

March 22, 1938.

K. C. BLACK

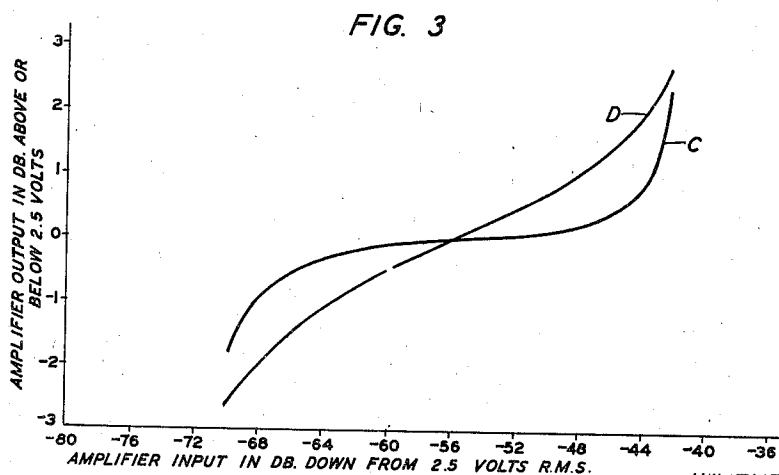
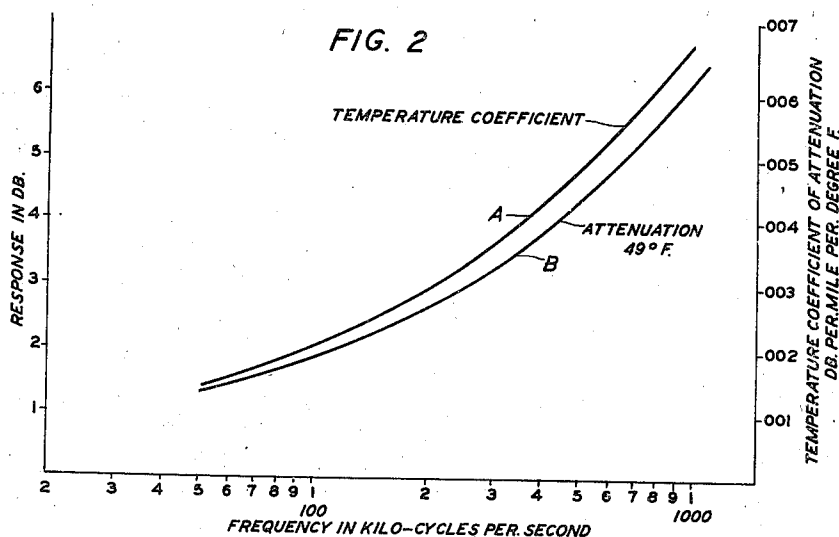
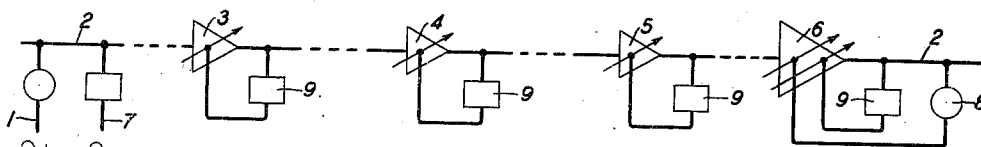
2,111,607

REPEATERED LINE SYSTEM

Filed Nov. 30, 1935

2 Sheets-Sheet 1

FIG. 1



INVENTOR
K. C. BLACK
BY *H. A. Burgess*
ATTORNEY

March 22, 1938.

