

May 1, 1934.

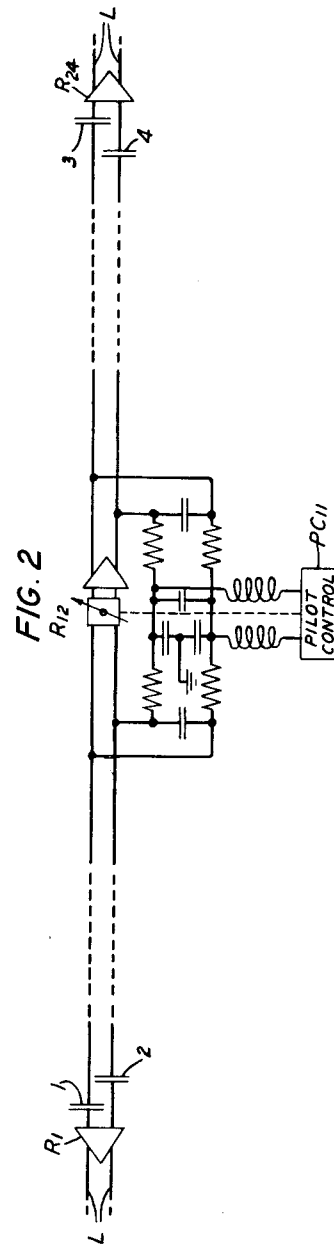
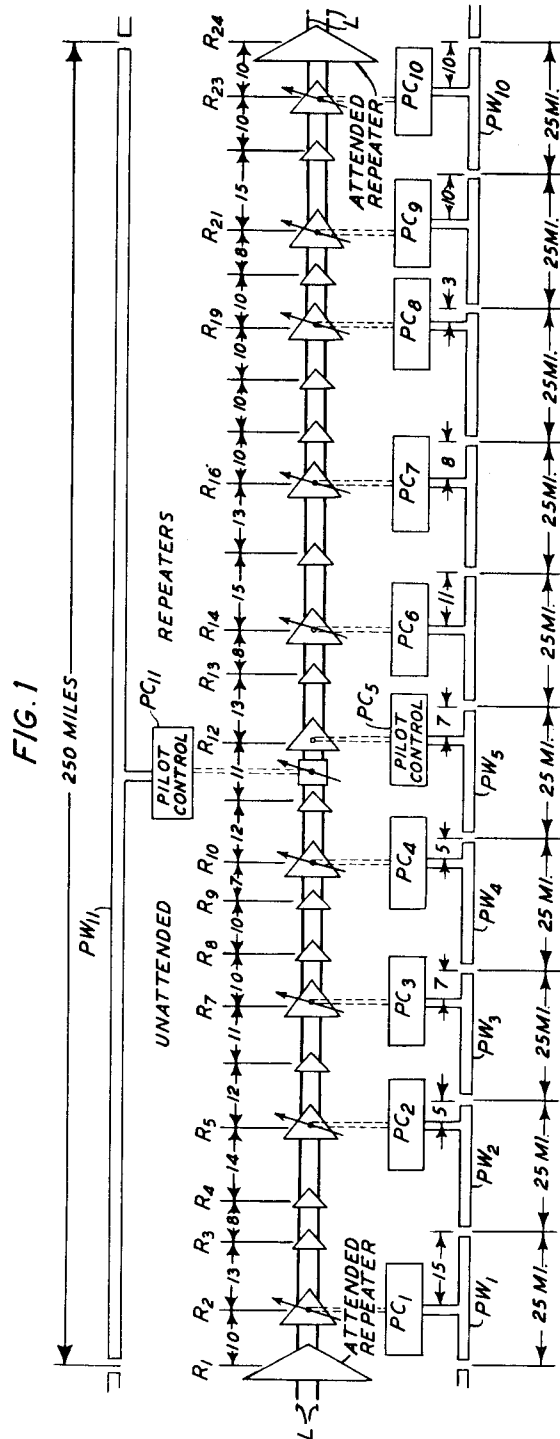
H. S. BLACK

1,956,547

REPEATED TRANSMISSION SYSTEM

Filed Aug. 11, 1932

4 Sheets-Sheet 1



INVENTOR  
H. S. BLACK  
BY  
H. A. Burgers  
ATTORNEY

May 1, 1934.

