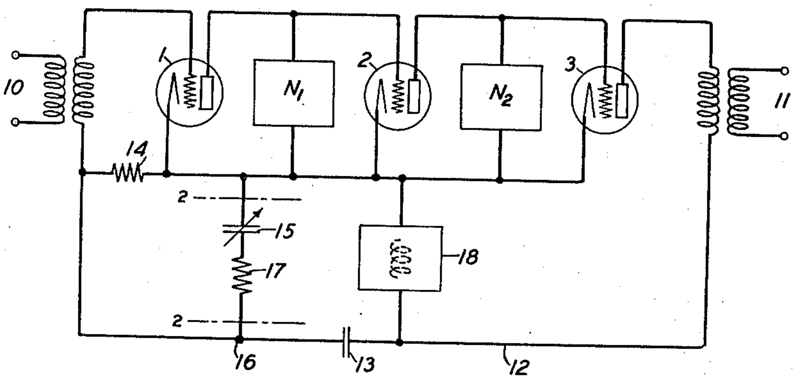
July 16, 1940. J. M. WEST 2,208,144

VARIABLE GAIN FEEDBACK AMPLIFIER

Filed March 10, 1938

FIG. 1



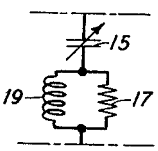
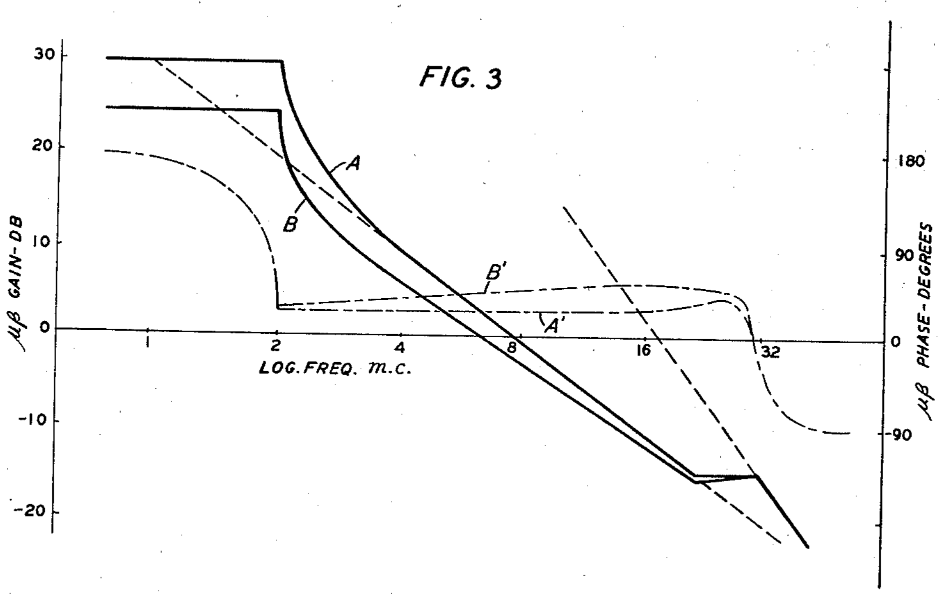


FIG. 2

FIG. 3



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VARIABLE GAIN FEEDBACK AMPLIFIER

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5 Claims. (Cl. 179—171)

The present invention relates to electrical wave amplifiers and particularly to broad band amplifiers of adjustable gain.

A general object of the invention is to provide gain adjustment in a stabilized feedback amplifier within the operating frequency band in effective and satisfactory manner.

It has been proposed heretofore to vary the gain of a stabilized feedback amplifier by use of a condenser type potentiometer in the feedback or β path. This has proved effective as a means for producing gain changes that are flat throughout the transmitted band, which may be, by way of example, the band used for multiplex carrier transmission on lines or in radio or other high frequency systems. It is found, however, that the use of a condenser potentiometer in shunt across the feedback loop as heretofore proposed raises a difficulty in applying the principles of feedback amplifier design disclosed in H. W. Bode Patent No. 2,123,178, issued July 12, 1938, in that it has a tendency to reduce or destroy the phase margin at the upper limiting frequencies of the wave components traversing the $\mu\beta$ loop, thereby limiting the amount of feedback that can be used.

