Feb. 1, 1944. J. G. KREER, JR., ET AL 2,340,813

ELECTRIC WAVE TRANSMISSION SYSTEM

Filed Dec. 5, 1942 2 Sheets-Sheet 1

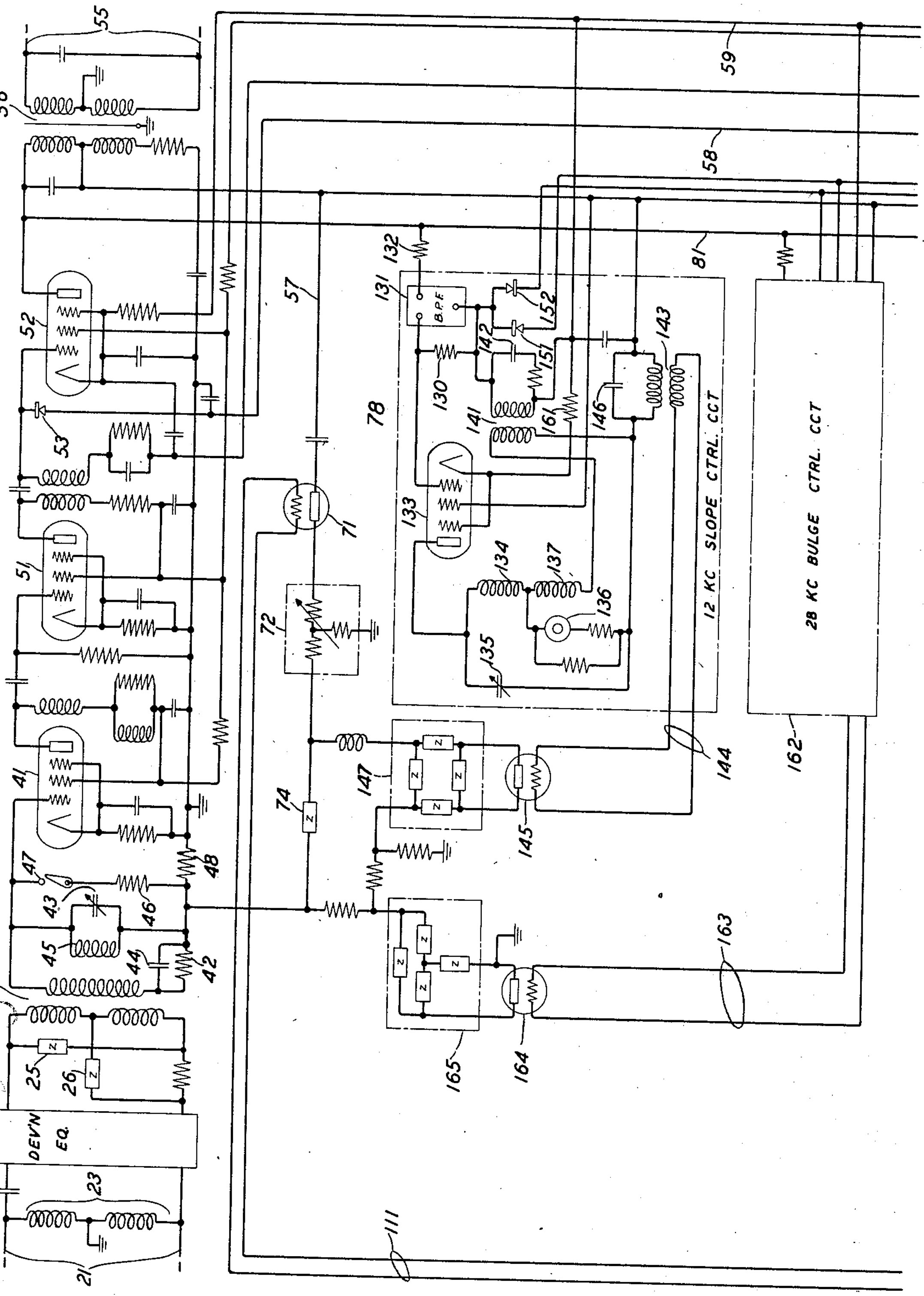

FIG. 1

INVENTORS J. G. KREER JR.
C. O. MALLINCKRODT

BY N. D. Ewing

ATTORNEY

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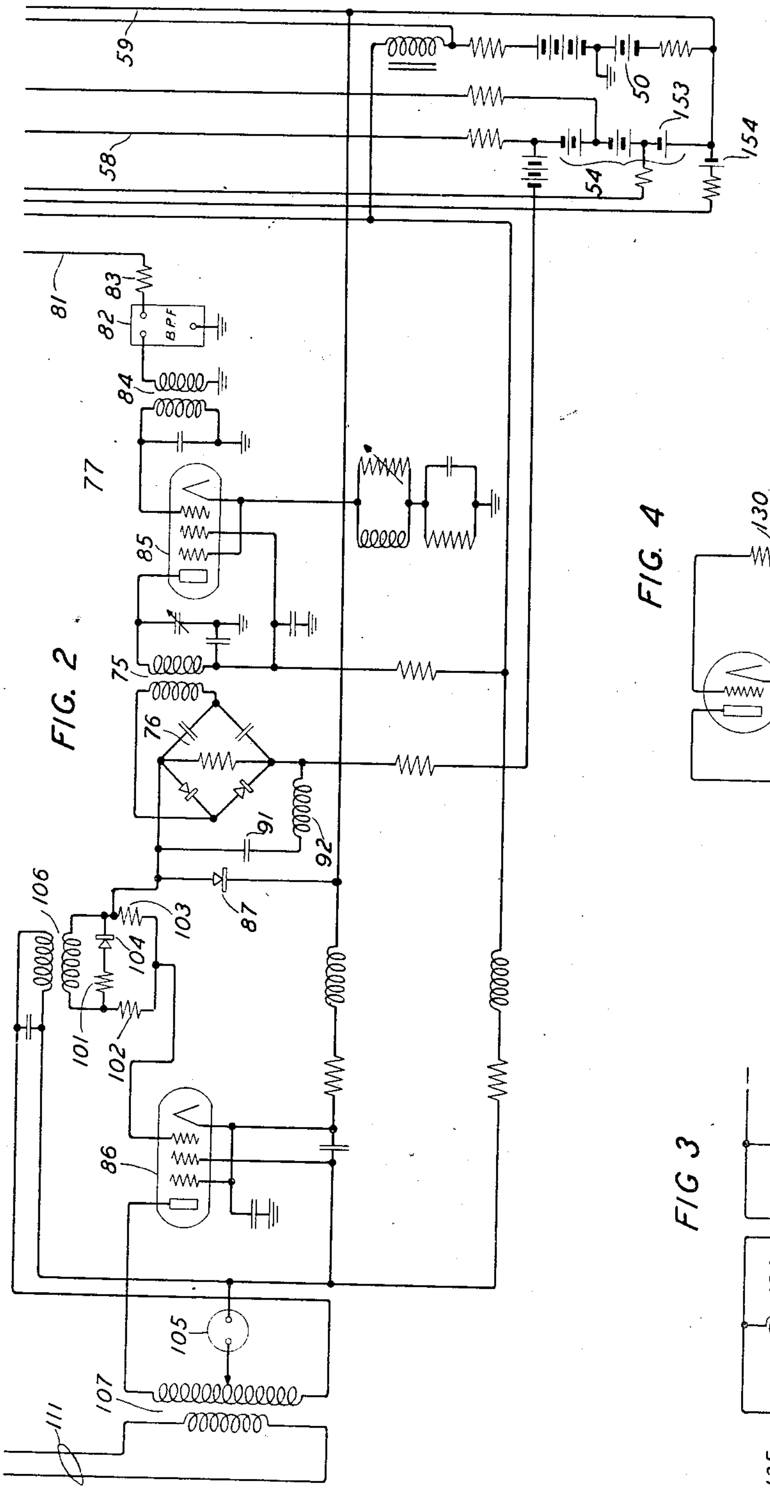

FIG. 2

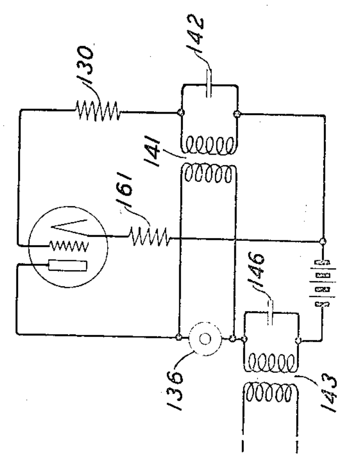

FIG. 4

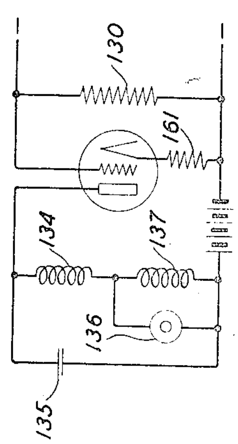

FIG 3

INVENTORS J. G. KREER JR.
C. O. MALLINCKRODT
BY
N. A. Ewing
ATTORNEY

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ELECTRIC WAVE TRANSMISSION SYSTEM

John G. Kreer, Jr., Bloomfield, and Charles O. Mallinckrodt, Summit, N. J., assignors to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application December 5, 1942, Serial No. 467,946

7 Claims. (Cl. 178—44)

This invention relates to electric wave transmission systems and more particularly, although in its broader aspects not exclusively, to circuits for the automatic control of the characteristics of signal transmission systems.