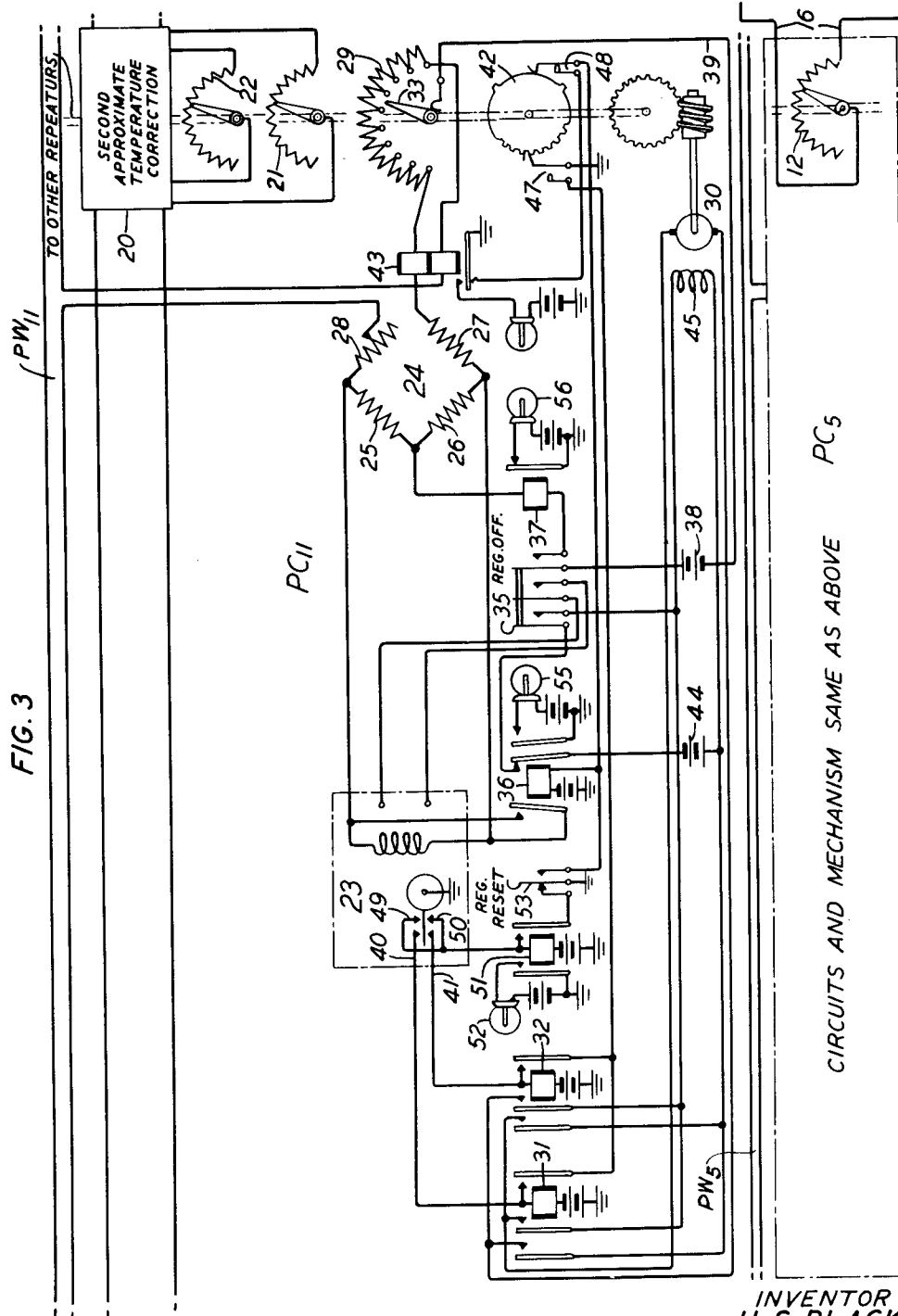
H. S. BLACK

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REPEATERED TRANSMISSION SYSTEM

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4 Sheets-Sheet 2



INVENTOR  
H. S. BLACK  
BY  
J. A. Burgess  
ATTORNEY

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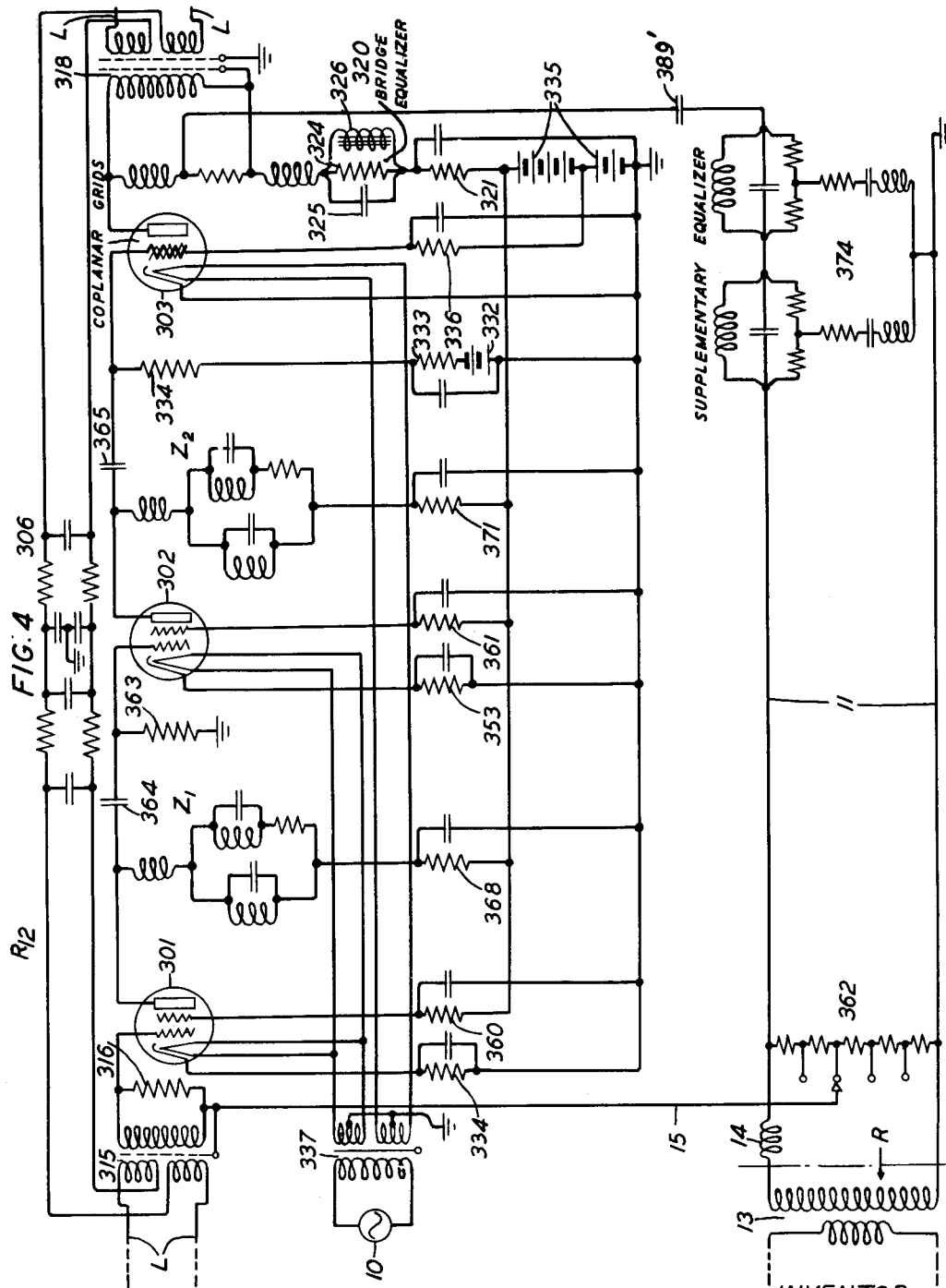
H. S. BLACK

