Jan. 23, 1945. H. W. BODE 2,367,711

BROAD BAND AMPLIFIER

Filed Jan. 12, 1943 3 Sheets-Sheet 1

FIG. 1

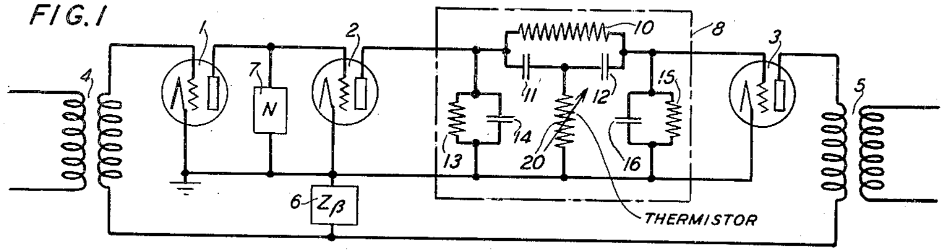


FIG. 2

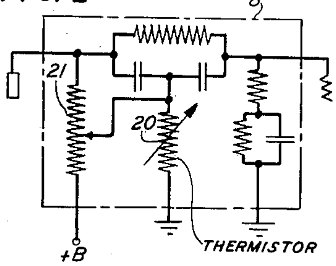


FIG. 3

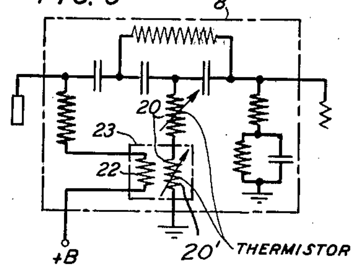


FIG. 4

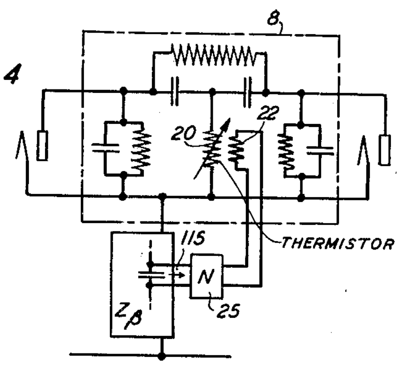


FIG. 5

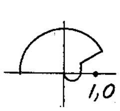


FIG. 6

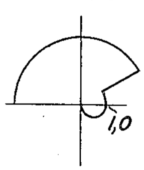


FIG. 7

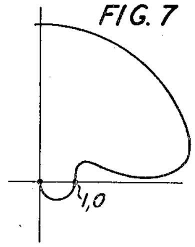
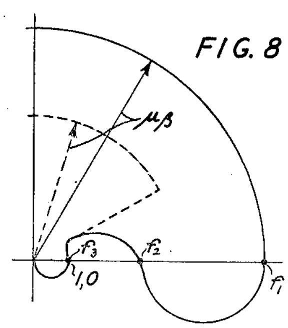