An object of the invention is to increase the sensitivity, accuracy and stability of an automatic control system.

Another and more specific object of the invention is to provide improved and simplified circuit means for translating variations in the intensity of a pilot, or other current indicative of variations in the characteristics of a transmission system, into exaggerated or expanded variations in the intensity of a control current for effecting a compensating adjustment of the characteristics of the system.

The present invention will be disclosed herein as embodied in an organization for automatic regulation of repeater gain in a long distance wire line transmission system, such as disclosed for specific example in an application of H. S. Black, Serial No. 467,947, filed of even date herewith. In a system of this character, auxiliary or pilot waves are transmitted through the line concurrently with the signals, and the several pilot waves are utilized at infrequent repeater stations for controlling automatic adjustment of the transmission characteristics of the repeaters to compensate accurately for variations in the transmission equivalent of preceding sections of the system. If the system is a carrier telephone system operating in the frequency range from 12 to 60 kilocycles, for example, these repeaters may be located at intervals about one hundred miles for aerial cable and of about 250 miles for underground cables, and in the same system automatically regulated repeaters of simpler type may be located at intervals of the order of fifteen miles. Whereas the pilot wave power available at repeaters for controlling the gain adjustment thereof is comparatively feeble and its range of variation is necessarily minute, such variations in pilot intensity are to be accurately translated into magnified or expanded variations in the intensity of a control current that is strong enough to operate the gain adjusting mechanism.

A feature of the present invention is an oscillator-amplifier circuit including a directly-heated oscillation-controlled thermistor that is heated principally by the pilot waves amplified therein and only to a small degree by the oscillations generated.

A further feature of the invention is a vacuum tube circuit that operates effectively as an amplifier with respect to waves of pilot frequency and as an oscillator with respect to waves of a different frequency.

A still further feature of the invention is an oscillator-amplifier circuit arranged to compensate for variations in the mutual conductance of the oscillator tube.

A complete understanding of the novel arrangements contemplated by the present invention, as well as appreciation of the various features thereof, may be gained from consideration of the following detailed description and the annexed drawings in which:

Figs. 1 and 2 illustrate schematically a repeater embodying the present invention; and

Figs. 3 and 4 show schematically simplified equivalent circuits of a part thereof.

Referring to Figs. 1 and 2 which should be assembled with Fig. 1 above Fig. 2, the repeater illustrated comprises in general outline a three stage amplifier of the stabilized negative feedback type having three variable impedance elements associated with the feedback path for automatically regulating the gain-frequency characteristic of the amplifier under the control of respective pilot waves transmitted over the line. In the input circuit of the repeater are fixed elements which effectively equalize the transmission level over the frequency range of interest for an assumed normal line temperature. The amplifier is required to maintain the transmission level at its output substantially uniform over the frequency range and at a substantially constant predetermined value irrespective of line temperature changes and other effects tending to vary the transmission equivalent of the system. The gain-frequency characteristic it must have to perform this function may be regarded as comprising three components of which the principal one, referred to as flat gain, is uniform over the frequency range. A second is a slope component which corresponds to a tilting of the gain-frequency characteristic; and the third is a curvature or bulge component.

The amount of flat gain introduced by the amplifier is regulated by a thermistor 71 under the control of one of the three transmitted pilot waves. Any departure in the output intensity of that pilot wave from a preassigned value operates through a control circuit 77 to vary the temperature and resistance of thermistor 71 in such sense and amount as to effect a compensating change in the gain of the amplifier. Thermistor 71, as well as other thermistors to be referred to subsequently, has a relatively large negative temperature coefficient, i. e., the resistance decreases rapidly as the temperature increases. Similarly, the slope of the frequency characteristic of the amplifier is controlled by a second pilot wave which operates through a second control circuit 78 to vary the resistance of a thermistor 145 which in turn, through a beta circuit network 147, controls the slope characteristic of the amplifier. The third pilot similarly operates through a control circuit 162 on a beta circuit network 165 to curve the gain-frequency characteristic of the amplifier an amount sufficient to maintain the third pilot wave at a substantially constant intensity value at the output of the repeater. Thus the loss introduced under the control of the three variable impedance elements is continuously adjusted so as to maintain the respective pilot levels substantially constant at the output of the amplifier. Such being the case, it will be evident that a very slight change in pilot intensity at the output of the amplifier must suffice to produce a relatively large percentage change in the resistance of its associated thermistor.