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REPEATED TRANSMISSION SYSTEM

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4 Sheets-Sheet 3



INVENTOR  
H. S. BLACK  
BY  
*H. A. Burgess*  
ATTORNEY

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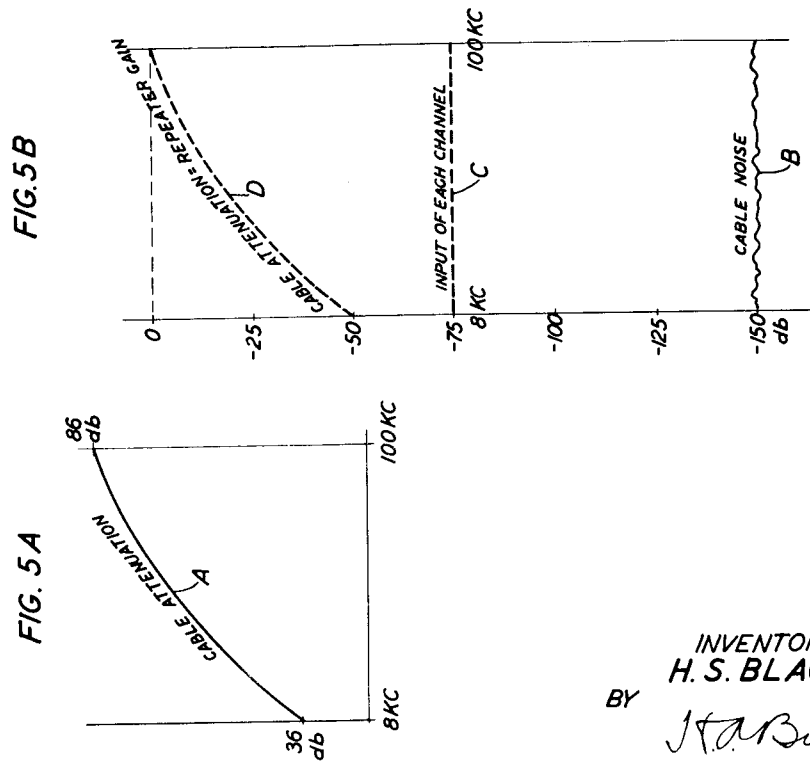
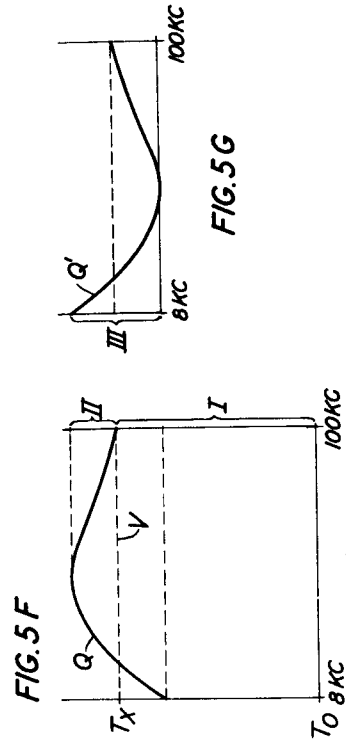
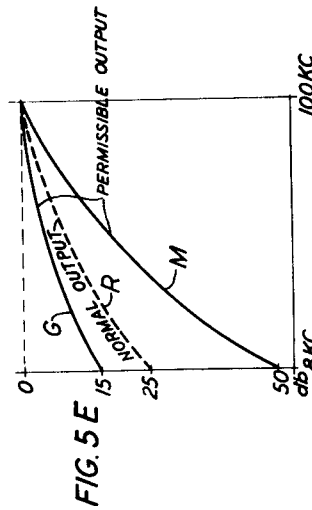
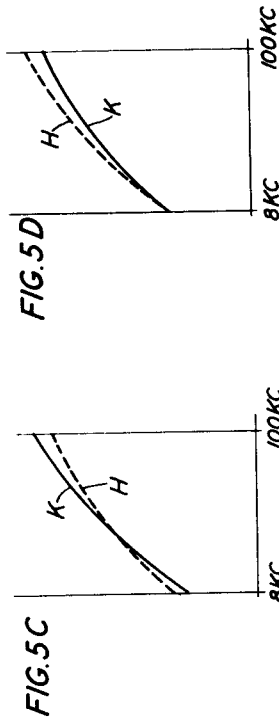
H. S. BLACK

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REPEATED TRANSMISSION SYSTEM

Filed Aug. 11, 1932

4 Sheets-Sheet 4



INVENTOR  
H. S. BLACK  
BY  
J. A. Burgess  
ATTORNEY

## UNITED STATES PATENT OFFICE

1,956,547

## REPEATERED TRANSMISSION SYSTEM

Harold S. Black, Westfield, N. J., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application August 11, 1932, Serial No. 628,400

8 Claims. (Cl. 178—44)

The present invention relates to the transmission of a wide range of frequencies over long lines having repeaters intermediate the terminal stations, one example being multiplex carrier telephone transmission over a telephone cable with tandem repeaters at intervals in each line.

