

Nov. 30, 1937.

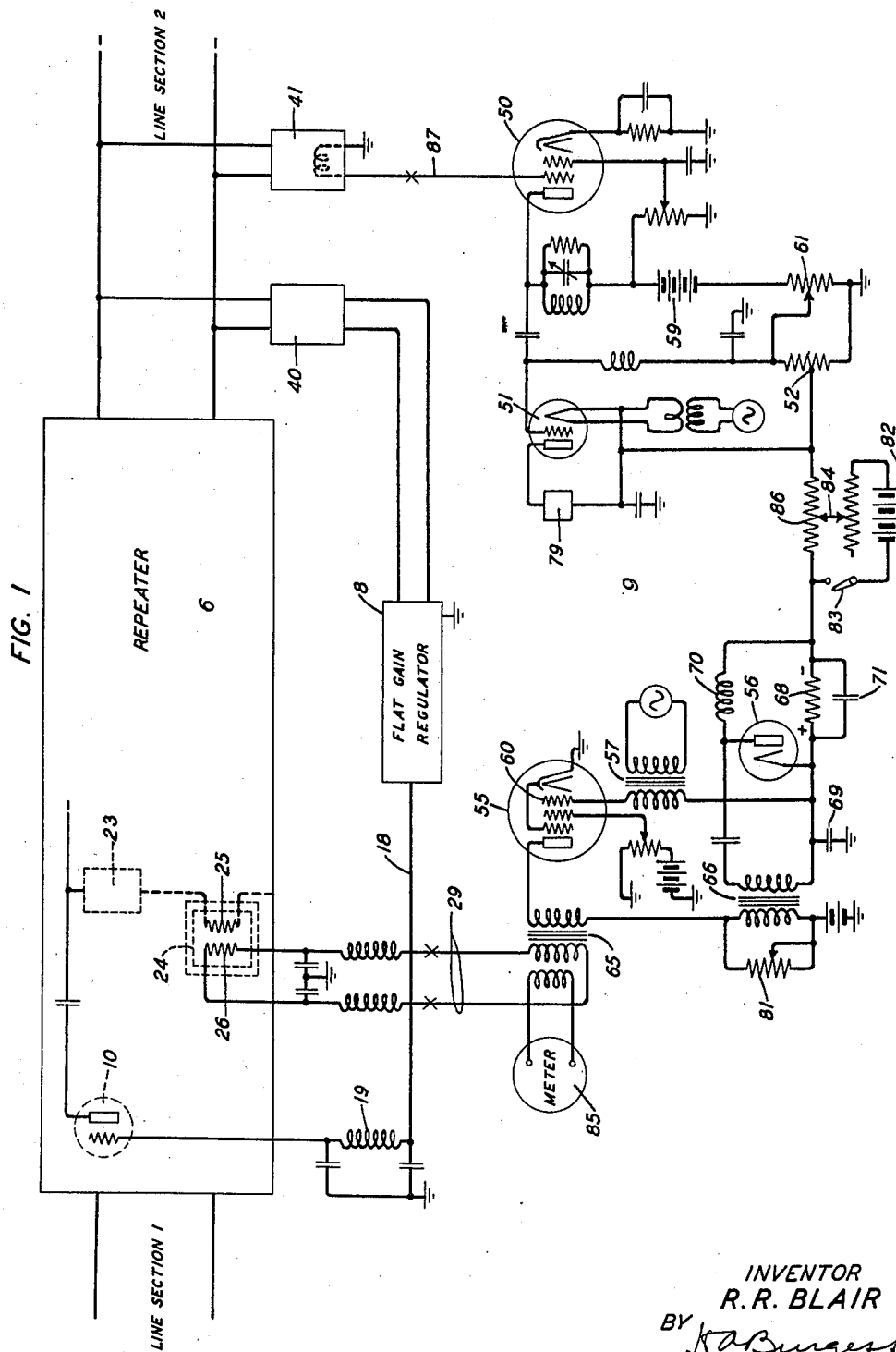
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2,100,375