The provision of a thermistor in the feedback path of an amplifier for gain control purposes has been described in earlier patents, as for example Patent 2,179,915 issued November 14, 1939, to R. R. Blair.

In the following detailed description it will be assumed that the repeater is incorporated in a 12-channel carrier telephone system utilizing line frequencies ranging from slightly more than 12 kilocycles to slightly less than 60 kilocycles. It will be assumed further that the three pilot waves have frequencies of 12, 28 and 60 kilocycles per second respectively, and that they control the slope, curvature and flat gain characteristics respectively.

Considering first the slope control circuit, it is to be noted that its function is to supply to the heater associated with thermistor 145 a heating current which varies widely in intensity in predetermined correlation with the variations in the intensity of the 12 kilocycle pilot wave appearing at the output of the repeater.

The slope control circuit 78 comprises a single amplifying pentode tube 133 which is arranged to generate oscillations of comparatively low frequency for application to the heater associated with thermistor 145. The rate of change of intensity of the generated oscillations depends on the resistance of a current dependent thermistor 136 and will be zero, i. e., in a stable condition, if thermistor 136 has a predetermined value such that the gain around the oscillator loop is exactly 1 and the phase shift is zero. The resistance of thermistor 136, in turn, is largely controlled in accordance with the intensity of the 12 kilocycle pilot which is taken from the output of the amplifier and applied to pentode 133 through filter 131. The configuration of the control circuit and the proportioning of the various elements thereof are so arranged that the applied pilot waves are amplified with high efficiency and the power content of the amplified waves is dissipated substantially exclusively in the thermistor 136 to effect maximum control of the resistance thereof. In addition, the circuit configuration is such that the pentode 133 comprises an efficient low frequency oscillator with the intensity of oscillations stabilized and controlled by thermistor 136.

The 12 kilocycle pilot is picked off line 81, which is connected to the anode of pentode 52, by band-pass filter 131 which may be a crystal type filter and which is designed to pass only a narrow band of frequencies including 12 kilocycles. Resistance 132 acts as an input termination for filter 131, while resistance 130 acts as an output termination of the filter and as a grid leak. The output terminals of filter 131 are connected to the control grid of pentode tube 133 and to the cathode thereof through an antiresonant circuit comprising an inductance (the secondary winding of transformer 141) and condenser 142, and cathode resistor 161. The antiresonant circuit is tuned to the comparatively low oscillation frequency of 3.25 kilocycles, for example, hence it offers negligible impedance to the effective application of the pilot wave to the input electrodes of tube 133. The anode circuit of tube 133 comprises an antiresonant circuit made up of condenser 135 and reactors 134, 137 and 141, and a second antiresonant circuit comprising condenser 146 and the primary winding of transformer 143. The second of these antiresonant circuits is tuned to the oscillation frequency, hence it offers but little or negligible series impedance at the pilot frequency. The other antiresonant circuit is tuned to the pilot frequency, thereby presenting to tube 133 a high impedance of the order of 100,000-ohms, and adapting the circuit for high voltage gain at the pilot frequency. Thermistor 136 is connected across the series combination of coil 137 and the primary winding of transformer 141. At the pilot frequency the latter presents negligible impedance whereas the impedance of coil 137 is made approximately equal to that of thermistor 136. Hence, substantially all of the pilot power output of pentode 133 is delivered to and dissipated in thermistor 136.

The circuit constants are so chosen that the pilot voltage normally appearing at the control grid of tube 133 will produce about 1.5 milliwatts of power in thermistor 136.

The loss through transformer 141 at the slope pilot frequency is sufficiently great that the amount of feedback at 12 kilocycles in the oscillator circuit is negligible.

Fig. 3 is a simplified equivalent circuit in which the elements that do not contribute to amplification of the pilot are omitted.

Considering now the elements of the control circuit that are significant at the oscillation frequency of 3.25 kilocycles, the simplified equivalent circuit takes the form illustrated schematically in Fig. 4.

Transformer 141 is part of a feedback path provided to produce oscillations in pentode tube 133 at the selected oscillation frequency of 3.25 kilocycles which is, of course, substantially lower than the slope pilot of 12 kilocycles. At this oscillation frequency capacitance 142 parallel-resonates with the inductive component of transformer 141 resulting in the maximum possible feedback at the oscillation frequency.