In such a system using frequencies extending up to the order of 100 kilocycles or higher, it is necessary or advantageous to place the line repeaters at much shorter intervals than in the case of ordinary voice repeaters. While the maintenance of continuous high-grade service in such a system could be achieved by having a sufficient number of attendants to exercise immediate and constant supervision over all of these repeaters, this would be prohibitive from the cost standpoint in many situations.

It is an object of the present invention to provide regulation at repeater points by means which are to a large extent automatic in operation and do not require constant personal supervision.

In a system of the character described, one variable that requires to be compensated for is the changing resistance of the line with temperature change. Even in the case of underground cable, the seasonal change in transmission characteristic due to this cause may amount to the order of 100 decibels in a 1,000 mile cable. In the case of aerial cable, the variations in temperature may occur 800 times as rapidly and the total change in transmission characteristic may be three times as great as in the case of underground cable. The change in characteristic from this cause is not linear with frequency, but in general is greater at the higher frequencies in the range 8 to 100 kilocycles.

One feature of the invention comprises a simplified and economical method and means of effecting accurate compensation for such changes in transmission characteristic.

The invention includes various other and related features which will appear more fully from the following detailed description of a typical system in accordance with the invention, reference being had to the accompanying drawings in which:

Fig. 1 shows in schematic diagram a general layout of a system in accordance with the invention comprising a large number of repeaters; Fig. 2 shows a modification of Fig. 1;

Figs. 3 and 4 placed together with Fig. 3 at the left and Fig. 4 at the right show a complete regulating repeater station, the regulator being on Fig. 3 and the associated repeater on Fig. 4; and

Figs. 5—A to 5—G, inclusive, show curves illustrative of the operation of the invention.

If a long transmission line were made up of identically similar sections and an automatic regulator were provided which would compensate for variations in attenuation of the line with temperature or other variables, the apparatus design would be simplified since it would merely be necessary to supply one type of equalizer and compensating network to be installed in all of the regulating repeater stations.

This rarely happens in practice, however. A typical transmission line is made up of repeater sections of unequal electrical length as is indicated, for example, in Fig. 1 where the line L is shown provided with 24 repeaters averaging approximately 10 miles apart but actually varying in separation from 7 miles to as high as 15 miles. In the total distance between repeaters  $R_1$  and  $R_{24}$ , of about 250 miles, 10 of the repeaters are made regulating repeaters and are so chosen that their average spacing is about 25 miles. The actual distances between adjacent regulating repeaters in the example given, however, vary from 18 miles between ( $R_{19}$  and  $R_{21}$ ) and 35 miles between ( $R_2$  and  $R_5$ ).

While it might be possible either by calculation or by empirical trial to design a separate regulating system for each one of the regulating repeaters such that it would accurately compensate for temperature variations appearing in each respective repeater section, this would be a costly procedure and would involve the design of much special apparatus.

One of the objects of the present invention is to economize in the design and construction of special apparatus in a system such as that illustrated in Fig. 1 where the repeater sections are of diverse electrical characteristics.

In accordance with one feature of the invention, an approximate compensation for temperature variations is made at each one of the regulating repeater stations and the actual amount of compensation that is made at each of these stations may be the same, thus enabling the use of but one type of regulator for this approximate compensation at each of the repeaters. A more accurate compensation is then effected by the use of a second-approximation compensation at less frequent intervals along the line, for example, once every 250 miles as is indicated in Fig. 1.

In order to effect the approximate regulation, pilot controls  $PC_1$  to  $PC_{10}$  are provided for the regulating repeaters  $R_2$ ,  $R_5$ ,  $R_7$ ,  $R_{10}$ ,  $R_{12}$ ,  $R_{14}$ ,  $R_{16}$ ,  $R_{19}$ ,  $R_{21}$  and  $R_{23}$ , respectively. Each of these

pilot controls is associated with a corresponding pilot wire  $PW_1$  to  $PW_{10}$ . All of these pilot wires are of equal length, that is, 25 miles in the example under discussion, so that the total 250 mile span is divided into ten parts as far as the pilot wires are concerned. The terminals for each pilot wire are brought out as near as practicable at the center of the 25 mile span but in the example of Fig. 1 it is impossible in any case to bring the terminals out at exactly the middle of the pilot wire, the actual position of the leads being from 3 miles to 11 miles from the end of the loop.

In order to effect the second-approximation compensation, a long pilot wire, 250 miles long,  $PW_{11}$ , is shown with pilot control  $PC_{11}$  associated with the regulating repeater  $R_{12}$  near the center of the 250 mile span.

While the invention is applicable to any suitable type of transmission line, it will be described in connection with a telephone cable in which a large number of conductors are included within the same lead sheath. The pilot conductors  $PW_1$  to  $PW_{11}$ , inclusive, are also pairs of wires included in the same cable sheath and subject to the same temperature variations as the signaling conductors themselves, one pair of which is shown at L of Fig. 1.

The nature of the pilot control apparatus as well as of the regulating repeaters and the manner in which the first-approximation and second-approximation compensating adjustments are made, will be described more fully in connection with Figs. 3 and 4 and the curves of Fig. 5.

Fig. 1 shows two attended stations  $R_1$  and  $R_{24}$  and twenty-two unattended repeater stations  $R_2$  to  $R_{23}$ . The numerical values that have been given in connection with Fig. 1 are to be taken as merely illustrative and not as in any wise limiting. The regulating may, of course, be done at an attended station as well as at an unattended repeater station. Also Fig. 1 shows a large number of unattended repeater stations partly in order to illustrate a considerable range of lengths of repeater sections. In practice there may be no unattended stations at all or possibly only one or two, between attended stations. The 250 mile span for the second-approximation adjustment is reasonable for buried cables and, in fact, this span may probably be considerably longer, say 375 miles, whereas for aerial cables the span would perhaps be 125 miles for the second-approximation adjustment.