K. C. BLACK

2,111,607

REPEATERED LINE SYSTEM

Filed Nov. 30, 1935

2 Sheets-Sheet 2

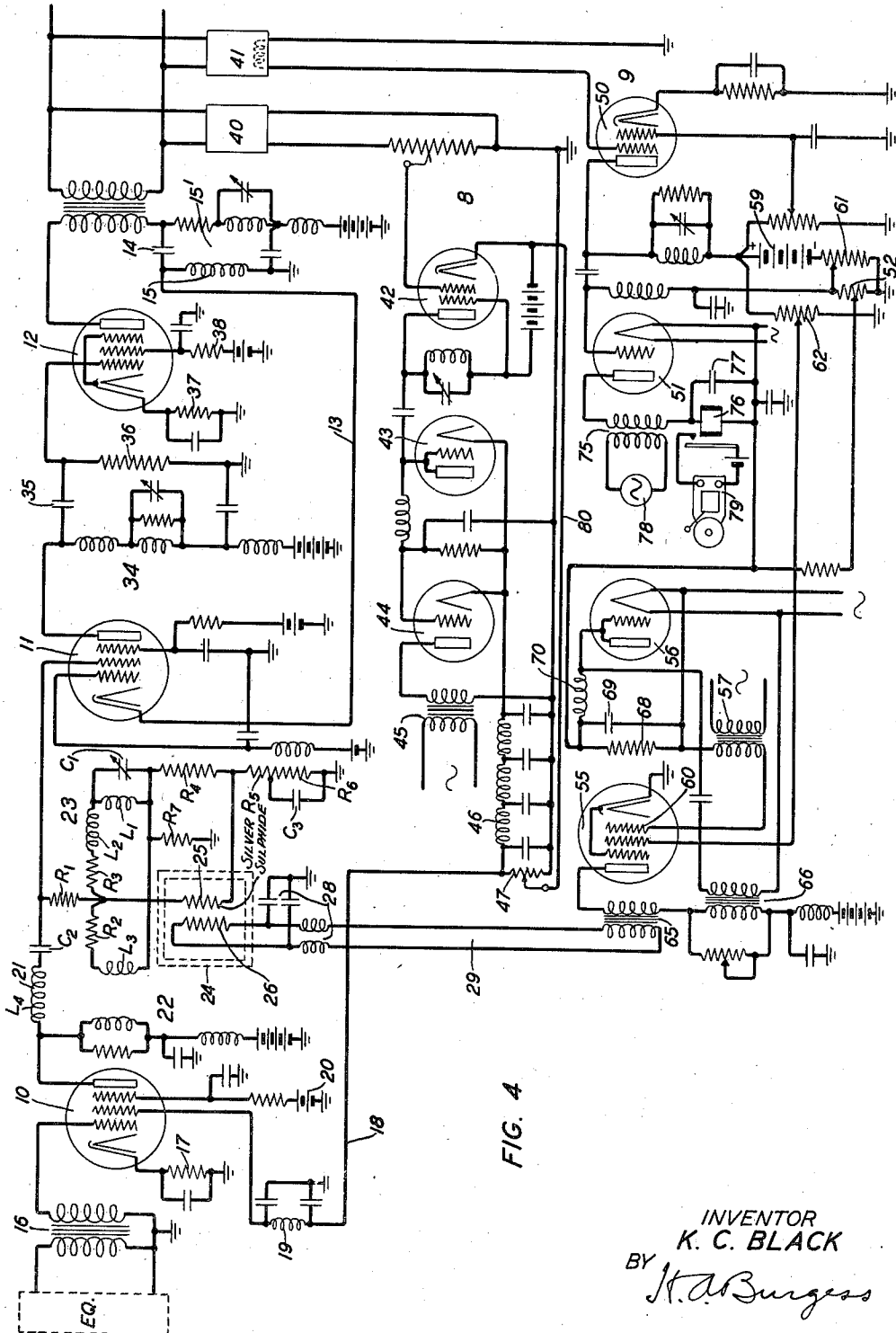


FIG. 4

INVENTOR
K. C. BLACK
BY *H. A. Burgess*
ATTORNEY

UNITED STATES PATENT OFFICE

2,111,607

REPEATERED LINE SYSTEM

Knox C. Black, Mountain Lakes, N. J., assignor
to Bell Telephone Laboratories, Incorporated,
New York, N. Y., a corporation of New York

Application November 30, 1935, Serial No. 52,351

9 Claims. (Cl. 178-44)

The present invention relates to the automatic control of transmission through a repeatered line to maintain the levels within prescribed operating limits under variable temperature and other changing conditions encountered in practice.