In accordance with the present invention the convenience and effectiveness of the condenser type potentiometer as a flat gain control are retained but the high frequency phase margin is not reduced harmfully, if at all.

In a specific embodiment the invention comprises a series impedance in the condenser shunt arm of such character as not to impair the operation of the condenser potentiometer over the useful band while permitting the total shunt impedance to hold up to the required value in the region of the upper limiting frequencies traversing the loop.

The invention and its various features will be more clearly understood from the following detailed description taken in connection with the drawing, in which:

Fig. 1 is a schematic circuit diagram of an amplifier equipped with one form of gain controlling circuit in accordance with the invention;

Fig. 2 shows a modification according to the invention; and

Fig. 3 shows curves illustrating an example of operating characteristic of an amplifier according to the invention.

Fig. 1 shows a three-stage amplifier comprising triodes 1, 2 and 3 with interstage networks N_1 and N_2. It will be understood that as regards the amplifier, the showing is general and that tubes other than triodes are contemplated as well. Also the direct current supplies and connections are omitted for simplicity since any known or usual circuits for these purposes are to be assumed. An input 10 leads up to the grid of stage 1 and an output or load circuit 11 is coupled to the last anode circuit.

The amplifier is provided with a gain reducing feedback path indicated as leading from a suitable point in the output side of stage 3 by way of lead 12, blocking condenser 13 and resistance 14 to the cathode of stage 1, the grid of this stage being connected to a point in resistor 14 remote from the cathode. This feedback connection is of the type and for the purposes generally disclosed in U. S. Patent 2,102,671 of H. S. Black issued December 21, 1937. That is, the feedback voltage is in a direction and of an amount to reduce substantially the gain of the amplifier in order (among other things) to increase its linearity and stability of amplification.

As an example of one use to which the amplifier of Fig. 1 may be put, it may be inserted in a broad band transmission line such as a multiplex carrier telephone line to amplify in suitable manner the waves comprised in the entire frequency range traversing the line. This range is referred to as the useful or utilized range or band. Within this band the resultant or overall amplification is equal to the amplification without feedback minus the reduction in amplification due to the feedback. In the usual terminology, the gain or amplification with zero feedback is μ and the gain with negative feedback is equal to

$$\frac{\mu}{1-\mu\beta}$$

It is convenient to refer to the amplifying portion or forwardly transmitting portion of the circuit as the μ-circuit or μ-path and the feedback circuit as the β-circuit or β-path. (Exact definitions are given in Black's patent, cited above, to which reference may be made.)

When $|\mu\beta|$ is very large compared to unity, the overall gain is substantially proportional to

$$\left|\frac{1}{\beta}\right|$$

so that the overall gain, shape of characteristic, etc. are determined by the design or adjustment of the β-circuit. For the purpose of adjusting the gain of the amplifier of Fig. 1 (still keeping $|\mu\beta|$ large compared to unity) the value of β is controlled by the condenser potentiometer comprising condensers 13 and 15. The impedance of 13 within the band is very high compared with that of the feedback circuit to the right of 13 in the figure. The impedance to the left of the point 16 is high compared to that of 13 and to that of the shunt 15, 17. Under these conditions, condensers 13 and 15 (neglecting for the moment resistance 17) form a potential divider, by which a proportionate amount of the voltage in the feedback circuit is applied to the grid of tube 1 under control of variable condenser 15. In this way the overall gain of the amplifier is varied and moreover the gain changes are independent of frequency within the utilized band since 15 and 13 are both capacitive impedances which behave similarly over the frequency band.

It will be understood that the condensers 13 and 15 do not interfere with the use of equalizers or wave-shaping networks in the β-circuit. These would be included to the right of the condenser 13 in the figure.

At 18 there is shown a shunt impedance across the feedback circuit which in a typical case might be an independent gain control or it may be a network for any suitable purpose. This network is assumed to exhibit an inductive reactance at the upper limiting frequencies so as to anti-resonate with the parasitic capacities and increase the feedback (which turns positive) in the upper limiting frequency range.