It may not always be possible or convenient to provide a long pilot wire  $PW_{11}$  in a cable in addition to the short pilot wires. For example, in applying the invention to existing voice frequency cables, there may be no pair of wires available for pilot wire purposes as long as 100 miles or so or long enough to serve for pilot wire  $PW_{11}$ . In such case, the arrangement illustrated in Fig. 2 may be used.

In Fig. 2, the line L is used not only for message transmission but is also composited to serve as pilot conductor. For this purpose, the line between the output of repeater  $R_1$  and the input of repeater  $R_{24}$  is segregated as a direct current circuit by use of the series condensers 1, 2, 3, 4. Ordinarily the repeaters in the line, such as  $R_{12}$  will be provided with a direct current by-pass as will be indicated more clearly in connection with Fig. 4. The pilot control  $PC_{11}$  is then connected across a point in the by-pass around the repeater, or if there is no direct current by-pass it may be connected to points on each side of the repeater

across the line L. In either event the pilot control  $PC_{11}$  measures the direct current resistance of the length of line L between repeaters  $R_1$  and  $R_{24}$  and adjusts the characteristic of repeater  $R_{12}$  in such a way as to compensate for changes in resistance of the circuit, due, for example, to changes in temperature. It is assumed in connection with Fig. 2 that the short pilot wires  $PW_1$  to  $PW_{10}$ , inclusive, of Fig. 1 are present and operate in the manner described in connection with Fig. 1.

Referring now to Figs. 3 and 4, a description will first be given of the repeater in Fig. 4.

This repeater may be identical with that shown in Fig. 65 of my prior application, Serial No. 606,871 filed April 22, 1932, and reference may be made to that application for a fuller disclosure of the circuit, its mode of operation, the circuit constants, etc. In order to facilitate reference to the previous application disclosure, similar reference characters are used on the drawing of the present figure.

In Fig. 4 two screen grid tubes 301 and 302 in tandem feed into the third stage 303 comprising a tube having coplanar grids. Tubes 301 and 302 are impedance-coupled by means of series condenser 364, shunt resistance 363 across the grid circuit of tube 302 and impedance generally indicated at  $Z_1$  across the plate circuit of tube 301. Similarly, for tubes 302 and 303 there is a series condenser 365, shunt grid resistance 334 and shunt plate impedance  $Z_2$ . The amplifier as a whole is inserted between two sections of line L, L by input transformer 315 and output transformer 318. A direct current by-pass 306 is shown connecting the sections of L, L independently of the repeater.

The tubes 301, 302 and 303 have indirectly heated cathodes for which the heating current is derived from source 10 through transformer 337. Plate potential is supplied to all of the tubes from battery 335, through impedance  $Z_1$  and resistance 368 in the case of tube 301; through impedance  $Z_2$  and resistance 371 in the case of tube 302; and through resistance 321 and the bridge equalizer 320 in the case of tube 303. Screen grid potential is supplied from this same battery through resistance 360 in the case of tube 301 and through resistance 361 for tube 302. Negative grid bias for tubes 301 and 302 is provided by the voltage drop across resistances 334 and 353, respectively. Positive bias for one of the coplanar grids of tube 303 is derived through resistance 336 from battery 335 while negative bias for the other coplanar grid is derived through resistances 334 and 333 from battery 332. Condenser by-passes around all of these resistances that have been mentioned in the various supply leads are provided, leading to ground, so that coupling between the tubes is prevented for frequencies within the signaling band and higher frequencies by way of the voltage supply sources and resistances.

The amplifier is provided with a feed back circuit generally indicated at 11 connecting the plate of the last tube with the grid of the first tube and feeding back a relatively large amount of waves in the signal frequency band so as to reduce the gain of the amplifier as a whole. This circuit 11 also includes a bridge equalizer 320 and a supplementary equalizer 374 so that the high frequencies fed back are attenuated more than the low frequencies. These equalizers are designed with reference to the line L, so as to have substantially the same attenuation-frequency characteristics as the line. Assuming that the attenuation of

the line L at 100 kilocycles is 20 decibels greater than at 8 kilocycles the feedback 11 due to the equalizer design causes the gain of the amplifier to be 20 decibels less at 8 kilocycles than at 100 5 kilocycles. Similarly, for frequencies between the two limits of the band, the gain of the repeater is proportional to the attenuation at those frequencies so that the unequal attenuation of the line is completely compensated for.

10 Reference may be made to my prior application above referred to for actual design data and a more complete disclosure of the mode of operation of the amplifier circuit as a whole. As pointed out in that application, the feeding back 15 of a large amount of the output wave in such a way as to reduce the overall gain of the amplifier results in several advantages, among which are increased stability of the amplifier as regards variation in voltage supply, tube characteristics 20 and other variables, and a great reduction in the level of modulation produced in the amplifier.

The equalizers 320 and 374 are preferably of the co-called constant resistance type disclosed in Stevenson Patent 1,606,817, November 16, 1926 25 and Zobel Patent 1,603,305, October 19, 1926. In order to have the proper attenuation-frequency characteristic or slope the equalizers 326 and 374 must be designed properly with respect to their terminating impedances. The internal 30 plate resistance of tube 303 is the terminating resistance on one side of the equalizer, whereas the circuit 11 to the left of equalizer 374 in the drawings, makes up the other terminating impedance. It is found that if a large amount of feed- 35 back is used such as to reduce the gain of the amplifier by a large amount, the internal resistance of tube 303 may vary widely without seriously affecting the slope or shape of the attenuation-frequency characteristic of the equalizer.

40 The circuit is arranged, as will be more fully described, so that the terminating resistance at the left of equalizer 374 in the drawings may be varied so as to change the gain of the amplifier. This is done by varying a resistance 12, Fig. 3, 45 which, by virtue of transformer 13, is effectively in the circuit 11.

