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WAVE AMPLIFYING SYSTEM

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FIG. 1

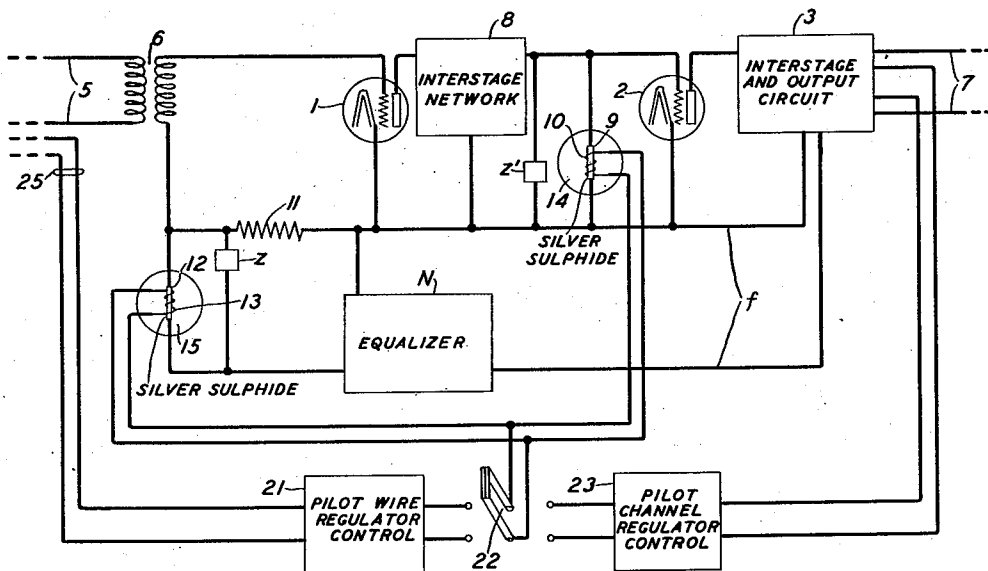
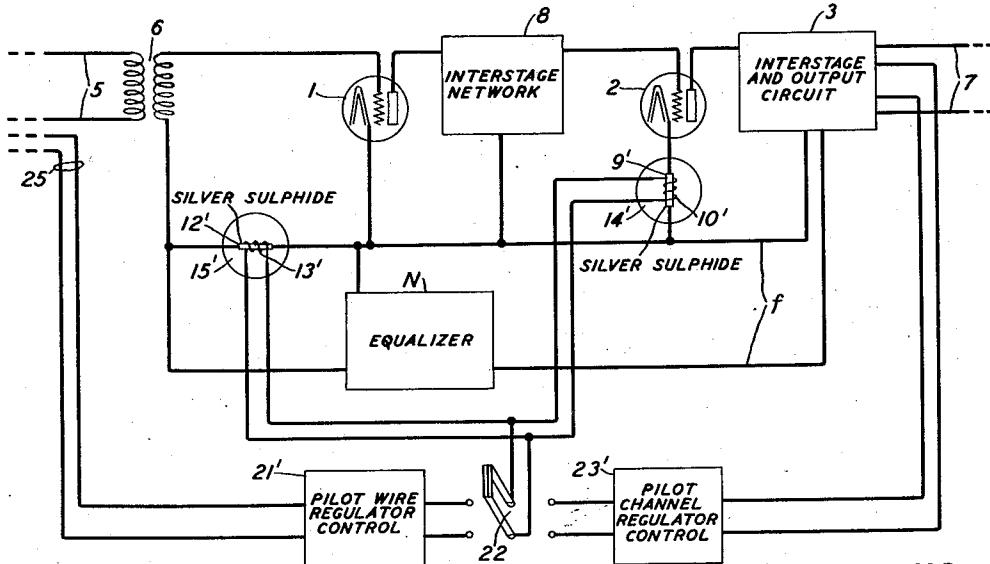


FIG. 2



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WAVE AMPLIFYING SYSTEM

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15 Claims. (Cl. 179—171)

This invention relates to wave amplifying systems, as for example, vacuum tube amplifiers.

Objects of the invention are to control transmission properties of such systems, for example, gain and distortion introduced by the systems, to facilitate application of feedback in the systems, and to reduce singing tendency or maintain proper margin against singing in the systems.