FIG. 8



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BROAD BAND AMPLIFIER

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FIG. 9

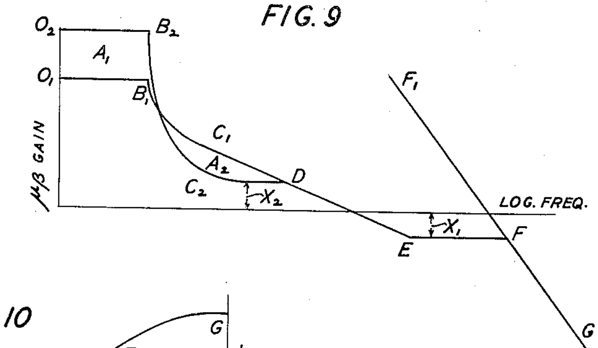

FIG. 10

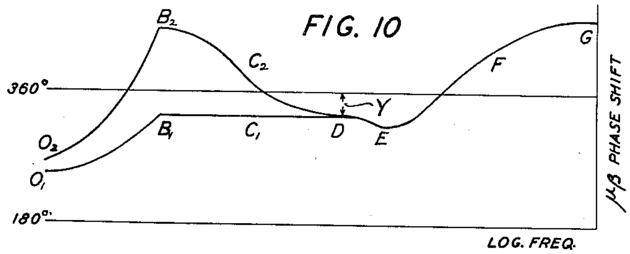

FIG. 11

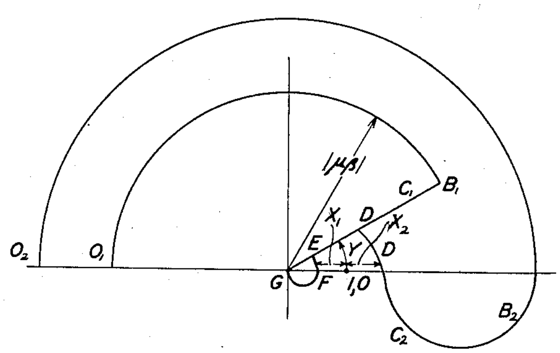

FIG. 12

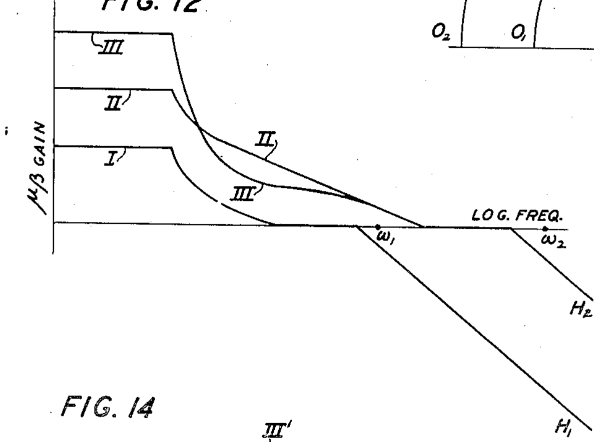

FIG. 14

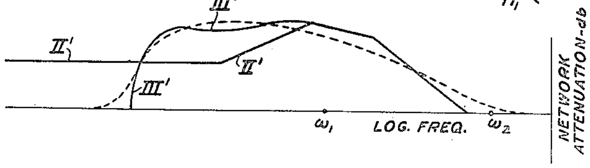

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FIG. 13

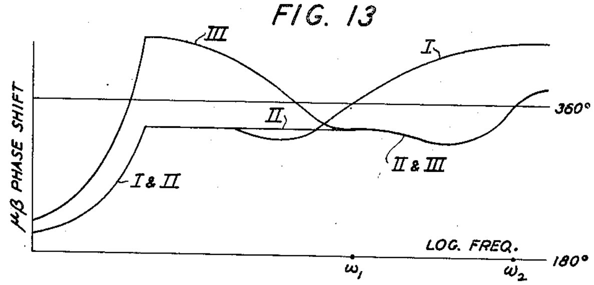


FIG. 15

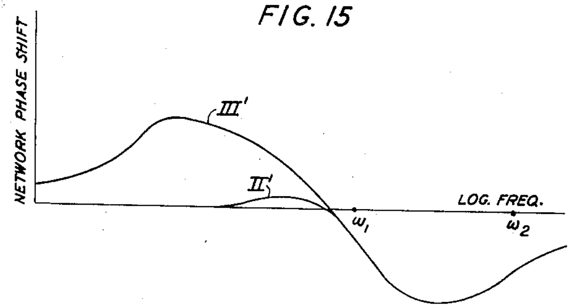


FIG. 16

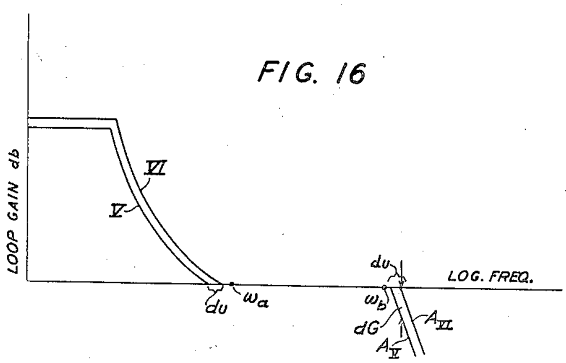
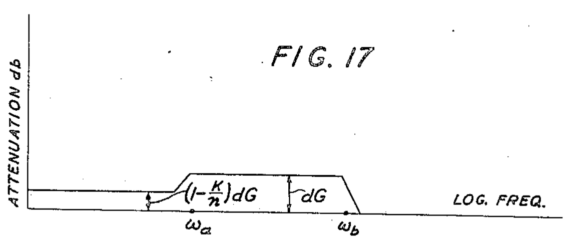