At the oscillation frequency of 3.25 kilocycles the impedance of capacitance 135 is large compared to that of retard coil 134 so that the latter has only a minor effect on the loop gain. Thermistor 136, on the other hand, is connected directly across the oscillation feedback path and its resistance has an important effect on the loop gain. The circuit constants are such that when the resistance of thermistor 136 is nominally about 1000-ohms the loop gain is unity, i. e., will barely produce oscillations without building up. Accordingly, when the resistance of thermistor 136 is less than 1000-ohms the circuit will cease oscillating and when the resistance is greater than 1000-ohms the oscillations will build up.

The 3.25 kilocycle oscillations produced by pentode tube 133 are applied through output transformer 143 to line 144 and supplied thereover to the heater element of slope thermistor 145. Capacitance 146 parallel-resonates with the inductive component of transformer 143 to build up an impedance of the order of 50,000-ohms at the oscillation frequency of 3.25 kilocycles. This high impedance yields the maximum power from tube 133 in its linear operating range. The impedance is small, however, at the 12 kilocycle pilot frequency so that only a negligible amount of 12 kilocycle pilot power appears in the heated element of thermistor 145.

So long as the regulator circuit just described is oscillating at constant amplitude the resistance of thermistor 136 must remain substantially constant at 1000-ohms and since the resistance is solely a function of the sum of the pilot power plus the oscillation power dissipated in it, it follows that the sum of these two powers must remain substantially constant while the circuit is oscillating. What actually happens is that when the pilot power changes, the oscillation amplitude automatically adjusts itself until this condition is met. In one instance in practice, the circuit described is so proportioned that the total power dissipated in the thermistor is 1.63 milliwatts. In the same case the amount of pilot power represented in the total ranged from 1.5 to 1.6274 milliwatts during normal operation, corresponding to normal variations in the pilot power at the output of the repeater of only plus and minus 0.18 decibel. The oscillation power represented in the total power dissipated in the thermistor therefore ranged from 0.13 to 0.0026 milliwatts; and the oscillation output power ranged from 50 to 1 milliwatts. Thus a variation in applied pilot power of about 8.5 per cent produced a 50 to 1 change in the strong control currents delivered to the slope thermistor 145.

Slope network 147 is designed to provide proper regulating slope in the transmission efficiency of the amplifier, the amount of slope provided being determined by the resistance of slope thermistor 145; this resistance in turn depends upon the strength of the oscillations supplied over line 144 which depends in turn, as we have just seen, upon the level of the 12 kilocycle slope pilot.

Varistors 151 and 152, together with biasing batteries 153 and 154, function as a limiter to prevent loss of control of the oscillations by thermistor 136 in the event of certain abnormal disturbances in the pilot input.

To recapitulate briefly the operation of the slope regulator, the oscillations applied to the heater of thermistor 145 are supplied by oscillator tube 133 which is, in effect, stabilized by directly heated thermistor 136. The intensity at which the oscillations are stabilized at any given time is controlled by the 12 kilocycle pilot wave which is effectively amplified by tube 133 and applied to heat thermistor 136. The arrangement of this portion of the circuit is such that the oscillation power dissipated in thermistor 136 is relatively small compared to the pilot power dissipated therein, from which it follows that a small percentage of change in the latter will induce a relatively large percentage change in the former.

In view of the planned design of the circuit of tube 133 as outlined above, the circuit is, with respect to the waves of pilot frequency, essentially an amplifier with thermistor 136 as load (as represented in Fig. 3) and, with respect to waves of oscillation frequency, it is essentially an oscillator with thermistor 136 loosely coupled in the oscillator loop (as represented in Fig. 4).

Control thermistor 136 is designed to be fast operating as compared to thermistor 145; as a specific example, the ratio may be of the order of 40:1. With such a ratio it is apparent that the heating and cooling time of thermistor 136 will have a negligible effect on the control circuit operation. The purpose of this is to reduce to a minimum the transmission variation in the amplifier gain resulting from abrupt changes in the pilot level; the design of the circuit is, therefore, such that the only element having substantial effects on the restoring time of the regulator is thermistor 145.