In one specific aspect, the invention is applied to an amplifier with a forwardly transmitting, wave amplifying portion and a feedback path from the output to the input of the amplifying portion for producing negative or gain-reducing feedback around the amplifying portion, for example, to stabilize the gain or reduce the modulation introduced by the amplifier, in accordance with the principles described by H. S. Black in his article entitled "Stabilized feed-back amplifiers," Bell System Technical Journal, January 1934, and in his Patent 2,102,671, December 21, 1937.

With sufficient feedback, the gain of such an amplifier varies substantially as the loss in the feedback path, and is substantially independent of the amplification ratio or transmission efficiency of the amplifying portion. It is usual to control the amplifier gain for any given frequency by changing the loss in the feedback path for such frequency.

However, this change causes variation in the amount of feedback or the loop gain of the amplifier (i. e., the gain in decibels for propagation once around the feedback loop), and the variation in the loop gain may be objectionable. For example, it may unduly reduce the singing margin or the amount of modulation reduction or amplifier gain stability obtained by the feedback action, or objectionably change the amplifier input or output impedance.

A feature of the present invention is provision of means for stabilizing the amount of feedback or the loop gain, for a given frequency, against variation due to change produced in transmission efficiency of the feedback path. For example, such change may be a given decrease made in the transmission efficiency of the feedback path in order to increase the gain of the amplifier, and operation of the loop gain stabilizing means may increase the transmission efficiency of the amplifying portion of the amplifier substantially the given amount in order to reduce variation of the loop gain or maintain the amount of feedback substantially unchanged, as for example, to maintain the feedback at the maximum value that is permitted by the required margin against

singing; or the change in the transmission efficiency of the feedback path may be a given increase made in order to decrease the gain of the amplifier, and then operation of the loop gain stabilizing means may insure decrease of the transmission efficiency of the amplifying portion of the amplifier substantially the given amount in order to reduce variation of the loop gain or maintain the loop gain substantially unchanged, for instance at the maximum value that is permitted by the required singing margin.

If desired, the inverse or complementary changes in transmission efficiency of the feedback path and transmission efficiency of the amplifying portion of the amplifier may be made automatically, as for example by a pilot wire or pilot channel gain control or an automatic volume control. For example, the automatic gain control may vary the temperature (and thereby the resistance) of a heat responsive resistance (thermistor), for instance a silver sulphide resistor in a shunt arm of the feedback path, and the temperature (and thereby the resistance) of a silver sulphide resistor in series in the grid-cathode and plate-cathode circuits of a vacuum tube included in the amplifying portion of the amplifier, to produce the desired changes in the transmission efficiencies of the forward and feedback paths.

Other objects and aspects of the invention will be apparent from the following description and claims.

Figs. 1 and 2 show circuit diagrams of two forms of the invention.

The amplifier of Fig. 1 may be a stabilized feedback amplifier of the general type disclosed, for example, in the above-mentioned patent and published article. It comprises an amplifying path or element shown as including tandem connected vacuum tubes 1 and 2 and interstage and output circuit 3 which may include one or more stages of vacuum tubes. It also comprises a feedback path f shown as including a transmission control network N. The amplifying path or element, that is, the forward path including the elements 1, 2 and 3, may be referred to as the μ -circuit and the feedback path may be referred to as the β -circuit, the significance of μ , β , μ -circuit and β -circuit being as indicated in the patent and published article, just mentioned. The network N may be referred to as the β -circuit network. The quantity $\mu\beta$, the propagation around the closed feedback loop, or the modification that a voltage undergoes in transmission once around the closed feedback loop, may be large compared

to unity, as for example of the order of 50 or 100; and μ , the propagation of the forwardly transmitting path, may be large compared to β , the propagation of the feedback path.

5 The network N may be any suitable transmission control network, for example for amplitude or phase equalization or correction of distortion in the general manner disclosed in the patent and published article just mentioned. For instance, 10 it may be a transmission equalizing network such as network 374 in Fig. 65 of that patent or in Fig. 4 of H. S. Black Patent 1,956,547, May 1, 1934, or network 14 of F. A. Brooks Patent 2,075,975, April 6, 1937, network N of E. B. Payne 15 Patent 2,075,956, April 6, 1937, or network 27 of R. W. Chesnut Patent 2,154,062.