Under the conditions assumed, that is, with a large amount of feedback so as to reduce the amplifier gain by a large amount, variation of resistance 12 changes the gain of the amplifier for 50 all of the frequencies in the total band equally without changing the slope of the attenuation-frequency characteristic.

As was stated, this repeater is adapted to be 55 used in a system such as is shown in Fig. 1, where the length of the repeater section may vary quite considerably so that the amplifier gain, for, say, the highest frequency transmitted may be quite different in one repeater from that of another. 60 The shunt resistance 362 across the feedback circuit 11 is provided with taps so that the proportion of the voltage across the feedback circuit 11 that is applied to the grid of tube 301 may be varied by changing the setting of the contact 65 along the movable taps. When the amplifier is being installed at a given repeater point the lead 15 is connected to the tap on resistance 362 which gives the repeater the proper gain for the highest frequency to be transmitted, this being the frequency of highest line attenuation. This adjust- 70 ment may then remain fixed.

The use of transformer 13 facilitates the association of a large number of repeaters with a common gain control mechanism such as is disclosed in Fig. 3. Some or all the repeaters may 75

be located at a considerable distance away from the gain control apparatus, requiring leads of considerable length between the repeaters and the resistances 12 in the pilot control panel. Because of singing difficulties the impedance R looking to the left in Fig. 4 must be kept as nearly as practicable a resistance and, in particular, must not be shunted by capacity. The distributed capacity across leads 16, which may be of considerable length, is minimized in its effect by 85 employing a high ratio transformer 13 with its low winding connected across circuit 16 so that a comparatively small value of resistance 12 is equivalent to a large resistance across circuit 11. A radio frequency choke coil 14 aids in protecting 90 the circuit against singing at frequencies above the transmission range.

It is advantageous to proportion the circuit so that at the lowest temperature at which the line L is operated the resistance R, Fig. 4, is from five 95 to ten times as large as the internal plate impedance ( $R_o$ ) of the final tube 303. As the temperature of the line L increases and its resistance therefore increases so that it is necessary to increase the gain of the repeater, this is done 100 by decreasing the amount of feedback, that is, by decreasing resistance 12 which is in effect shunted across the feedback circuit 11.

Resistance 362 should be large compared to resistance R while resistance 316 should be large 105 compared to resistance 362.

The control of the gain of the repeater by varying resistance 12 in the manner that has been described above, effects the first approximation adjustment of the repeater, that is, the adjustment that is controlled by the 25 mile pilot wire 110 loop. In order to effect the second approximation or more accurate adjustment it is preferred to place in series in the line L ahead of the repeater a network 20 the constants of which may 115 be adjusted under control of the long pilot wire so as to increase or decrease the attenuation in series in the line L throughout the frequency range being utilized. The network 20 is preferably a constant resistance type of network such 120 as is disclosed in the Stevenson and Zobel patents above referred to. It is necessary for the attenuation-frequency characteristic of this network 20 to vary non-uniformly over the total frequency range for uniform variations in temperature of 125 the line L. This is for the reason that the relation between attenuation of line L and temperature is not uniform throughout the frequency range from 8 to 100 kilocycles. Either by calculation or by empirical trial a network 20 can be 130 constructed to fit any particular case such that by varying a sufficient number of the resistances in the network a suitable succession or family of characteristic curves is obtainable for different temperatures of line L so as accurately to correct 135 for the variation in attenuation of the line with temperature changes over the entire frequency range. The type of automatic temperature compensator to be described lends itself to the simultaneous control of any number of resistances for 140 a network 20 but it will be assumed for purpose of the present disclosure that the necessary changes in attenuation of the network 20 can be obtained by controlling simply two resistances 21 and 22. These resistances are controlled by 145 the pilot control PC<sub>11</sub> which is connected to the pilot wire PW<sub>11</sub>.

The resistances 21 and 22 are varied by means of a shaft driven from motor 30 through suitable reduction gearing, motor 30, in turn, being con- 150

trolled through the medium of either relay 31 or relay 32 from contacts of galvanometer 23. Galvanometer 23 is connected across the diagonals of a Wheatstone bridge 24 comprising fixed resistance arms 25 and 26 and two other arms 27 and 28. Arm 28 is made up of an adjustable resistance 28 in series with the pilot conductor line  $PW_{11}$ , also a variable portion of resistance 29, the portion of which is included in the bridge arm depending upon the position of the contact arm 33. Arm 27 is made up of a fixed resistance and the remainder of resistance 29 that is not included in arm 28. The battery diagonal for bridge 24 includes the windings of relay 37, contacts of key 35, battery 38 and lead 39 to the movable arm of resistance 29, key 35 being closed when the regulator is conditioned for operation.

The bridge is normally set to be balanced when the pilot wire  $PW_{11}$  has its lowest operating temperature and arm 33 is positioned to remove all of resistance 29 from bridge arm 27. In this condition, resistances 21 and 22 cause the network 20 to have its maximum attenuation. An increase in the temperature of pilot conductor  $PW_{11}$  unbalances the bridge and causes galvanometer 23 to make contact with one or the other of its two normal contacts 40 or 41. At this time, relay 36 may be assumed to be operated by a circuit from ground at the lower armature of relay 43 and normally closed spring contact 48 of centering cam 42 so that the shunt across the galvanometer 23 is open at the left armature and back contact of relay 36 while the right-hand armature of relay 36 connects battery 44 across the field winding 45 of motor 30 and prepares a circuit for the armature of this motor to be completed through contacts of relay 31 or 32 when the galvanometer 23 is deflected.