FIG. 17



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Patented Jan. 23, 1945

2,367,711

UNITED STATES PATENT OFFICE

2,367,711

BROAD BAND AMPLIFIER

Hendrik W. Bode, New York, N. Y., assignor to Bell Telephone Laboratories, Incorporated, New York, N. Y., a corporation of New York

Application January 12, 1943, Serial No. 472,123

10 Claims. (Cl. 179—171)

The present invention relates to broad band amplifiers using negative feedback to secure such well-known advantages as increase of linearity and stability of amplification.

It is known that the degree of improvement in such factors as linearity and gain stability is roughly proportional to the amount of feedback used so long as the feedback is large. A practical limitation is placed upon the amount of feedback that can be used in the transmission frequency band by the tendency of the amplifier to sing at some high frequency well above the band. This presents a problem of so controlling the gain and phase shift around the feedback loop as to secure the maximum amount of feedback in the useful band while maintaining a suitable margin against singing at potential singing frequencies. My Patent 2,123,178, granted July 12, 1938, discloses how to control the transmission characteristics around the feedback loop to insure complete stability against singing without the sacrifice of gain in the useful band. Amplifiers designed in accordance with the teachings of that patent are referred to as completely or absolutely stable amplifiers.

As an alternative to providing a margin against singing, it has been suggested that this margin could be sacrificed in the interest of increased useful gain provided the sing amplitude is held down to so low a level that no harmful overloading is produced by it. It was proposed to operate a gain control or a loss device capable of responding to a singing condition to control the net gain around the feedback loop in such manner as to oppose an increase of the sing amplitude above some predetermined value too low to produce harmful overloading.

The present invention represents an improvement over the latter type of amplifier, and achieves a marked increase in useful gain and feedback factor by controlling both the gain and phase shift characteristics of the feedback loop in response to the singing condition. In my prior patent it was shown how to control the rate of diminution of the magnitude of the feedback factor ($\mu\beta$) in the cut-off ranges, especially in the high frequency cut-off range above the useful band, to provide optimum attenuation and phase characteristics for the purpose of securing maximum feedback in the used band with minimum loss of useful frequency range and with complete stability against singing. A restriction was necessarily placed upon the rate of diminution of the magnitude of the feedback factor with increasing frequency in the cut-off region by the assumed requirement that the circuit be completely stable against singing. In accordance with the present invention, this restriction is observed at all gain levels below that at which the sing condition begins so that the circuit remains completely stable while being turned on or when either momentarily passing through low gain levels or kept at low gain level indefinitely, but as soon as a sing condition is established with increasing gain the invention provides for more or less radically reshaping the course of the feedback factor over the cut-off region in such manner as to increase in corresponding degree the magnitude of the feedback factor in the useful range. This type of control enables a much greater feedback ratio to be obtained over the useful band than could be had with the mentioned prior art types of sing control.

In accordance with a feature of the present invention, a network is included at a suitable point in the feedback loop, adapted to have its attenuation and phase characteristics changed under control of a current responsive device forming an element of the network. The arrangement is such that this device is affected by the sing current and under control of the sing current it changes both the attenuation and phase shift of the feedback loop in mutually aiding manner to permit an increase of feedback and a controlled sing condition. The current responsive device can advantageously be a thermistor arranged to be heated under control of the sing current.

The nature and objects of the invention will appear more fully from the following detailed description in connection with the drawings, in which:

Fig. 1 is a schematic circuit diagram of a complete amplifier circuit incorporating the invention in one form;

Figs. 2, 3 and 4 show modified types of network that may be substituted in the circuit of Fig. 1; and

Figs. 5 to 17, inclusive, show graphs to be referred to in the description.