The amplifier receives waves from an incoming line or circuit 5 terminated in amplifier input transformer 6 and transmits the amplified 20 waves to outgoing line or circuit 7. The circuits 5 and 7 may be, for example, sections of a multiplex carrier cable or open wire circuit. For instance, the amplifier may amplify simultaneously the waves of a number of carrier telephone or 25 telegraph channels, or both, extending over a wide frequency range.

The interstage circuit coupling tubes 1 and 2 comprises interstage network 8 and a shunt arm or branch including a thermistor or thermosensitive element 9, as for example a silver sulphide resistor. Associated with resistor 9, but electrically insulated therefrom, is a heating element 10 therefor. The feedback path f comprises a shunt arm including a resistor 11 and comprises 35 a series arm including a thermosensitive element 12, as for instance a silver sulphide resistor. Associated with resistor 12, but electrically insulated therefrom, is a heating element 13 therefor. Elements 9 and 10 are shown in a heating chamber 14; and elements 12 and 13 are 40 shown in a heating chamber 15. Current for heating the elements 10 and 13 to vary the resistance of elements 9 and 12 is supplied from a power source in a regulator control circuit, for example a pilot wire regulator control circuit 21 45 when switch 22 is closed to the left, or a pilot channel regulator control circuit 23 when the switch is closed to the right. The pilot control 21 is, as usual, responsive to resistance changes 50 in a pilot wire or loop circuit, indicated by pilot conductors 25, which may be, for example, a pair of wires that is included in the same lead cable sheath as the signal conductors such as 5 and extends over the length of the line section assigned to the amplifier and is subject to the same 55 temperature variations as the signaling conductors.

With switch 22 closed to the left, increase of attenuation of the line 5 and the pilot wire loop 60 circuit 25 causes the control 21 to decrease the current transmitted to heaters 13 and 10, for increasing the resistances of elements 12 and 9 simultaneously. The increase of resistance 12 increases the loss or reduces the transmission efficiency of the feedback path f or the β -circuit of 65 the amplifier, or in other words reduces the magnitude of β , and thereby increases the amplifier gain to compensate for the increased attenuation of line 5 caused by the increase of temperature of the line and thus maintain a constant transmission equivalent for the line and amplifier; and the increase of resistance 9 decreases 70 the loss or increases the amplification of the forward path or μ -circuit of the amplifier, preferably by the same amount that the loss of the

β -circuit increases, so that the magnitude of $\mu\beta$ remains unchanged.

By additional impedance arms, for instance as shown by Z and Z', controlled by resistances 12 5 and 9, changes in the phase shift of $\mu\beta$, that is, in the phase shift around the over-all feedback loop, may be introduced.

For example, variation of the resistance 12 may produce a substantially flat amplifier gain change across the used frequency band but due to stray 10 capacity produce undesired loop phase shift outside that band. By connecting Z' around resistance 9 and suitably proportioning the constants of impedance Z', the deleterious phase shift outside of the used frequency band may be 15 annulled at the same time that resistance 9 is varied when obtaining the desired amplifier gain settings in the used frequency band.

Further, if by the combination of Z and 12 20 an amplifier gain characteristic is obtained which is not flat across the used frequency range, then as 12 is varied the $\mu\beta$ gain and phase (i. e., the gain and phase around the over-all feedback loop) may tend to change materially. By properly designing the impedance Z' connected across 25 resistance 9, compensatory and opposite change of phase shift, as well as of gain, can be introduced by 9 in transmission through the μ -circuit, that is the forward path of the amplifier. In 30 this way, the $\mu\beta$ gain and phase shift (i. e., the gain and phase shift around the over-all feedback loop) may be maintained constant in the working frequency range, for various temperatures or settings of 12.

If desired, the networks Z and Z' may be 35 designed to give constant loop phase shift, i. e., constant phase angle of propagation around the over-all feedback loop, both inside and outside of the operating frequency range, as the amplifier gain setting is varied by changing temperature 40 of resistance 12.

Decrease of the temperature or the attenuation of the line 5 and the pilot wire 25 causes operations to take place which are the reverse 45 of those indicated above for increase of the attenuation, the current to the heaters increasing so that the β -circuit loss and the μ -circuit gain decrease equally to maintain constancy of the transmission efficiency around the feedback loop, and at the same time to decrease the over-all 50 amplifier gain and thereby maintain constancy of the transmission equivalent of the line and amplifier.