The invention will be illustrated and described as embodied in a carrier wave transmission system for a wide band of frequencies, but in certain of its aspects it is adapted for use in other types of systems. The system to be illustrated and described herein is a multiplex carrier wave system containing repeaters at suitable intervals which are provided with regulating mechanism responding automatically to varying line or apparatus conditions to change the gain of the repeaters in such manner as to compensate the effect of such varying conditions.

The invention is in the nature of an improvement on prior systems of this general type and aims to achieve a higher degree of constancy of operation of the system than has heretofore been realized.

In carrying out the invention in practice two pilot frequency waves are used, one at the upper edge of the utilized range and the other at the lower edge of the range; the upper pilot frequency wave is used to compensate line changes by making adjustment of repeater gains at frequent intervals along the line while the lower frequency pilot wave is used at less frequent points to make a separate adjustment of a repeater to correct for cumulative errors arising from changes that are not fully corrected by the higher frequency pilot wave. The gain changes controlled by the higher frequency pilot wave are carried out much more slowly than those controlled by the lower frequency wave, and preferably are effected by use of a material such as silver sulphide having a temperature coefficient of resistance which is made use of as the control variable. The lower frequency pilot preferably acts by varying the bias of a tube grid in the repeater.

The various features and objects of the invention will be more clearly understood from the following description of a preferred embodiment as illustrated in the accompanying drawings.

In the drawings:

Fig. 1 is a simple diagram of a long system with several repeaters, showing the relation of the two pilot controls to the various repeaters;

Figs. 2 and 3 are curves to be referred to in the explanation of the detailed circuit; and

Fig. 4 is a schematic circuit diagram of a complete repeater station.

Referring first to Fig. 1, a low frequency pilot

wave is sent out from circuit branch 1 at the transmitting terminal and is transmitted over the line 2 and through the various repeaters 3 to 6, inclusive, and thence over the rest of the line which may be assumed to lead to other repeaters and eventually to a terminal. A high frequency pilot wave is sent out from circuit branch 7 over the line 2 and through the various repeaters. The circuits for transmitting to and receiving from the line the message waves are not shown, but any suitable types of circuits for that purpose may be assumed, for example, multiplex carrier channel apparatus utilizing the range from just above 60 kilocycles to just below 1024 kilocycles. In that case the lower pilot frequency may be 60 kilocycles and the higher pilot frequency may be 1024 kilocycles with a sufficient interval of frequency separation from the next adjacent message channel to avoid interference.

The general arrangement shown in Fig. 1 is similar to that disclosed in my prior application, Serial No. 681,514 filed July 21, 1933 (Patent No. 2,019,594 granted November 5, 1935) but differs (among other ways) in that the circuit of Fig. 1 employs only one of the two pilot controls at certain repeaters. For example, at each of repeater stations 3 to 5, a control 9 is indicated as actuated by only the high frequency pilot wave. At repeater station 6, the repeater apparatus is under control of both the low and the high frequency waves by controls 8 and 9, respectively. Repeaters 3 to 5 may, in practice, be unattended repeaters located in metal containers in manholes or similar positions and occupying small space and requiring only infrequent attention. Repeater 6 is an attended station located in a repeater building. A repeater spacing of about ten miles is reasonable.

The change in attenuation of the line for a given temperature change is greater at high than at low frequencies. This is indicated in Fig. 2 by curve A which shows that the temperature coefficient or the decibel change per mile per degree Fahrenheit increases with increase of frequency. This curve applies to a 0.270 inch (inner diameter) Z-tape coaxial conductor of the type disclosed in F. Wentz application, Serial No. 630,552 filed August 26, 1932 (Patent No. 2,018,477, granted October 22, 1935). The attenuation curve of such a line at the temperature 49° F. is shown at B.

On account of this higher rate of change of attenuation at higher frequencies, the higher frequency pilot control 9 is more sensitive to temperature changes than the low frequency pilot

control 8. If the only change to be compensated for were that due to line temperature changes, the single pilot control 9 would be sufficient. A second source of variation in over-all transmission equivalent arises from changes in the repeater itself. Such changes may arise from the change in gain of a tube, for example, where the tube is outside the stabilizing feed-back loop, or from other cause. A change of this type may, in itself, be small but in the aggregate where a large number of repeaters are used in tandem, this type of change may mount up to a significant value. The change in repeater gain, such as that arising from a change in tube gain, is constant over the frequency range, and the provision of two pilot waves enables compensation to be made for both those changes which follow some such curve as A of Fig. 2 and also those which are uniform at all frequencies whatever the origin of these latter changes.