Fig. 1 is intended to represent by way of illustration a typical broad band feedback amplifier such as might be used as a repeater in a multiplex carrier telephone system, a television system, or the like. It is shown as comprising three stages represented by the tubes 1, 2, and 3 with an input transformer 4 and output transformer 5 for coupling to sections of line and with a feedback network 6. The first interstage network is shown at 7 and the second interstage network at 8. The latter is represented as a network of the bridged-T type of symmetrical proportions. It includes as the series arm a resistance 10 and two capacities 11, 12. The plate circuit branch comprises resistance 13 and parallel capacity 14. The grid circuit branch comprises resistance 15 and parallel capacity 16. In a typical case the capacities 11, 12, 14, and 16 may all be equal; the resistances 13 and 15 may be equal; and the resistance 10 may have twice the magnitude of resistance 13 or 15. Bridged across at the center point is the thermistor or other variable control device 20 whose function it is to control the attenuation and phase shift characteristics of the interstage 8 in response to a sing current developed in the amplifier, as will be more fully disclosed hereinafter.

For purposes of simplicity, the battery supplies have been omitted from the circuit of Fig. 1. Also, it will be understood that the tubes would ordinarily be pentodes in the type of system referred to. In general, the number of stages, type of feedback used and type of transmission system are not critical, since the invention is capable of use in various types of amplifiers, so that the circuit of Fig. 1 is to be regarded as illustrative rather than limiting.

Figs. 2 and 3 show for illustration modified types of interstage network that may be used at 8 in Fig. 1. In each of these modified types the thermistor 20 is provided with a bias for bringing its temperature to a normal operating value. In this way the thermistor is rendered more sensitive to small changes in heating current. In Fig. 2 this is done by tapping off a small amount of heating current from plate supply resistor 21 and passing this current conductively through the thermistor 20. In Fig. 3, alternatively, a portion of the plate current supplied to the preceding tube is used to heat a heater resistance 22 which is associated in heat transfer relation to thermistor 20', both elements being shown as included in a suitable enclosure 23 which may be heat insulated to a suitable degree, if desired, to control the time lag. The thermistor 20 may in this case be additional to thermistor 20' or, if desired, a single thermistor 20' may be used. In the Fig. 1 construction the thermistor 20 is illustrated as heated only by the high frequency sing current flowing in the amplifier circuit. In the cases where a thermistor bias is used the thermistor is heated by the steady bias current as well as by the sing current.

Fig. 4 shows an alternative manner for controlling the thermistor 20 in which a constant resistance network 25 is connected to a point in the feedback network 6 and the current transmitted through the network 25 is applied to a heater 22. Except for the configuration of the interstage 8 and the network 25 the circuit may be in accordance with Figs. 8 and 9 of my prior patent referred to, replacing the lower of the two 115-ohm resistances shown in Fig. 9 by the input impedance of the network 25 which is made to have the value of 115 ohms. In this case the sing current circulating in the feedback loop is used to vary the resistance of the thermistor 20 by flowing through resistance 22 associated with the thermistor 20 in such a way as to heat the latter. Network 25 may have any desired frequency characteristic and may, for example, highly attenuate current of a frequency in the neighborhood of the upper edge of the used band or currents of frequencies in the band and for a considerable range above the band to insure against operation of the equalizer by any except currents of the intended frequencies.

Fig. 8 shows a polar plot (dotted curve) of an absolutely stable amplifier designed in accordance with the disclosure in my amplifier patent referred to, while the solid curve shows a Nyquist stability or conditional stability characteristic. The $\mu\beta$ value of the latter is shown as much greater and it has been recognized that this offered the possibility of a valuable improvement in amplifier operation provided the additional amount of feedback could be obtained with reliable operation in other respects. The solid curve crosses the zero phase axis at three points representing three frequencies f_1, f_2 and f_3 in ascending order. One difficulty in attempting to operate with conditional stability has been that as the envelope expands or contracts with the building up or dying down of tube gain, there is a danger that either the f_1 or f_2 cross-over might pass through the 1, 0 point causing the amplifier to remain permanently in a sing condition with a correspondingly low value of $|\mu\beta|$. This could happen, for example, when the amplifier is turned on and the gain builds up from zero or again as the tubes age and lose gain.