The above discussion assumes that the transconductance of oscillator tube 133 will hold constant at its normal value. In actual practice, however, the transconductance will vary somewhat with battery changes and aging. While these changes are reduced by a factor of about 2:1 by feedback through cathode resistor 161, the effect of variations in transconductance is substantially minimized, in accordance with a feature of the invention, by proper choice of the resistance versus power relationship for thermistor 136. As an illustration, let us assume that the transconductance of tube 133 increases 1 decibel above its nominal value. This has two effects on the circuit operation, first, the value of the resistance of thermistor 136 required to barely maintain oscillations is reduced and, second, the amount of pilot power supplied to thermistor 136 is increased. The effect of increasing the pilot power supplied to thermistor 136 is to lower its resistance, and by designing thermistor 136 to have a resistance-power relationship such that the increase in pilot power supplied due to an increase in transconductance of tube 133 reduces the resistance of thermistor 136 by exactly the amount necessary to maintain the gain around the loop at unity, these two effects can be made to cancel each other and the output of control current for a given pilot input will be unchanged by the change in transconductance of tube 133.

The method of determining the required resistance-power relationship of thermistor 136 may be described in detail as follows: First, the value of resistance at the position of thermistor 136 shall be such that the gain around the oscillator loop is exactly unity at the frequency for which the phase shift is zero; and the proper resistance values are calculated for various values of transconductance of tube 133. Second, with these values of resistance assumed at that point and a fixed pilot input voltage assumed on the grid of tube 133, the pilot power dissipated in the assumed resistance is calculated for the same values of transconductance of tube 133. Third, with these same values of resistance and the desired value of control power in the output, the pilot power in the assumed resistance is calculated. Fourth, these two values of power are added together and the total associated with the corresponding resistance gives the required characteristic.

It may be noted that the calculations are carried out only for a specific value of pilot input which must be chosen as a matter of judgment to correspond to the condition under which most accurate compensation is required.

Coming now to the operation of the bulge regulator, the operation and arrangement of the bulge regulator circuit is the same as that of the slop regulator circuit described in detail above. The bulge regulator circuit has not been illustrated in detail, therefore, but is represented in the drawings by box 162. The bulge pilot frequency, which we will assume to be 28 kilocycles, is picked off line 81 by the bulge pilot filter of circuit 162 and applied to the oscillator tube which is similar in arrangement and operation to tube 133 of the slope control circuit. The controlled oscillations are applied over line 163 to the heater of bulge thermistor 164. Bulge network 165, similar in arrangement and operation to slope network 147, is designed to provide proper regulating bulge in the transmission efficiency of the amplifier, the amount of bulge provided being determined by the resistance of bulge thermistor 164; this resistance, in turn, depends upon the strength of the oscillations supplied over line 163 which depends, in turn, upon the level of the 28 kilocycle bulge pilot.

Considering now the "flat gain regulator," i. e., the means for providing automatic and continuous regulation of the variations in the system transmission which are "flat" with respect to the nominal working range, thermistor 71 acts as the flat gain regulator, operating under control of the flat pilot frequency control circuit now to be described. A predetermined flat pilot frequency, which we will assume to be 56 kilocycles, is picked-off line 81 by band pass filter 82; filter 82 may be of the crystal type and is designed to pass only a narrow band of frequencies which includes 56 kilocycles.

If desired, an adjustable resistance pad may be included in line 81 to provide initial adjustment in order to compensate for minor manufacturing variations in the elements. Resistance 83 acts as a termination for the input of filter 82.

The 56 kilocycle pilot selected by band pass filter 82 is transmitted by tuned input transformer 84 to amplifier pentode tube 85. The pilot, after amplification by pentode tube 85 in the usual manner, is transmitted by output transformer 75 to voltage-doubling rectifier bridge 76. The elements of the rectifier bridge act to convert the fluctuating pilot voltage impressed across the input terminals into a fluctuating direct current voltage which appears across the output terminals. We will assume that the average normal output voltage of the rectifier is about 28 volts and is poled with the positive terminal toward the control grid of 5 kilocycle oscillator tube 86.

A bucking bias voltage of about −50 volts is introduced in series opposing relationship with the rectifier output voltage of +28 volts to provide a net grid bias of about −22 volts on oscillator tube 86. Any increase in the output of rectifier bridge 76, resulting from increase in the intensity of the 56-kilocycle pilot, accordingly makes the grid bias of tube 86 less negative thereby increasing the mutual conductance of the tube and causing the oscillations produced thereby to increase in amplitude.

Rectifier 87 is provided to prevent the bias applied to the control grid of oscillator tube 86 from going positive; it limits the value of the direct current voltage obtained from rectifier bridge 76.

Capacitance 91 and inductance 92 connected across the output terminals of rectifier bridge 76, serve to suppress the transient changes in gain resulting from the operation of the flat gain regulator when it compensates for an abrupt change in input level. For example, if the elements 91 and 92 were not present in the circuit, the amplifier gain would tend to fluctuate after the fashion of a damped oscillation before stabilizing at its new value, when compensating for an abrupt change in input level. However, with elements 91 and 92 in the circuit, the gain will change smoothly from its initial value to its final value.

