected across each of said signaling channels, and means connecting the series impedance elements to the output of one of the electron discharge devices and the shunt impedance elements to the other electron discharge device.

10. A plurality of signaling channels, the impedances of which undergo similar variations with change in ambient temperature, a corresponding plurality of thermistors respectively

5 connected to said channels to compensate for variations in impedance thereof, each of said thermistors having an individual electric heating element, the thermistors having similarly shaped but differing magnitude characteristics relating thermistor resistance to heater current and a variable resistor shunted across each of said thermistor heating elements of such a magnitude that the heater elements may be connected in series in the same circuit and the resistors so adjusted that the resulting thermistor resistance characteristics are substantially identical for any given current in the series circuit.

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