GAIN CONTROL

Filed May 1, 1936

2 Sheets-Sheet 1



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FIG. 2

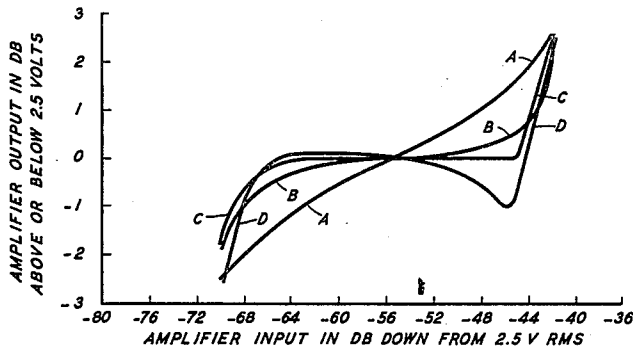


FIG. 3

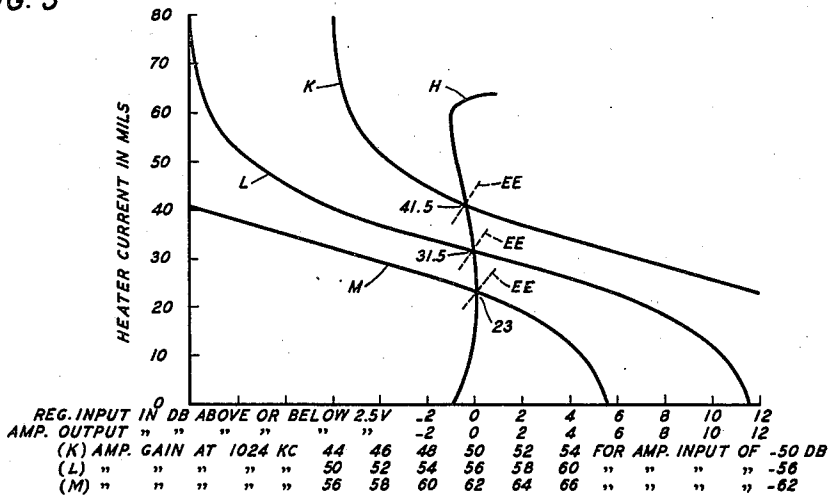
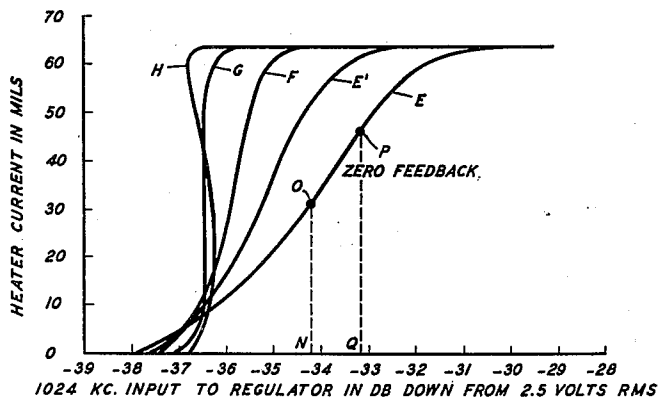


FIG. 4



UNITED STATES PATENT OFFICE

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GAIN CONTROL

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Application May 1, 1936, Serial No. 77,303

9 Claims. (Cl. 178-44)

The present invention relates to transmission regulation and more particularly to the automatic control of the gain characteristic of a repeater in a signaling or other transmission system.

An object of the invention is to effect stable and accurate operation of a backwardly acting type of automatic gain control.

A feature of the invention comprises a backwardly acting control of such timing or such proportioning of parts that a substantially flat, or even a negatively sloping, control characteristic is obtained.

The invention is in the nature of an improvement on the system disclosed and claimed in an application of K. C. Black, Serial No. 52,351, filed November 30, 1935.

In the drawings, Fig. 1 is a schematic circuit diagram of a complete repeater station embodying the invention; and

Figs. 2, 3 and 4 show curves explanatory of the mode of operation of the system of Fig. 1.

Fig. 1 discloses in simplified diagrammatic form the same repeater station that is illustrated in Fig. 4 of the Black application referred to, modified to incorporate the present invention. The same reference characters are used as are used in the Black application, to facilitate identifying the same parts in the two disclosures.