The present invention completely obviates this difficulty for the amplifier is made to have unconditional stability at all lower gains than that required to produce a sing at or near the frequency f_3 and the cross-overs at f_1 and f_2 do not exist until a sing is definitely established at some frequency near f_3. This is represented by the curves in Figs. 5 to 8 which show how the polar diagram grows as the amplifier is turned on and the gain increases. In Fig. 5 the circuit has unconditional stability. In Fig. 6 the circuit is just on the point of singing at a frequency higher than f_1 or f_2. In Fig. 7 the sing has been established and the envelope is beginning to be deformed by the thermistor controlled network to contribute more favorable gain and phase shift for changing over to conditional stability. In Fig. 8 the solid curve has looped over, giving the characteristic conditional stability case. If the tube gain is lowered the curve shapes change in the reverse direction, that is, in the order from Fig. 8 to Fig. 5.

As an aid to determining the design requirements of the network 8 in relation to the rest of the amplifier some general discussion will be given with special reference to Figs. 9, 10, and 11. In each of these figures the curve O_1, B_1, C_1, D, E, F, and G is the characteristic of an unconditionally stable amplifier as developed in my amplifier patent referred to. The curve F', F, G defines the high frequency asymptote and the portion D, E, F shows the optimum shape of the characteristic as it approaches and merges with the high frequency asymptote. As the curves are drawn in these three figures, a gain margin X_1 and a phase margin Y are indicated as is usual in the design of completely stable amplifiers. The position of the limit F', F, G is determined by the available tube gains up to the frequency at which the parasitic capacities become controlling and it may be assumed as a matter of basic design that the portion of the characteristic E, F, G as determined by the teachings of my amplifier patent gives the most advantageous shape for securing maximum feedback. For simplicity it will be assumed that this portion of the characteristic should be the same for either the unconditionally or the conditionally stable design. It remains, therefore, to determine what type of shaping is possible at lower frequencies to secure maximum feedback with conditional or Nyquist stability while keeping the attenuation and phase unchanged over the range E, F, G. Characteristics for a conditionally stable design are given on these three figures at O_2, B_2, C_2, D, E, F, G and in Fig. 9 areas A_1 in the band and A_2 in the cut-off region are indicated respectively above and below the characteristic of complete stability.

It can be shown that for maximum feedback in the band, A_1 should equal A_2 when plotted on a linear scale on the condition that both curves coincide in the region E, F, G. This may be shown by the aid of Equation 7 of my amplifier patent (2,123,178) which states the relation

$$B_c=\frac{2\omega_c}{\pi}\int_0^\infty\frac{A-A_c}{\omega^2-\omega_c^2}d\omega$$

where A_c and B_c are the attenuation and phase at $\omega=\omega_c$ and A is the attenuation at the general point ω. Let this equation be applied to the difference between the characteristics in Fig. 9. Then A=0 beyond the point D in Fig. 9 since both characteristics follow the path D, E, F, G here. Also, let ω_c be chosen as a point beyond D. Then $A_c=0$ and the equation reduces to

$$B_c=\frac{2\omega_c}{\pi}\int_0^D\frac{A}{\omega^2-\omega_c^2}d\omega$$

since the integrand is zero beyond D. But ω_c^2 is always greater than ω^2 in the new integrand and is much greater if ω_c is well to the right of D. Thus we have approximately

$$B_c=-\frac{2}{\omega_c\pi}\int_0^D A\,d\omega$$

On the basis of coinciding attenuation characteristics to the right of D in Fig. 9, this last expression shows that the phase characteristic in the neighborhood of the cross-over, or at high frequencies generally, will not be substantially affected by the change from unconditional to conditional stability provided the total area under the attenuation characteristics at lower frequencies is kept constant, or in other words, provided $A_1=A_2$ when plotted on a linear frequency scale. Fig. 9 is plotted to a logarithmic frequency scale for convenience but it is obvious that with a linear scale the potential area A_2 can be very large, the limit being reached when the line B_2C_2 comes vertically down to the horizontal axis. The greatest advantage from conditional stability is obtained, therefore, when B_2C_2 is steep and the margin X_2 (Fig. 9) is small, giving the largest value for A_2 and, consequently, for A_1.