If the galvanometer is deflected in the direction to close contact 40, relay 31 is energized causing motor 30 to rotate in the proper direction to restore bridge 24 to a balanced condition by movement of arm 33 on resistance 29. As soon as cam 42 starts to move in response to the starting up of motor 30, the centering spring contacts 47 are closed holding relay 31 locked so that motor 30 continues to rotate until the arm 33 is moved off from one contact and on to the center of its next contact at which time springs 47 are opened and relay 21 is allowed to fall back opening the circuit of the armature of motor 30, if at this time galvanometer 23 has opened contact 40 so that no further movement of the motor results. The movement of the shaft controlling arm 33 of course also moves the arms that change resistances 21 and 22 thereby decreasing the attenuation of network 20 a suitable amount to correct for the increase in temperature assumed to have taken place in pilot wire  $PW_{11}$  and also line L. For successive increases in temperature, the pilot control  $PC_{11}$  operates in a similar manner to decrease the attenuation in network 20. For a decrease in temperature the galvanometer 23 is caused by the bridge unbalance to close contact 41 energizing relay 32 which operates in a manner entirely analogous to that described for relay 31 to cause motor 30 to rotate in the opposite direction such as to restore the balance of bridge 24 and adjust resistances 21 and 22 in a direction to increase the attenuation of network 20.

Various alarms are provided for notifying an attendant when the pilot control is not properly operating. If a major unbalance of the bridge occurs such as to cause galvanometer 23 to con-

tact with either contact 49 or 50, relay 51 is energized causing lamp 52 to light to notify the attendant and locking up over reset key 53. If the arms which control resistances 21, 22 and 29 have moved to either limit of their adjustment, cam 42 causes springs 48 to open and release normally energized relay 36 which places a protective shunt at its left armature and back contact across the galvanometer 23 and at its right contact opens the circuit for motor 30 from battery 44. A third armature on relay 36 causes lamp 55 to light. If battery 38 fails to apply suitable operating voltage to the battery diagonal of bridge 24, relay 37 releases causing lamp 56 to light. If the unbalance becomes still greater than sufficient to light lamp 52, for example, twice as great, relay 43, which is a differential relay is caused to operate lighting lamp 27 and also breaking the normal circuit for relay 36 which operates as already described.

Pilot control  $PC_5$  operates in a manner entirely analogous to that described of  $PC_{11}$  except that it is controlled from a short pilot wire  $PW_5$  and controls resistance 12.

In a cable installation there will ordinarily be at the same repeater station a repeater in each cable pair for each direction of transmission. A single pilot control  $PC_5$  and a single pilot control  $PC_{11}$ , however, serves for all of the repeaters transmitting in the same direction at one repeater point for introducing respectively the first approximation and second approximation adjustment to compensate for temperature variations in all of the lines. This is indicated in the drawings, Fig. 3, by extension of the control shaft of the pilot controls  $PC_5$  and  $PC_{11}$  to other repeaters.

The mechanism of the pilot controls and the repeaters having been given, reference will now be made to the curves of Figs. 5—A to 5—F for a more detailed description of the manner of lining up the system and adjusting the repeaters under conditions of actual operation.

Referring to Fig. 5—A let it be assumed that the curve A is the attenuation curve of the cable over the working frequency range 8 to 100 kilocycles. At 8 kilocycles the attenuation is 36 decibels while at 100 kilocycles the attenuation is 86 decibels, or 50 decibels higher.

In Fig. 5—B it is assumed that the noise represented by curve B is substantially constant and is at level of minus 125 decibels when referred to the zero level as that of the topmost channel, at frequency 100 kilocycles, that is, the twenty-third channel. In accordance with the preferred method of operation the equalizers 326 and 374 associated with each repeater are so designed that the output amplitudes over the frequency range follow the curve D which, by reference to Fig. 5—A, will be seen to be the same as the attenuation curve of the cable. The variations in attenuation are therefore compensated for in advance so that the input of each repeater is flat over the frequency range and is represented in Fig. 5—B by the dotted line C. Curve D shows that the amplitude of channel No. 1 is very much less than that of channel No. 23, the highest channel, since channel No. 1 is 50 decibels lower in level than channel 23. This curve shows the load distribution of the amplifier over the working frequency range. Practically the entire load consists of the highest channel, the twenty-third channel, and this is an important factor in the operation of the present invention.

For reasons of efficiency it is desired to load



the repeaters to practically their maximum limit in their normal operation. To greatly exceed this limit would mean that distortion is introduced to an undesirable degree. If on the other hand, a repeater is adjusted to too low an output level, the signal to noise ratio may be reduced below the permissible limit. Figs. 5—C and 5—D may represent undesirable conditions at a single repeater point or the result of cumulative error at several repeater points. In Fig. 5—C where curve K represents the gain which the repeater should have in order to match exactly the cable characteristics and curve H shows the actual output of the repeater, it is seen that the repeater is very much underloaded since the output is low at the uppermost frequencies which make up the principal load on the amplifier. In this case, the amplifier is not only inefficiently used but the signal to noise ratio has been lowered for those channels where the curve H lies below the curve K. In the case of Fig. 5—D the amplifier is overloaded as is shown by the fact that curve H lies above curve K, particularly at the upper end.

It will be noted that if the output level curve of the repeater follows curve D of Fig. 5—B the signal to noise ratio is the same for all channels. This is seen from the fact that a curve such as D for the amplifier output results in exact compensation for unequal attenuation by the cable so that the input to the next repeater is flat as represented by curve C which is at all points equidistant from the cable noise curve B. If curve D had a different shape, then curve C would no longer be straight but would have some portions where the signal to noise ratio differed from that at other portions.