The repeater 6 is indicated by a rectangle including only such elements as are necessary or helpful to an understanding of the present invention, and reference may be had to the Black application for further details, if desired. This repeater 6 is shown connected between line section 1 and line section 2 for repeating in the direction from line section 1 to line section 2 a broad band of waves representing, for example, a plurality of speech modulated carrier waves.

Connected to the output of the repeater 6 are two filters 40 and 41 for diverting from the line section 2 a low frequency pilot wave of 60 kilocycles and a high frequency pilot wave of 1024 kilocycles, respectively. The 60-kilocycle pilot wave is selectively transmitted through the filter 40 to the flat gain regulator 8 (shown only by a rectangle) which operates, as described in the Black application, to apply a variable bias over conductor 18 and through filter 19 to the grid of the first tube 10 of the repeater 6, to vary the amplifier gain. This regulator may be omitted if desired and would ordinarily be used only at certain of the repeater stations.

The 1024-kilocycle pilot wave is selectively transmitted through the filter 41 to the grid of tube 50, the input stage of regulator 9. This regulator introduces a regulation that is different for different frequencies within the transmitted band as required to compensate for the different amounts of attenuation produced over the band by a given change in temperature of the line.

As described more fully in the Black application referred to, a change in the grid potential of the tube 50 produces a change in the amount of rectified output in the grid circuit of the tube 51 through bias resistor 52, this in turn changing the bias on the grid 60 of the tube 55. Grid 60 has continuously applied to it a 60-cycle voltage wave from a suitable source through input transformer 57. As the steady grid potential of grid 60 is changed the tube 55 transmits variable amounts of this alternating current wave to the output. Some of the output alternating current wave is transmitted through output transformer 65 over circuit 29 to the heater 26 within the heat chamber 24 for the purpose of varying the temperature of the silver sulphide resistor 25, thereby varying the shunt loss across the repeater 6 and controlling its gain. The silver sulphide resistor 25 is an element of a network, the remainder of which is diagrammatically indicated at 23, designed to translate the variations in resistance of element 25 into variations in network attenuation corresponding to the required relationship as determined by the line characteristic. It is seen, therefore, that the first effect of a shift in the level of the output high frequency pilot wave from the repeater 6 through filter 41 is to change the amount of heating current in the heater 26 through the medium of the control channel 9. This change in the heating current affects the silver sulphide 25 to produce a change in the gain of the repeater in a direction to restore the level of the output pilot wave to its normal value.

The control channel 9 is aided in doing this, as described in the Black application, by the use of a feedback action in the tube 55. This feedback effect is secured by use of the output transformer 66 and the two-element rectifier tube 56, across which are connected retard coil 70 and high resistance 68 shunted by condenser 71. It will be noted that the resistance 68 lies in the grid lead for grid 60 of tube 55 so that the rectified 60-cycle current from rectifier 56 develops a voltage in resistance 68 which changes the bias of the grid 60. This feedback action accentuates

the control that is initiated by a change in the pilot wave that is impressed on the grid of the tube 50, as explained more fully in the Black application referred to.

5 The present applicant has discovered from working with a circuit of the general type described that if a sufficient amount of retardation or a proper timing is given to the feedback circuit for the tube 55 the amount of feedback
10 used can be increased to much higher values than could be used with an insufficient amount of retardation or an improper timing in the feedback circuit without throwing the circuit into a condition of instability. Applicant has
15 discovered how to use a sufficient amount of feedback action to make the regulation flat throughout a wide range of input voltages or even to achieve a regulation following a downward curve (i. e. a negative slope) while still keeping the
20 circuit in a perfectly stable condition, a result which has generally been considered impossible with a backwardly acting type of control. In other words, applicant has found how with
25 widely varying values of input voltage either to maintain the output at the same value or actually to produce a decreasing output with increasing input.

Referring, for example, to the curves of Fig. 2, the two curves A and B are the same as the
30 curves D and C given in the Black application and they refer respectively to the condition in which no feedback in the regulator is used (curve A) and to the condition in which the amount of feedback in accordance with the disclosures of
35 the Black application (curve B) is used. It is found possible in accordance with the present invention to employ such amounts of feedback as will result, for example, in a curve of the type shown by curve C which is seen to be flat for
40 a range of inputs extending from about -45 to -63 decibels. It is also found possible by use of a still larger amount of feedback in the regulator to secure a regulation such as is indicated by curve D, such that for a wide range of increasing input level there is a gradual reduction
45 of output level.