The attenuation and phase shift requirements of the interstage network **8** can be determined in the light of the foregoing discussion and from the given amplifier characteristics. To illustrate this, reference will be made to Figs. 12 to 15. In Fig. 9 in order to make the demonstration in regard to equality between areas A_1 and A_2 quite general, the characteristics assumed a no-sing condition. This was true also of the characteristics given in Figs. 10 and 11. Figs. 12 and 13 are similar to Figs. 9 and 10 but are for the case in which the margin X_1 has been reduced to zero, so that in the case of curves I and II the amplifier is on the point of starting to sing. It is desirable in the practice of the present invention to allow this condition to be reached well below the full gain of the tubes as indicated by curve I and also by Fig. 6. This allows the controls adequate range in which to operate and permits the conditionally stable characteristic to be fully established to maximum advantage at the normal or expected operating point of the amplifier. Curve I is a normal unconditionally stable cut-off characteristic for the given instantaneous asymptote H_1. Curve II is the corresponding absolutely stable cut-off which is appropriate for the asmyptote H_2 which is realized in the circuit after the tubes have reached their full gain. Curve III of Fig. 12 shows curve II deformed into a conditionally stable characteristic. The typical features of increased feedback in the useful band, a region of very high cut-off rate just above the useful band and a region of roughly constant gain somewhat further out, which were illustrated in Fig. 9, reappear here. Also, at still higher frequencies from ω_1 up to the asymptote H_2 the curves II and III coincide. Similarly, for the loop phase shift characteristics shown in Fig. 13, there is a deformation of shape in the cut-off region in going from curve II to curve III but curves II and II merge and continue as one beyond ω_1.

The curves in Fig. 14 show the changes in the attenuation characteristic of the network **8** which are brought about by variation of the element **20** under control of the sing current, and the curves of Fig. 15 show the corresponding changes in phase characteristic of the network. Since a sing begins at the gain represented by curve I, the difference between curves I and III, less the change in tube gain, gives the required attenuation change to be effected by the network under control of the sing. This is given by curve III′ of Fig. 14. The dotted line curve shows a reasonable approximation for a practical design. Curve II′ of Fig. 14 has been drawn as an aid to drawing the required characteristic III′. Curve II′ shows the difference between curves I and II and is what would be required for the absolutely stable characteristic II (with zero margin). By not introducing the loss corresponding to II′ in the useful band the $\mu\beta$ gain is allowed to rise to the full value represented by III.

Curves III′ in Figs. 14 and 15, therefore, represent the required change in attenuation and phase characteristics which the network must introduce in response to the actuation of the thermistor or other control **20**, to permit the amplifier to work according to the assumed specifications. The curve can be described generally as a broad bulge in attenuation extending from the upper edge of the useful band to approximately the loss cross-over of the final amplifier. The curve should have, preferably, a steep rise at the lower edge, near the useful band, and a considerably more gentle trail-off near the upper edge. The accompanying phase shift changes appear in Fig. 15, including the introduction of some phase shift in the useful band and a relatively large amount in the cut-off region above the band.

The $\mu\beta$ attenuations corresponding to the characteristics given in Fig. 12 are the attenuations of the entire loop including N (7), equalizer **8** and the feedback impedance Z_β (6) while the characteristic III′ of Fig. 14 is the attenuation bulge that must be inserted under control of the variable element **20**; so that with the type of circuit given in Fig. 1 this bulge must be put in by the equalizer **8** alone. It is, of course, possible to apportion the total attenuation differently. The equalizer **8** can introduce a normal attenuation and phase plus a controlled variable attenuation and phase or two different networks may be used for separately contributing the normal and the variable components respectively. Alternatively, the variable component can be introduced partly at one point in the loop and partly at some other point, although from the standpoint of simplicity of design it is better to provide a single control where a sufficient degree of change can be effected by a single control. With the type of network shown at 8 there is sufficient frequency discrimination between signal and sing components so that only the latter component heats the thermistor control element 20 and as this element varies in resistance the attenuation and phase of the network in the cut-off range both vary progressively in the general manner shown in Figs. 14 and 15. Equalizer 8 also contributes to the normal $\mu\beta$ attenuation required to give the absolutely stable characteristic I of Fig. 12.