This is illustrated in the curves of Fig. 3 where characteristic A gives the $\mu\beta$ gain over the useful band (illustrated as extending from about 0.06 megacycle to 2 megacycles) and up to 30 megacycles, the topmost frequency of interest, corresponding to one gain setting of the condensers 13 and 15. Curve B is a similar curve corresponding to a different gain setting. These curves are seen to fall off rapidly just above the useful band and then to assume a definite slope and as the upper limiting frequencies are approached, the slope changes rather abruptly upward. This rise is due to the anti-resonance of the shunt inductance of network 18 and the parasitic capacities. However, if it were not for the presence of resistance 17, the capacity 15, which has substantially zero impedance at 30 megacycles, would shunt out the anti-resonant impedance of the feedback path at 30 megacycles and result in a much less favorable shape of curve. For example, the curves would be falling instead of rising or holding up as the 30 megacycle point is approached. As disclosed in the Bode patent referred to, such shape of $\mu\beta$ gain curve (without resistance 17) would be accompanied by a phase shift characteristic that would reach zero at some frequency, well below 30 megacycles, at which the $\mu\beta$ gain might still be positive. This would result in a less favorable singing margin.

By use of resistance 17, however, curves generally similar to curves A and B are obtainable. The corresponding phase shift characteristic A′ or B′ does not turn down and reach zero until well past the frequency at which the gain has become negative. This is due to the shunt loss introduced across the feedback path by network 18 assisted by parallel resistance 17. In one case resistance 17 had a value of 500 ohms which within the useful band was small compared with the impedance of condensers 13 and 15 each of which may be of the order of something less than 100 micromicrofarads throughout the entire range of adjustment.

It is clear from what has been said that the purpose of resistance 17 is to make the shunt impedance across the feedback circuit high at the highest frequencies of interest while preferably having negligible effect upon the gain adjustment in the useful band. Various types of networks will occur to those skilled in the art which could be used to good advantage in place of the simple resistance 17. A simple type of network is given for illustration in Fig. 2 in which inductance 19 has the effect of shunting out the resistance 17 in the useful band where 19 has very low impedance, but of effectively introducing resistance 17 at very high frequencies where 19 has high impedance. More complicated networks to give closer approximation to the ideal or desired shape of curve may be used.

The invention is not to be construed as limited by the numerical values given nor by the circuit details since these are for illustration. The scope of the invention is defined in the claims.

What is claimed is:

1. In a negative feedback broad band amplifier having a forwardly transmitting portion and a feedback circuit, said amplifier possessing a phase margin against singing at high frequencies outside the utilized band, means comprising a variable capacity in shunt relation to said feedback circuit for varying the overall gain within the utilized band and an impedance in series with said capacity for preventing the capacity from reducing the phase margin at the said high frequencies, said impedance having negligibly small effect on the gain within the utilized band.

2. In a broad band feedback amplifier having a μ portion and a β portion, said amplifier possessing a phase margin against singing at the high frequency end of its transmission range, means for controlling the amplifier gain within the utilized band comprising an adjustable capacity in shunt relation to said β portion, and a resistive impedance in series with said adjustable capacity, the value of the resistive impedance being too small to have a controlling effect on the gain within the utilized frequency band but high enough at frequencies approaching the high frequency limit of the $\mu\beta$ gain characteristic to prevent loss of the aforesaid phase margin.

3. In a broad band negative feed back amplifier having an input circuit and an output circuit, a feedback path from the output to the input feeding back waves in gain reducing sense, a series capacity in said path and a shunt capacity across said path, said two capacities forming a potential divider for controlling the magnitude of the fed-back waves, and an impedance in series relation with the shunt capacity having a value of impedance that is too small to have a controlling effect on the gain within the utilized band, and having a value of impedance that is high compared to that of said shunt capacity and of parasitic shunt capacities in the region of the upper limiting frequencies traversing the circuit.

4. An amplifier according to claim 3, in which said impedance comprises a resistance shunted by a reactive impedance of low value of impedance compared to the resistance in the operating range but of much higher value than the resistance in the region of the upper limiting frequencies traversing the circuit.

5. In a broad band amplifier circuit, a negative feedback circuit therefor, said amplifier possessing a phase margin against singing in the region of the upper limiting frequencies traversing the circuit, means for controlling the gain of the amplifier comprising a condenser in shunt relation to the feedback circuit, and an impedance in series with said condenser the value of impedance of which is small compared to that of said condenser within the utilized frequency band but the effective total resistance of which is high enough at frequencies in the region of the upper limiting frequencies traversing the circuit to prevent loss of the aforesaid phase margin.

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