The manner in which these effects are obtained will now be described.

Referring to the circuit of Fig. 1 the resistance
50 68 in one case had a value of .5 megohm while the capacity 71 was an 80-microfarad condenser giving the combination a time period of 40 seconds (for 63 per cent charging of the condenser). In another case resistance 68 was 5 megohms
55 and capacity 71 was 16 microfarads giving a time period of 80 seconds (for 63 per cent charging of the condenser). These values compare with a time period as previously used of the order of a fraction of a second. It is necessary
60 in order for the circuit as a whole to be stable to have the response of the silver sulphide element (or whatever other variable control element is used) more rapid than the feedback action in tube 55 through the rectifier tube 56.
65 In the circuit in which the resistance 68 and condenser 71 had the values given above, the response time of the silver sulphide element was of the order of 15 seconds cooling and 20 seconds heating, for a total resistance change between zero and infinity. Since a condenser requires four times as long to acquire substantially
70 100 per cent charge as to acquire 63 per cent, the true comparison between the response time of the silver sulphide and the retardation in the feedback, if made on the same basis, must take

the time period of the latter as four times the values of 40 and 80 seconds in the examples given. Thus the response of the silver sulphide element was many times more rapid than that of the feedback circuit. As noted above, the amount
5 of feedback that can be used while keeping the circuit stable is dependent upon the retardation of the feedback circuit relative to the time of response of the rest of the system.

Fig. 4 shows a series of curves giving the relation between the voltage input to the grid of tube 50 and the amount of current supplied
10 over circuit 29 to the heater. Curve E corresponds to the condition of no feedback for tube 55 through transformer 66. Curves E', F, G
15 and H represent successively increasing amounts of feedback obtained by varying the resistance 81, for example. Curves E', F and G are successively steeper than curve E while curve H shows a reverse slope. It is by use of a curve
20 such as H having a reverse slope that a repeater characteristic of the form of curve D of Fig. 2 is obtained.

The curve H appears again on Fig. 3 together with three curves K, L and M which show the
25 relation between the heater current to the silver sulphide element and the amplifier gain, assuming that the input to the amplifier is constant at three different values, curve K corresponding to a high level (or relatively low line
30 attenuation), curve L to an intermediate input level and curve M to a low input level. It will be observed that at the point where these curves intersect the curve H, a relatively small change
35 in heater current results in a rapid change in amplifier gain. It is also observed from the shape of curve H that a relatively small change in regulator input voltage (or repeater output) produces a rapid change in heater current. The point of intersection of curves H and K corresponds to a heater current of 41.5 milliamperes.
40 The intersection of curves H and L corresponds to a heater current of 31.5 milliamperes and the intersection of curves H and M corresponds to a heater current of 23 milliamperes. Thus,
45 for an input level corresponding to curve K the regulation must take place about the value of 41.5 milliamperes heater current, and for input levels corresponding to curves L and M the regulation must take place about heater current values of 31.5 and 23 milliamperes, respectively.
50

Referring (for comparison purposes) to curve E of Fig. 4, let it be supposed that the normal point is at O. An increase in regulator input causes an increase in heater current to some
55 value, P, for example. If the value P of heating current is to be maintained indefinitely, it is obvious that there must be an input to the regulator greater than normal by the amount NQ. So long as this input must all come from the output side of the repeater that is being regulated (there being in this case no feedback in the regulator), there must always be an unbalance voltage or, in other words, a less than complete correction, as is recognized to be the case in
65 backwardly acting regulator systems. In practice, instead of trying to maintain the correcting current at its required value, resort is made to a hunting action in which there is alternately over-correction and under-correction about a
70 mean value representing approximate correction.