While for the purpose of achieving maximum value of feedback factor in the useful band the invention provides for reshaping the $\mu\beta$ characteristic in the high frequency cut-off region as has been described, it is pointed out that some advantage can be gained from control of the loop gain and phase shift without going so far as to reshape the loop feedback characteristic in this region. Consider, for example, the case of a completely stable amplifier design where the gain margin X_1 (Fig. 9) is small so that it might be expected that in the intended use of the circuit there would be times when this gain margin might be wiped out for certain times or under certain conditions. The circuit then comes into the condition illustrated by the diagram of Fig. 6. By providing a network such as in the circuit figures of the drawings, a sing current starting as a result of the disappearance of the gain margin would produce a helpful change in both attenuation and phase around the loop such as to hold the sing to an innocuous level and allow the feedback factor in the band to remain high. Also a permanent sing condition is avoided and the circuit returns to stable condition when the assumed change that reduced the gain margin to zero disappears. The method of the invention is far more effective for this purpose than the flat gain control method of the prior art referred to earlier. This method involving a simultaneous control of both attenuation and phase is within the invention even though there be no substantial reshaping of the loop characteristic in the high frequency cut-off region.

An alternative way of specifying the equalizer loss characteristic will now be given with special reference to the curves of Fig. 16. The loop gain characteristic V is associated with the high frequency asymptote A_V and the loop gain characteristic VI representing an increase in tube gain over curve V has the asymptote A_{VI}. The change in asymptotic gain is represented by dG and is supposed to be differentially small. Let the asymptotic gain have a slope of $6n$ decibels per octave. (In a typical coaxial line broad band amplifier $n=3$.) Let the theoretical cut-off characteristic near the zero gain axis have the slope $6k$ decibels per octave. (k here is the parameter used in Equation 12, et seq., of United States Patent 2,123,178 above referred to and in a typical case may have a value of about 5/3. It can be regarded as specifying the phase margin in the region just before the loss cross-over even when the final cut-off curves are considerably deformed from the theoretical.)

With a logarithmic frequency scale, the interval du at ω_b in octaves is

$$\frac{dG}{6n}$$

octaves. This is also the interval du at ω_a between the curves V and VI since the breadth of the flat part of the ideal characteristic on a logarithmic frequency scale is fixed. The difference, therefore, between the curves V and VI is

$$6k\,du=\frac{k}{n}dG$$

Further

$$\frac{\omega_a}{\omega_b}=\frac{k}{n}$$

and ω_b is approximately the frequency of the controlled sing.

The total change between the characteristics V and VI is equal to the joint effect of the change in tube gain, dG, and the change in loss of the variable equalizer. This leads to a simple specification of the equalizer characteristic. Thus in the range ω_a to ω_b, where the net change is zero, the equalizer loss should be equal to the increase in tube gain, dG. Below ω_a the difference between curves V and VI corresponds to an equalizer loss

$$\left(1-\frac{k}{n}\right)dG$$

Above ω_b the equalizer loss should diminish rapidly to zero, since the analysis assumes that the full change in tube gain is applicable to improve the asymptote.

The corresponding equalizer characteristic is shown by Fig. 17. Strictly speaking, it applies only for differentially small changes in tube gain, but it should be roughly aplicable to gross changes also, if we take a suitable average value for the significant points, such as the "frequency of sing," ω_b, in the characteristic.

The area under the curve of Fig. 17 below ω_a is

$$\left(1-\frac{k}{n}\right)\omega_a dG$$

In accordance with the equations developed earlier, the phase characteristic in the neighborhood of the sing frequency will remain substantially unaltered if we replace the actual curve below ω_a by any other giving the same area. Thus, with this emendation the specification just developed for the equalizer characteristics can be applied to conditionally as well as unconditionally stable circuits.

What is claimed is:

1. A broad band negative feedback amplifier operating with controlled high frequency sing and having means in the feedback loop circuit controlled by the sing current for so modifying the loop transmission phase and gain characteristics in the high frequency cut-off region immediately above the useful band as to increase the magnitude of the feedback factor in the useful band to a higher value than the maximum value obtainable with unconditionally stable operation and the same value of tube gain.