In Fig. 1, therefore, compensation is made at each repeater for the relatively large effect due to temperature variation, while at periodic intervals the cumulative error that is constant over the whole band is corrected.

In Fig. 4 there is shown the circuit of the repeater 6 of Fig. 1, including both controls 8 and 9. If the control 8 is considered absent, the rest of the figure shows the circuit of an unattended repeater 3, 4 or 5.

The repeater of Fig. 4 is a one-way amplifier, it being assumed that the complete two-way transmission system would comprise two one-way lines with one-way repeaters. Three pentode tubes 10, 11 and 12 are used in tandem. Stages 11 and 12 are provided with a feed-back connection 13 from the output primary terminal of stage 12, through condenser 14 to the cathode of tube 11, this lead having a direct current path to ground through choke coil 15. The purpose of this feedback is to stabilize the amplifier and increase its linearity as disclosed more fully and claimed in H. S. Black application, Serial No. 606,871 filed April 22, 1932.

Tube 10, comprising the first stage, has its input connected through input coil 16 to the incoming line terminals, with bias from resistor 17. A line attenuation equalizer is indicated preceding the tube 10. The space charge grid is connected to lead 18 through direct current filter 19 for the "flat" control to be described later. The screen grid is connected, as usual, to battery 20 for suitable fixed potential and is by-passed to ground for alternating current as shown. Tube 10 is impedance-coupled to tube 11 through series arm 21 with plate supply network 22 on one side and grid network 23 on the other side. One element of the network 23 is a silver sulphide resistor 25 whose resistance is varied as its temperature varies under control of a heating coil 26 which may be enclosed with element 25 in a suitable box or heating chamber and which is connected through low-pass filter 28 to leads 29 of the pilot control 9 to be more fully described later on. The network comprising portions 21 and 22 makes the impedance looking back toward tube 10 from the point of connection of network 23 approximately a pure resistance. For a normal setting of this circuit corresponding to a normal line temperature, the network 23 plus the line equalizer plus the residual slope of the amplifier characteristic caused by the other elements of the circuit compensate for the line attenuation characteristic. The shape of the line characteristic may be seen in curve B of Fig. 2 for the line temperature of 49° F. As the temperature of the line changes

from the assumed normal value, the network 23 is controlled in a manner to be described so that its characteristic is changed to correct for all changes in attenuation due to the line temperature variations. The control of the network 23 is such as to make the output of the repeater flat over the transmitted range for all adjustments within the operating limits.

This network 23 and its mode of design is the invention of another and will be separately disclosed and claimed.

In the interest of a full disclosure of one embodiment, the following constants are given as suitable for the particular system herein disclosed: $L_1=511$; $L_2=3,450$; $L_3=3,960$; C_1 is a condenser variable between values 2 to 50 and is tuned to give a minimum amplifier gain at 1,400 KC; $C_3=260$; $R_1=1,715$; $R_2=23,200$; $R_3=3,630$; $R_4=3,430$; $R_5=506$; $R_6=3,240$; and $R_7=3,460$ (inductances in microhenries, capacities in microfarads, resistances in ohms). In one case the silver sulphide element had a total resistance range of variation between 400 and 100,000 ohms.

Tubes 10 and 11 are Western Electric Company type 7628 pentodes and tube 12 is a Western Electric Company type 7629 pentode.

Tube 11 is impedance-coupled to tube 12 through series capacity 35, with grid resistance shunt 36 on one side and plate feed network 34 on the other side, the latter assisting in providing a constant high resistance output for tube 11 to favor maximum gain. Bias resistor 37 and screen polarizing lead are provided as shown.

The network 15' provides an attenuation to ground such as to compensate the shunting effect of the feed-back for high frequencies and produce approximately equal feed-back at all frequencies in the range of interest.