Resistances 101, 102 and 103 and varistor 104 which are included in the grid bias supply circuit of oscillator tube 86 aid in providing a favorabale input-output characteristic. More particularly, they tend to produce a linear relation between the applied control voltage and the oscillation output intensity, and to control the steepness of the input-output characteristic. Cold cathode tube 105 which is conductively associated with oscillator feedback transformer 106, is designed to break down at about 70 volts and thereby limit the 5 kilocycle power delivered to the heater winding of thermistor 71.

The 5 kilocycle oscillations produced by oscillator tube 86 are applied through output transformer 107 and line 111 to the heater winding of thermistor 71, the flat gain regulating element. The circuit constants are such that a small change in the output from rectifier bridge 76 produces a large change in 5 kilocycle oscillation power produced by oscillator tube 86 and applied to the heater of thermistor 71. The amount of 5 kilocycle power applied to the heater element, in turn, determines the resistance of the thermistor bead and inasmuch as the latter element is included in negative feedback path 57, it determines also the gain of the amplifier circuit. Thus the resistance of thermistor 71, and therefore also the amplifier gain, changes in accordance with changes in the intensity of the 56 kilocycle pilot at the output of the amplifier, with the ultimate result that the flat gain of the amplifier is continuously and automatically controlled.

To recapitulate briefly the operation of the flat gain regulator, tube 86 oscillates at a frequency of 5 kilocycles, the strength of the oscillations depending upon the differential biasing voltage applied to its control grid; as this biasing voltage is obtained by bucking the 56 kilocycle pilot against a fixed direct current voltage, the strength of the oscillations depends upon the pilot level. Slight changes in the pilot level result in large changes in the strength of the 5 kilocycle oscillations, this being due to the expandor action of the oscillator tube and to the use of the differential bias arrangement. As a specific example, the circuit may be so arranged that a change of 0.8 decibels in pilot level will result in thermistor 71 going over 16 decibels of its operating range.

Describing now the mu or amplifying circuit, input line section 21 includes series capacitance 22 and shunt inductance 23 which together provide a portion of the input impedance and are effective in providing a balanced input. Deviation equalizer 24 is intended to compensate for slight deviations of the gain-frequency characteristic of a predetermined number of preceding amplifiers of the system from the desired characteristics.

A network represented schematically by impedances 25 and 26 is provided for adjusting line equalization and maintaining constant input resistance, this network being conductively associated with the primary side of input transformer 27. Input transformer 27 steps up the received carrier frequency voltages and applies them to the control grid of the first pentode vacuum tube 41; the input transformer in conjunction with associated resistance 42, capacitances 43 and 44 and inductance 45, has a sloping frequency characteristic sufficient to approximately equalize a predetermined length of the preceding line at average temperature. This portion of the input circuit may be designed for minimum losses in accordance with the disclosure of the copending application of H. W. Bode, Serial No. 435,171, filed March 18, 1942, entitled "Coupling networks." Resistance 46 may be connected across the line by key 47 in order to reduce the phase shift in the feedback circuit under certain conditions.

One side of the secondary winding of input transformer 27 is connected to the control grid of amplifying pentode tube 41 while the other side is connected through a feedback coupling impedance 48 to ground. The cathode of pentode tube 41 and the cathode of the second pentode tube 51 are connected through respective capacitance-shunted resistors to ground while the cathode of the third pentode tube 52 is grounded through a capacitance-shunted resistor and battery 50 which supplements the plate battery. The suppressor grid of each of the three pentode tubes is conductively connected to its respectively associated cathode while the respective screening grids of the three tubes are capacitance bypassed to ground. The interstage coupling between pentode tubes 41 and 51 is of the impedance-capacitance type, the coupling elements being proportioned for a substantially flat gain-frequency characteristic over the frequency range of interest. The interstage coupling between pentode tubes 51 and 52 is predominately of the impedance-capacitance type with respect to the higher frequencies in the transmitted range and of the transformer coupled type with respect to the lower frequencies in the transmitted range, the elements again being proportioned for substantially flat interstage gain.

Rectifier 53 is a substantially unilaterally conducting device conductively connected to the control grid of pentode tube 52 on the one hand and on the other hand over conductor 58 to the negative terminal of a biasing battery 54 and through the latter to the cathode of tube 52. Rectifier 53 is so poled as to allow flow of current through it only to the control grid of pentode 52, and the biasing battery source 54 has such voltage that the rectifier becomes conducting only when the signals being amplified become more negative than the cutoff voltage of pentode 52. The output of pentode tube 52 is delivered to output line section 55 through output transformer 56, the primary winding of which is tapped to afford a connection for feedback circuit 57. Further details concerning this manner of securing a negative feedback connection will be found in United States Patent 2,210,001 issued August 6, 1940, to E. H. Perkins entitled "Electric wave amplifying system."