The control 21 may be of any suitable type. 55 For example, it may be of the general type disclosed in Mallinckrodt Patent 2,098,968, November 16, 1937; or the control 21 may be, for example, a power source and a heater current adjusting rheostat such as the power source and the heater current adjusting, pilot apparatus controlled rheostat T of Fig. 3 of E. I. Green Patent 1,918,390, July 19, 1933, and a pilot wire transmission regulator control equipment for operating the rheostat, such as that which operates 65 the gain adjusting rheostat 12 of the above-mentioned H. S. Black Patent 1,956,547.

With switch 22 closed to the right, change of attenuation of line 5 causes control 23, instead 70 of control 21, to operate and the results of such operation are the same as those indicated above for operation of control 21.

The control 23 may be of any suitable type. For example, it may be of the type disclosed in the above-mentioned E. I. Green Patent 1,918,390 75 or of the type disclosed in R. W. Chesnut Patent

2,154,062, April 11, 1939; or it may be of the type disclosed in Fig. 2 of H. S. Black Patent 2,154,888, April 18, 1939.

The energizing circuits such as the plate current supply, grid biasing and cathode heating circuits for the amplifier are omitted from the drawing in the interest of simplicity as they may be of any usual or suitable type.

Fig. 2 shows a modification of the circuit of Fig. 1 in which the amplifier gain control resistor is a resistor 12' in a shunt arm of the β -circuit or feedback path, and in which the resistor for controlling the transmission efficiency or amplification of the forward path or μ -circuit is a resistor 9' in a cathode lead of tube 2 common to the alternating current plate and control grid circuits of the tube. The resistor 9' provides local negative feedback around tube 2, thereby controlling the gain of the stage comprising this tube.

A resistor 13' in a heating chamber 15' with resistor 12' acts as a heating element therefor. A resistor 10' in a heating chamber 14' with resistor 9' acts as a heating element therefor.

The operation of the system of Fig. 2 is generally similar to that of Fig. 1 and will be apparent from the description above of the operation of the latter system. It is to be noted, however, that since gain control resistor 12' is in a shunt arm of the feedback path f , and since increase of resistance 9' reduces the transmission efficiency of the forward path around which the feedback path f is connected, in case elements 12' and 9' have negative temperature coefficients of resistance, increase of the line attenuation should be accompanied by increase of the current transmitted to the heaters 13' and 10', for decreasing the resistances of elements 12' and 9' simultaneously and thereby maintaining the magnitude of $\mu\beta$ constant and maintaining the transmission equivalent of the line and amplifier constant. Similarly, decrease of the attenuation of line 5 should be accompanied by decrease of the current to the heaters 13' and 10', so that the β -circuit loss and the μ -circuit gain decrease equally to maintain constancy of the transmission efficiency around the feedback loop including the forward path and the feedback path f , and at the same time to decrease the over-all amplifier gain and thereby maintain constancy of the transmission equivalent of the line and amplifier.

The control 21' may be of any suitable type. For example, it may be of the type disclosed in the above-mentioned Mallinckrodt Patent 2,098,968 or it may be current source and rheostat such as that of Fig. 3 of the above-mentioned E. I. Green Patent 1,918,390 and a pilot wire regulator control equipment for operating the rheostat, such as that which operates rheostat 12 of the above-mentioned H. S. Black Patent 1,956,547.

The control 23' may be of any suitable type. For example, it may be of the type disclosed in the E. I. Green Patent 1,918,390, just mentioned, or of the type disclosed in the above-mentioned Fig. 2 of H. S. Black Patent 2,154,888.

What is claimed is:

1. The method of operating on a negative feedback amplifier which comprises changing the over-all amplifier gain and making the magnitude and frequency variations of the gain around the feedback loop the same for the changed over-all gain as for the original over-all gain.

2. The method of operating on a negative feed-

back amplifier which comprises changing the over-all amplifier gain and making the magnitude and frequency variations of the gain and phase shift around the feedback loop the same for the changed over-all gain as for the original over-all gain.

3. The method of operating a negative feedback amplifier which comprises changing the propagation of the feedback path at a given frequency and rendering the propagation around the feedback loop under the changed condition substantially the same as before said change by compensatory substantially equal but inverse change in the propagation of the forward path around which the feedback path is connected.