Across the output terminals of the amplifier are bridged a filter 40 passing the 60 kilocycle pilot wave and a filter 41 passing the 1024 kilocycle pilot wave. Filter 40 leads to control circuit 8 comprising amplifier 42, rectifier 43 and amplifier 44. The plate supply for amplifier 44 is the source of alternating current and transformer 45. Filter 46 is a smoothing filter for the output of tube 44 and terminates in resistance 47. Tube 42 in one case was Western Electric Company type 310A, tube 43 was Western Electric Company type 231D and tube 44 was Western Electric Company type 104D.

Control circuit 9 comprises an amplifier 50 followed by a tube 51, the grid-filament circuit of which includes an adjustable portion of resistance 52. A final amplifier 55 and a second rectifier 56 are provided for a purpose to be described. Tube 50 was in one case a Radio Corporation of America type 36; tubes 51 and 56 were Western Electric Company type 231D and tube 55 was a Radio Corporation of America type 38. A source of alternating current is connected through transformer 57 to the grid of amplifier 55. The bias on the grid 60 of tube 55 is controlled principally from the battery 59 and resistances 61 and 52 and in part (when there is sufficient pilot input voltage) from tube 51. The alternating current supplied at 57 may be 60-cycle and of the order of 9 or 10 volts, by way of example. This voltage on the grid 60 of tube 55 produces 60-cycle alternating current in the plate circuit which is impressed by way of transformer 65 and leads 29 on the heater 26 to control the temperature of the silver sulphide resistance 25 which in turn adjusts the loss of the network 23 to vary the gain of the repeater. Some of the 60-cycle output is supplied

by way of transformer 66 back on rectifier 56 where it is rectified and caused to vary the bias of grid 60 in a manner to be described.

It will be seen from the foregoing description that the flat gain changes controlled from the low frequency pilot wave are effected by changing the bias on the space charge grid of the first stage 10 of the amplifier, while the control by the high frequency pilot is exercised by way of temperature control of silver sulphide element 25 constituting the variable element of the network 23.

The operation will now be described. The control of the higher frequency pilot wave will be considered first, this being the control that is present in each of the repeater circuits, as stated above. It is assumed first that the repeater has the correct gain and that the temperature of the interior of the heat chamber 24 is well above room temperature. If now the attenuation of the line falls due to a drop in its temperature, the pilot wave in the input of control 9 will tend to rise causing an increased voltage on the grid of tube 51 from the input amplifier 50. The grid of tube 51 is connected through a portion of high resistance 52 to the cathode and is normally biased negative from battery 59. So long as there is any substantial input to the grid from amplifier 50, grid rectification occurs and makes the average grid potential still more negative in proportion to the strength of the incoming pilot wave. That is, the grid and cathode of tube 51 act as an ordinary diode. That part of the bias on grid 60 that is derived solely from battery 59 is so far negative as to prevent current flow through tube 55. Any substantial rectified current in the grid circuit of tube 51, however, flowing through resistance 52 opposes the normal bias on grid 60 and permits some of the 60-cycle wave from source 57 to set up a current of that frequency in the output of tube 55. Some of this current is transmitted through transformer 65 to the heater circuit and the portion that is fed back through transformer 66 to rectifier 56 causes rectified current to flow through resistance 68 such as to add a positive bias and shift the operating point of tube 55 to increase the amplifying factor of the tube for the 60-cycle input from source 57. This has the effect of greatly increasing the amount of current supplied to the heater 26 whenever an increment in the high frequency pilot current is received, calling for increased heating of the regulator resistance 25.

As the temperature of element 25 is raised the shunt loss in the network 23 is increased over the whole frequency range at a varying rate as determined by the network characteristics, such as to compensate the assumed drop in line attenuation by a lowered repeater gain. The repeater gain drops to a value such that the output of the high frequency pilot wave is restored to its normal value. The rectified current from the grid of tube 51 flowing in resistance 52 again falls to a value which makes the bias of grid 60 of tube 55 so far negative as to reduce the heater current to normal value.

If a rise in line temperature occurs requiring an increase in amplifier gain, the reverse of the process described takes place. First, the need for increased gain is "sensed" by a slight decrease in output of the high frequency pilot wave. This reduces the rectified grid current of tube 51 making the bias of grid 60 of tube 55 more negative and decreasing the 60-cycle current supplied to the heater 26. The accompanying decrease in 60-cycle current rectified in tube 56 accentuates this

change in heater current by making the bias on grid 60 still more negative. (Condenser 69 and inductance 70 together form a smoothing filter for the rectified current in resistance 68). With reduced heating current, element 25 cools by loss of heat to its surroundings.