In accordance with the invention the difficulties described above in connection with Figs. 5—C and 5—D are avoided by so regulating each of the repeaters that the output level of the uppermost or twenty-third channel is always kept constant as is represented in Fig. 5—E. In the first place, when the amplifier is installed at a given repeater point the proper tap on resistance 362 is used to give the repeater the proper gain at the twenty-third channel for the normal temperature condition of the cable. This is represented at Fig. 5—E as zero level. The automatic gain control which makes the first approximation correction for temperature variations by varying resistance 12, Fig. 3, changes the gain of the repeater only in a linear manner. It makes no attempt to introduce different gains at different frequencies. The manner of variation is such as always to maintain the output level of the uppermost channel at the proper value. With this manner of compensation, it is evident that the cumulative errors all occur at the lower frequency channels, two extreme cases being given by the curves G and M of Fig. 5—E. Here the dotted curve R represents the ideal curve in a case where the difference in attenuation between the lowest and highest channels is assumed to be 25 decibels instead of 50 decibels as previously considered. (With a difference of 50 decibels in level between the highest and lowest channel a still greater breadth could exist between curves G and M of Fig. 5—E with only a corresponding error, or, in other words, the requirement would be much more lenient than in the case of Fig. 5—E). Changes within wide limits as indicated by the extreme curves G and M do not appreciably affect the load on the amplifier and do not materially impair the transmission on the lower channels.

As stated above, the first approximation regu-

lators introduce only linear change in the gain of the repeaters so that it is necessary for the second approximation regulators to introduce the non-linear changes in amplification that are required by the fact that the change in attenuation of the line L with temperature is non-linear with respect to frequency. Referring to Fig. 5—F, suppose that at some temperature  $T_x$  higher than the lowest temperature  $T_0$  to which the cable is subject, the first approximation regulators have introduced a total gain into the amplifiers represented by I which is the same for all frequencies. Suppose, further, that the gain curve over the frequency range which is necessary to completely compensate the line at the temperature  $T_x$  is represented by curve Q. It is the function of the second approximation regulator to change the gain of the repeater from the horizontal line V to the curved line Q. One way in which this may be done is to introduce a gain represented by II constant for all frequencies and then to introduce a loss which is non-linear with frequency as represented by Q' in Fig. 5—G. For other temperatures differing from  $T_x$  the second approximation curve would have the same general form as Q but its exact shape would vary depending upon the temperature. The resistances 21 and 22, together with the other elements of the attenuation network 20, are designed to give the proper shaped curve for Q at the various temperatures at which the line may be operated.

It will be observed that the foregoing method of operation has many advantages over adjusting the output of each repeater flat with respect to frequencies. In such a case, an error in the first approximation adjustment would result in too high or too low an output level of the repeater over the entire frequency range, thus either increasing the loads on the amplifiers above the permissible limit or increasing the noise ratio throughout all channels. The method of operation in accordance with the invention enables the repeater to operate at full load at all times without danger of overloading and maintains the signal to noise ratio at maximum value at least in the higher frequency channels. It also permits the use of a single type of adjusting mechanism for the first approximation adjustment for all repeaters and the adjustable element itself may take the form of a simple resistance thus making for low first cost of apparatus.

What is claimed is:

1. In a multi-section line for transmitting waves having a band of frequencies, said line being subject to changes in transmission characteristic, the method of transmission regulation comprising making, in accordance with such changes, an accurate regulation of the characteristic of each section at one frequency and a rough regulation at the other frequencies, and making, also in accordance with such changes, an overall accurate regulation of the characteristic of a plurality of successive sections over the entire band.

2. In a repeatered line for transmitting waves having a band of frequencies, the method of transmission regulation comprising adjusting the gain of each of several repeaters to compensate roughly for the variable attenuation of the line over the band and to regulate the transmission accurately at the frequency of the waves of greatest amplitude, and at greater intervals along the line making accurate adjustment of the gain throughout the entire frequency band.

3. In a repeatered line for transmitting waves of a broad band of frequencies, said line having a sloping attenuation characteristic variable with temperature changes, the method comprising adjusting the gain of each of several repeaters to the reverse slope of the attenuation characteristic and regulating the gain accurately at the highest frequencies of the band for changes in temperature of the line, and at less frequent repeater points regulating the gain accurately over the entire transmitted band for changes in line temperature.
4. In a repeatered line for transmitting waves in a broad band of frequencies, said line comprising repeater sections of unequal attenuation from section to section, repeaters between sections having respectively a gain-frequency characteristic which is the inverse of the respective section, said line being subject to variations in resistance with time, means to vary the gain of each of several repeaters uniformly over the frequency range for the same change in line resistance to compensate said change in resistance and means to change the gain at less frequent repeater points to give more accurate compensation for the overall variation in line resistance, throughout the transmitted frequency range.
5. The combination with a line made up of repeater sections of non-uniform electrical length with repeaters between sections, said line being subject to change in resistance with change in temperature, of pilot conductors of equal length subjected to the same temperature as said line, and means for adjusting the gain of each of certain repeaters in accordance with the variation in resistance of the adjacent pilot conductor.
6. In a repeatered line for transmitting waves of a broad band of frequencies, said line comprising sections with repeaters between the sections, short pilot conductors associated with said sections and subjected to the same temperature variations as the line, means controlled by said pilot conductors for compensating in individual repeaters for the variations in line resistance due to temperature variations of the line, long pilot conductors also associated with said sections and subjected to the same temperature variations as said line, and means controlled by said long pilot conductors for making additional compensation in certain of said repeaters for changes in line resistance due to temperature variations.
7. In a transmission system, a line, a repeater in said line having an adjustable gain, an adjustable attenuating network in said line, automatic adjusting means adapted to be controlled in response to changing transmission characteristic of said line, said means effecting a change in gain of said repeater to compensate partially for a change in line transmission characteristic, and making a change in adjustment in said network for effecting a further compensation for change in line transmission characteristic.
8. In combination with a line for transmitting waves of a broad band of frequencies, a repeater for amplifying waves of said band of frequencies, means operating in response to a change in line transmission characteristic for effecting a compensating change in gain in said repeater, uniform over said frequency band, and other means operating in response to a change in line transmission characteristic for effecting a further compensating change in gain in said repeater, varying over said frequency band, said latter compensating gain change being greatest at those frequencies in the band at which the change in line transmission characteristic to be compensated is greatest.
- HAROLD S. BLACK.

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