In contrast to such a situation, the invention makes possible full regulation about any required value of heating current within a large
75

portion of the curve (such as H). The invention accomplishes this by making it unnecessary for the repeater output (regulator input) to do substantially more than indicate the direction of whatever change is required to keep the regulation at a certain point. The heating current is kept at the proper value, either large, medium or small, as the case may be, by the feedback action. A tendency to depart from the correct value is immediately taken by the regulator as an indication to set the heating current at a new value, which is thence maintained subject to an indication from the repeater output that a different value is required. For any setting within the regulator range, therefore, there is no necessity for an uncompensated output in order to maintain a correcting current or voltage proportional to the departure from normal. While this bears a resemblance to hunting action, there is an important difference in that the correcting current or voltage can be maintained at approximately the necessary value without a corresponding departure of the output voltage from normal value. The output changes necessary are reduced to those required to indicate to the regulator whether the correcting current is already of the right value or needs to be changed.

Referring now to Fig. 1, let it be supposed that the system is set to follow a curve of negative slope (such as curve D, Fig. 2) and that the input is normal, requiring a heater current of 31.5 mils (Fig. 3). The amplifier gain is then following curve L as respects the effect of changes in heater current. In order to supply this heater current the tube 55 must be assumed to be operating as a self-biased tube at the proper point on its characteristic. Since the output is normal, there is a normal input to tube 50 (2.50 volts), a normal bias developed in resistance 52 by rectified current from tube 51, and a further bias developed by the rectified fed-back wave across resistance 68. These voltages make up the existing bias on grid 60 of tube 55, and with no change in repeater output, grid 60 retains this value of bias.

If now there is a slight change in output, say an increase, this produces an immediate shift in the bias of grid 60 to increase the heater current. This shift of bias takes place before the sluggish feedback can respond, and hence is the same kind of effect as would occur without feedback, and can be pictured as following the curve E of Fig. 4. For this reason a small portion EE of curve E is shown dotted in Fig. 3 to show the first effect that a change in repeater output will have on the heating current.

After a time, the feedback increases and produces a shift in the bias on grid 60 in the same direction. Due to the timing of the feedback, this shift does not progress very far until some correction has already occurred in the repeater gain, and therefore until the repeater output is falling. This reduction in output withdraws from the grid 60 the increment of positive bias due to the originally assumed increase in output, but the gradual building up of the feedback action tends to maintain the grid bias at proper value to effect full correction of repeater gain. The feedback remains substantially at the same value indefinitely in the absence of a change in repeater output. When such change occurs, the feedback is set to a new value in the general manner described above.

It might be thought from mere inspection of curve H that a decrease in regulator input might

result in either an increase or a decrease in heater current, especially when operating on repeater gain curve M, or that an increase in regulator input would have no definite corresponding effect on heater current. Curve H must, however, be interpreted as involving a time element as above explained. There is no uncertainty or instability since the initial response is in accordance with one of the EE curves, and the eventual response indicated by curve H must follow in the same direction as the initial response.

It should be clear from what has been said above that regulation can occur in the same way about any point on the curve H below the uppermost bend where attempted regulation might carry over on to the horizontal part of the curve. Consider for example a high value of line attenuation requiring high repeater gain represented by curve M. Regulation is to occur about the point 23 milliamperes of heater current. This point was reached by decreasing repeater output resulting in decreasing amplitude of fed-back wave in tube 55 until operation at the given value of heater current was reached. A correspondingly small bias is developed across resistance 68, holding the current transmitted through tube 55 at the proper low value. If the regulator input remains substantially fixed after that for a time, any tendency for it to change in either direction is interpreted as due to a departure of fed-back current from its proper value, which is corrected in the manner described. Thus, with constant input regulator at the assumed level, operation of the regulator takes place about the new "normal" of heater current. The character of the regulation is thus seen to be determined by the shape of the curve H with reference to the heater gain curves K, L and M. The total regulation can be made of positive slope, zero slope or negative slope (curves B, C or D, for example).