Negative feedback circuit 57 includes thermistor 71 which functions as described above to control or determine the amount of loss or attenuation in the feedback circuit. The feedback circuit 57 extends through the series arms of variable T-network 72, used for adjusting the amplifier gain, through impedance 74 provided for reducing interaction between the slope and bulge networks, and to the input side of the amplifier circuit.

While certain specific embodiments of the invention have been selected for illustration and detailed description, the invention is not restricted in its application to such embodiments. The embodiments described should be looked upon as illustrative and not as restrictive.

What is claimed is:

1. In a system for automatic regulation of the gain characteristics of a signal repeater under the control of pilot waves transmitted through the system, an electric wave amplifier, means for diverting pilot waves from said repeater to said amplifier for amplification therein, a transmission loop circuit including said amplifier for the generation of oscillations, a thermistor connected to receive and absorb the pilot wave power output of said amplifier, circuit means whereby said thermistor is disposed also in oscillation stabilizing relation in said transmission loop and supplied with oscillation power in an amount that is small compared with the pilot power supplied thereto, and means for utilizing the generated oscillations to adjust the gain characteristic of said repeater.

2. In combination, an oscillation generator, a source of control waves of variable intensity, a thermally variable impedance element connected in oscillation controlling relation to said generator, means for variably heating said impedance element under the control of said waves, and means for concurrently heating said impedance element with power derived from said oscillations, the derived heating power being small relative to both the total power content of said oscillations and the heating power supplied under the control of said waves.

3. A pilot controlled oscillator comprising an amplifier, means for applying pilot waves to be amplified to the input of said amplifier, a current dependent thermistor heated by the amplified pilot waves, an oscillation generating loop including said amplifier and said thermistor, and means for passing the generated oscillations through said thermistor whereby the intensity of said oscillations is dependent on the intensity of the applied pilot waves, said amplifier being subject to changes in gain and resulting concomitant changes in the resistance of said thermistor and in the amount of heating power delivered by the amplified pilot waves to said thermistor, said thermistor having a power-resistance characteristic complementary to the relation between said concomitant changes in thermistor resistance and heating power whereby the effect of said changes in gain on the intensity of oscillations is substantially minimized.

4. A repeater gain control circuit comprising an amplifier, means for applying control current of variable intensity from the repeater to the said amplifier for amplification therein, a loop circuit including said amplifier for the generation of oscillations, a current dependent impedance element interposed in said loop circuit and connected to be traversed by both the generated oscillations and the amplified control current, and means for varying the gain of the repeater in response to variations in the intensity of the generated oscillations.

5. A control circuit adapted to translate small percentage variations in the intensity of a control current into large percentage variations in the intensity of a comparatively strong oscillation, comprising means for amplifying the variable

control current, an oscillation generator comprising said amplifying means, a current dependent impedance element connected to be traversed by the amplified control current and by a small proportion of the generated oscillations, the control current traversing said element being large compared with the oscillations traversing said element, and said impedance element being connected in oscillation stabilizing relation to said oscillation generator.

6. In combination, an amplifying discharge device having input and output circuits, means for applying variable control current of a first frequency to the input of said amplifying discharge device, a positive feedback path for said amplifier including frequency selective means whereby oscillations of a second frequency are generated, said output circuit including an antiresonant circuit tuned to said first frequency, a thermistor connected across said antiresonant circuit, a second antiresonant circuit in said output circuit tuned to said second frequency and disposed effectively in series relation with said thermistor, and an oscillation output circuit coupled to said second antiresonant circuit.

7. In a pilot controlled regulator, a vacuum tube circuit including an amplifier-oscillator vacuum tube, a thermo-variable impedance element connected in oscillation controlling relationship to said vacuum tube, a source of pilot frequency waves, the oscillation frequency of said vacuum tube being substantially different from the pilot frequency, and means for applying waves of said pilot frequency to said vacuum tube, the frequency responsive characteristics of certain elements of said vacuum tube circuit being such that said circuit functions effectively with respect to waves of said pilot frequency as an amplifier with said impedance element as a load and functions effectively with respect to waves of said oscillation frequency as an oscillator with said impedance element loosely coupled in the oscillator loop.

JOHN G. KREER, Jr.
CHARLES O. MALLINCKRODT.