4. The method of operating a negative feedback amplifier which comprises changing the phase shift of the feedback path at a given frequency and rendering the phase shift around the feedback loop under the changed condition substantially the same as before said change by compensatory substantially equal but inverse change in the phase shift of the forward path around which the feedback path is connected.

5. A negative feedback amplifier with means for changing the transmission efficiency of the feedback path at a given frequency, and means whose operation insures change of the transmission efficiency of the forward path, around which the feedback path is connected, inversely and by substantially the same amount.

6. The method of operating a negative feedback amplifier which comprises changing the loss and the phase shift of the feedback path at a given frequency and rendering the gain and the phase shift around the feedback loop under the changed condition substantially the same as before said change by compensatory change in the gain and the phase shift of the forward path around which the feedback path is connected.

7. A negative feedback amplifier comprising means for changing the over-all amplifier gain whose operation tends to change the feedback, and means coordinately controlled for making compensatory changes in the feedback and thereby making the magnitude and frequency variation of the gain around the feedback loop the same for the changed over-all gain as for the original over-all gain.

8. A reverse feedback amplifier with means for changing the transmission efficiency of the feedback path at a given frequency, and means for simultaneously inversely by substantially the same amount changing the transmission efficiency of the forward path around which the feedback path is connected.

9. A negative feedback amplifier with means to increase the transmission efficiency of the feedback path for reducing the amplifier gain, means to correspondingly decrease the transmission efficiency of the forward path around which the feedback path is connected and thereby make the magnitude and frequency variation of the gain around the feedback loop the same as before said increase and decrease, and means comprising common operating means for said two first-mentioned means for causing said increase and said decrease to take place together.

10. A wave translating system comprising an amplifier having a forward amplifying path transmitting a broad frequency band of waves and a feedback path connected around said forward path for producing reverse feedback in said amplifier, a network in said feedback path having a transmission characteristic varying with

frequency over said band for controlling the overall amplification of said amplifier, and means operable for inversely varying the transmission efficiencies of said paths and causing the variation of the transmission efficiency of said amplifying path to substantially equal in magnitude the variation of the transmission efficiency of said feedback path.

11. A negative feedback amplifier with gain control means comprising a temperature dependent impedance in the feedback path, transmission efficiency control means comprising a temperature dependent impedance in the forward path around which the feedback path is connected, and means coordinately controlling the temperatures of said impedances and thereby causing variation of their impedance values that produces substantially equal but inverse changes in the transmission efficiencies of said paths.

12. In a gain control system, a negative feedback amplifier with gain control means comprising a heat-responsive resistor in the feedback path and transmission control means comprising a heat-responsive resistor in the forward path around which the feedback path is connected, current responsive heating means for heating said resistors, and means for supplying heating current to said heating means and so changing said heating current that the resulting changes in the resistances of said resistors inversely vary the transmission efficiencies of said paths substantially equally.

13. In an automatic gain control system, an amplifier comprising a forward amplifying path and a feedback path connected around said forward path for producing negative feedback in said amplifier, a silver sulphide resistor in a shunt arm of said feedback path, means for varying

the transmission efficiency of said forward path without materially affecting the transmission efficiency of said feedback path including a silver sulphide feedback resistor producing in a portion of said forward path negative feedback that increases with increase of the resistance of said feedback resistor, current responsive means for heating said resistors, and an automatic gain regulator control circuit for supplying said current.

14. In an automatic gain control system, an amplifier comprising a forward amplifying path and a feedback path connected around said forward path for producing negative feedback in said amplifier, a silver sulphide resistor in a series arm of said feedback path, means for varying the transmission efficiency of said forward path without materially affecting the transmission efficiency of said feedback path including a silver sulphide resistor in a shunt arm of said forward path, current responsive means for heating said resistors, and an automatic gain regulator control circuit for supplying said current.

15. The method of operating a negative feedback amplifier having the transmission efficiency of the feedback path vary over a range of frequencies which comprises changing the transmission efficiency and the phase shift of the feedback path at frequencies in said range and rendering the transmission efficiency and the phase shift around the feedback loop under the changed condition substantially the same as before said change by compensatory substantially equal but inverse change in the transmission efficiency and the phase shift of the forward path around which the feedback path is connected.

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