For testing the regulator or observing its behavior, its input and output may be disconnected by opening leads 87 and 29 at points X, and the switch 83 may be closed to connect a variable bias source 82, 84, to resistance 86. The meter 85 may be read as the bias applied at 86 is varied, giving a curve which may be plotted between regulator input and heater current. By using a different setting of resistance 81 for each curve, a family of curves of the type shown in Fig. 4 can be obtained. Applicant has observed that operation on any of the types of curves such as E to H is readily possible, and that even when operating on a curve of negative slope such as curve H, it is possible, by watching the meter indications and making, by hand, small corrections in the voltage applied at 86, to hold the regulation steady at any point below the topmost bend of the curve. In the complete repeater system of Fig. 1 the slight changes corresponding to those made manually in such a test are made in the form of small variations in regulator input as a result of corresponding changes in repeater gain. The extent of these variations in repeater output are very small in comparison to the total grid bias of tube 55 (on an equivalent basis), however.

What is claimed is:

1. An amplifier having a backwardly acting gain control from an output portion to an input portion of the amplifier, said gain control including an amplifier having a backwardly acting gain control from an output to an input portion thereof, and means making the response of the

second-mentioned gain control slow in comparison with the response of the first-mentioned gain control.

2. The combination with an amplifier having a backwardly acting gain control path leading from an output portion to an input portion of the amplifier, means in said path for quickly changing the amplifier gain toward a new required value in response to a control impulse transmitted over said path from said output portion, and means in said path for generating a corrective impulse in the same direction and maintaining it operative to bring the gain to the said new value and hold it at such new value notwithstanding decay of said control impulse.

3. The combination with an amplifying repeater having an input and an output of a circuit for deriving a wave from the output, means controlled by the wave so derived for varying a characteristic of the repeater in response to variations in the derived wave, an amplifier connected between said circuit and said means, said amplifier having a gain control circuit, the response time of which is many times slower than that of said means.

4. The combination with an amplifier circuit having an input portion and an output portion of a path leading from the output portion to the input portion having means operating in response to an output variation for quickly changing a characteristic of the amplifier circuit to compensate in part for such variation, and means in said path operating in response to the same variation and having a delayed action for continuing the compensating action of said means indefinitely notwithstanding the compensation of said variation.

5. In a wave transmission system having a wave input and a wave output, means to regulate the system for substantially constant output with varying values of input comprising a control device acting in response to variations in the output of the system to change the translation factor which determines the ratio of output to input of the system, said control device having a given response time, transfer means between the system output and said control device for passing on to said control device a variation from the system output, said transfer means causing said control device to make a compensating change in said translation factor, said transfer means including an element having an initial rapid response to said variations for quickly effecting a compensating change and containing a slow-operate follow-up element responsive to the same variations for causing said control device to maintain a change in said translation factor

after the output has been restored to its value before variation.

6. The combination with an amplifier circuit of a backwardly acting gain control circuit from an output portion to an input portion of said amplifier circuit, said gain control circuit responding to an output variation and having a fast-acting control characteristic tending to compensate output deviations from normal to a first approximation and having follow-up means responding to the same output variation for effecting more exact compensation.

7. In a gain control circuit for an amplifier, means comprising a space discharge tube having a grid for effecting changes in amplifier gain in response to control variations impressed on said grid, self-biasing means for said grid operative following a change in grid voltage in response to a control variation, to build up on the grid a voltage of a magnitude and sign to replace the effect of the control variation on said grid even after the required change in amplifier gain has been effected.

8. In an amplifier circuit, a gain control circuit for effecting changes in gain of the amplifier in response to amplifier output level changes to compensate such changes, a space discharge tube in said gain control circuit having a grid, means to effect initial change in voltage on said grid in response to an amplifier output level change to control the amplifier gain to reduce the change in output level, and means for maintaining a corrective voltage on said tube to maintain the amplifier gain at a changed value even after the initial response to the change in output level has diminished or ceased, comprising a self-biasing connection from the output of said tube to an input element, including a rectifier.

9. In a transmission system having a repeater, means to compensate changes in transmission characteristic of the system comprising a backwardly acting gain control leading from an output to an input portion of said repeater for effecting changes in repeater gain in response to output level variations to compensate such variations, said gain control including means to enable a corrective control to be maintained on the gain of the repeater without requiring continuance of a departure from normal of the repeater output, comprising a tube initially responsive to a change in repeater output level to effect a change in repeater gain, said tube having a delayed self-biasing action for generating and maintaining a gain-controlling effect on said repeater similar to that produced initially in response to a repeater output level change.

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