For any line temperature, the action of the regulator is such as to maintain the output of the high frequency pilot wave at the terminals of filter 41 at a constant voltage level. Any deviation from that constant or normal value results in a change in the heating of element 25 such as to restore the output level to normal. The output of all of the carrier channels is simultaneously maintained at required value as governed by the network 23 as already explained.

The curves of Fig. 3 indicate the character of the regulation obtained with regulator channel 9. Curve C applies for the condition when the transformer 66 and rectifier 56 are used as described to feed back some rectified 60-cycle current to control the bias on tube 55 in aiding manner, and curve D applies for the condition in which these elements are missing. A much flatter regulation is obtained with the use of this revertive action. The 2.5 volts output assumed as reference output for these curves is the normal voltage output of the high frequency pilot wave. The curve C shows a regulation within plus and minus 1 decibel for a change in input voltage of 24 decibels.

This channel 9 regulator is of the hunting rather than dead beat or asymptotic type. That is, it seeks its final setting by slightly overcorrecting in successively smaller extents instead of slowly approaching but never exactly reaching full correction. A sudden change in pilot level will cause slow oscillations of the order of half a minute periodicity which completely dampen out in a few minutes. The amplitude of these oscillations is not large enough to be disturbing. Moreover, in practice sudden changes do not arise from temperature variations, for which this regulator channel 9 corrects.

A feature of the invention is an alarm circuit which may conveniently be associated with the tube 51 of regulator 9. When there is anything like a normal amount of pilot wave in the output of amplifier 50, the grid rectification taking place in the grid circuit of tube 51 makes the average grid potential more negative than normal, as above described, and this negative bias prevents plate current flow in the plate circuit of tube 51 and through winding of relay 76, from the secondary of power transformer 75, the primary of which is indicated as connected to alternating current power source 78. With no current flow in winding of relay 76, the circuit for alarm 79 is open and the alarm is unoperated.

If there is a line failure or any apparatus failure such as to interrupt the supply of pilot wave to control circuit 9 or if this pilot wave falls to an abnormally low value, the grid rectification in tube 51 ceases and the average negative bias of the grid falls to a value determined solely by the drop in resistance 52 from battery 59. With this small negative bias on the grid of tube 51, plate current is permitted to flow and operate relay 76, actuating the alarm 79. Large condenser 77 around the winding of relay 76 improves its operation.

The operation described for regulator 9 is the type of operation that takes place at all repeater points. In addition to this, at the main repeater station 6, of Fig. 1, the regulator 8 is used with

operation as follows. For normal output, the low frequency pilot wave at the terminals of filter 40 places such a voltage on the input of amplifier 42 as to produce a mean value of bias on tube 44, allowing a moderate amount of rectified current to flow through resistance 47 and produce corresponding bias on the space charge grid of tube 10 in the repeater. This tube has a substantially linear relation between space charge grid bias and amplification constant (other things being equal) over a wide range of gain values. Departures from normal output level of low frequency pilot wave vary this bias through the control 8 to vary the effective cathode surface and hence make a change in tube gain just sufficient to restore the output low frequency pilot wave to its normal value.

A portion of the rectified filtered output from tube 44 is taken off from resistance 47 and put back on the grid of tube 42 by conductor 80 in an aiding manner, so as to accentuate the correcting effect of small changes in the amplitude of the pilot wave received through filter 40, in an analogous manner to the accentuating action secured in control channel 9 by use of the feedback coupling 66. This makes the regulation for flat gain more nearly linear than if this back coupling were omitted.

That these two controls work in harmony may be seen from considering that the control 9 fully corrects for temperature changes in the line leaving the 60 kilocycle pilot output at proper level after a correction has been effected by the 1024 kilocycle pilot wave. If a linear or flat change has occurred, the control 8 responds quickly (e. g., in a fraction of a second) and effects a uniform correction over the whole band, but this does not satisfy the demands at the high frequency, and the slower control channel 9 (which may take several seconds to effect its correction) carries the correction along until the proper compensation has been effected at the upper edge of the range as well as at the lower edge. Network 23 by its design characteristic insures proper compensation at all intermediate frequencies.

What is claimed is:

1. In a carrier wave system, a long line subject to variations in attenuation, repeaters at intervals in said line, means to send message carrier waves and a plurality of pilot waves over said system, means at certain repeater points controlled by one of said pilot waves for effecting a compensating change in the repeaters at said certain points and means at less frequent repeater points controlled by the other of said pilot waves for effecting a compensating change of a different character in the repeaters at such less frequent points.
2. In a carrier wave system, a long line subject to variations in attenuation with time, the variations being of different extent at different frequencies, repeaters at intervals in said line, means to send message carrier waves and a plurality of pilot waves over said system comprising a higher frequency pilot wave and a low frequency pilot wave, means at certain repeater points controlled by the high frequency pilot wave for producing a correcting effect in the repeaters at said certain points such as to compensate the variations in attenuation throughout the transmitted frequency range and means at less frequent repeater points controlled by the low frequency pilot wave for correcting for the cumula-

tive error remaining after correction by the high frequency pilot wave.

3. In a broad band transmission system, a line whose attenuation varies with time at different rates in different parts of the frequency band, repeaters at intervals in said line, means to transmit a high frequency pilot wave and a low frequency pilot wave over the line, means controlled by one pilot wave to produce compensating changes of different amount at different frequencies in certain repeaters such as to compensate the line attenuation variations throughout the band, and means controlled by the other pilot wave to produce in certain only of said certain repeaters other compensating changes which are the same at all frequencies within the band.

4. In a system for transmitting waves of a broad frequency band, a line subject to varying attenuation at different rates at different portions of the band, repeaters in said line, means to transmit two pilot waves of spaced frequency, means at a repeater controlled by one of said pilot waves and operating relatively slowly to effect compensating changes of different amounts at different frequencies such as to compensate the line attenuation variations, and means controlled by the other pilot wave and operating relatively quickly to effect in said repeater a compensating change which is substantially constant over the transmitted band.

5. A combination according to claim 4 in which the repeater includes a space discharge tube amplifier and an attenuating network comprising an element of temperature-coefficient of resistance with a heater to vary its temperature, the means controlled by said first-mentioned pilot wave operating to vary the heating effect of said heater to vary the resistance of said element, and the means controlled by said second pilot wave operating to vary the gain of said repeater tube.

6. In a broad band system, a line whose attenuation varies with time at a non-uniform rate over the band, means to send through the system a high frequency pilot wave and a low frequency pilot wave, a repeater having an element having a temperature coefficient of resistance controlling the repeater characteristic in accordance with the temperature of the element, said element being included in a network determining the attenuation at each frequency in the band as a function of resistance of said element, means controlled by the first-mentioned pilot wave for varying the temperature of said element to compensate line attenuation changes, and means controlled by the other pilot wave for making a supplementary compensation in said repeater.

7. The combination with a transmission line having a variable attenuation and means to transmit over the line message waves comprised in a band of frequencies and two pilot waves of different frequencies of a repeater for said line comprising a space discharge amplifier device having an input and an output, a gain stabilizing feed-back for said repeater feeding back in the repeater waves of the message frequencies sent over the line, two circuit branches connected to the output of the repeater and selective to the two pilot waves respectively, and means controlled by said two circuits for varying characteristics of the repeater under control of said pilot waves to maintain the message waves in the output of the repeater at constant level at all frequencies within the message frequency band independent of variations in line attenuation.

8. A repeater, according to claim 7, in which

said stabilizing feed-back is brought back to a point in the repeater and the means controlled by the pilot wave circuits for varying the repeater characteristics exert their controls on the side of said point toward the repeater input.

9. The combination with an amplifying repeater having an input and an output of a circuit for deriving a wave from the output having a

component varying in accordance with a characteristic of the repeater that is to be regulated, means comprising an amplifier for utilizing the variable component of the wave for regulating said repeater, and means comprising an auxiliary source of waves in a regenerative circuit for said amplifier for accelerating said regulating action.

KNOX C. BLACK.