2. A broad band negative feedback amplifier operating with controlled high frequency sing and having a variable equalizer included in the feedback loop, said equalizer comprising a current dependent resistance responsive to the sing current, said resistance, in response to the initiation of the sing current, changing the equalizer characteristic in such manner as greatly to steepen the high frequency gain cut-off of the loop transmission characteristic immediately above the useful band and produce a correspond-

ing increase in feedback factor in the useful band.

3. A broad band negative feedback amplifier having its loop gain and phase shift characteristics proportioned in known maner to provide unconditionally stable operation for low tube gains representing a fraction of the total tube gain of the circuit whereby a high frequency sing sets in with increasing gain beyond said fractional value of gain, and means in the feedback loop operating in response to the initiation of the sing condition for limiting the sing amplitude to a relatively low value and for modifying the shape of the gain and phase shift characteristics of the feedback loop to convert the loop characteristic from the unconditionally stable type to the conditionally stable type.

4. A broad band negative feedback amplifier having its loop transmission characteristic designed in known manner to provide unconditionally stable operation at low tube gains from near zero up to a value well below the operating tube gain value, whereby a high frequency sing sets in with increase of tube gain beyond said low value, means to limit the sing amplitude to too low a value to interfere with operation of the amplifier in the utilized band, and means controlled by the sing current in increasing from zero up to said limited amplitude for transforming the loop transmission characteristic to provide a greater feedback ratio in the used band when the operating value of tube gain has been reached than could be obtained with the same tube gain and unconditionally stable loop characteristic.

5. In a broad band negative feedback amplifier, an impedance network included in the feedback loop and comprising a current dependent resistance, said amplifier having a total loop transmission characteristic, including that of said network, designed in known manner to provide unconditionally stable operation for all tube gains from near zero up to some relatively low value comprising only a fractional part of the eventual operating tube gain, whereby a sing sets in with increasing tube gain above said relatively low value at a frequency well above the used band, means to utilize the resulting sing current to control the magnitude of said current dependent resistance, said network in turn limiting the maximum amplitude of the sing current with increasing tube gain to too low a value to interfere with operation of said amplifier in the utilized band, said network under control of increasing sing current below said maximum value operating to modify the loop gain and phase shift characteristics in such sense as to reduce the sing margin in the high frequency cut-off interval and correspondingly increase the value of the feedback factor in the used band.

6. A wave translating system comprising a space discharge tube amplifying system, a feedback path forming therewith a negative feedback loop, and means comprising a temperature dependent resistance in said loop having at less than normal tube gain a value rendering the loop completely stable and having at normal tube gain a value rendering the loop conditionally stable, said temperature dependent resistance being responsive to energy traversing said loop for changing the loop characteristic from the completely stable to the conditionally stable state and maintaining the loop in the stable condition throughout said change.

7. A wave translating system having an amplifying path and a feedback path forming with the amplifying path a negative feedback loop, said system having its gain and phase shift characteristics proportioned in known manner to make said loop completely stable for low values of amplifying path gain, said system developing a high frequency sing at operating values of amplifying path gain, a network in said loop including a current dependent resistance, said network changing its loss and phase shift characteristics under control of changes in value of said resistance, said resistance being effective in response to the magnitude of the high frequency sing current to cause the consequent change of loss and phase shift of the network to vary both the loop gain and loop phase shift characteristics in a direction to prevent the sing current from rising above an unimportant small amplitude.

8. A negative feedback space discharge tube amplifier comprising means maintaining said amplifier completely stable at low values of tube gain while allowing said amplifier to develop a high frequency sing at high values of tube gain, means maintaining a phase margin against singing at all frequencies lower than said high frequency at all values of tube gain lower than the tube gain at which said high frequency sing sets in, and means for causing the sing current to control the loop gain and phase shift characteristics to cause operation with conditional stability.

9. A broad band negative feedback amplifier having a loop characteristic of the unconditionally stable type but such a small phase margin as to be liable to become unstable under operating conditions, said amplifier having a current responsive network of controllable attenuation and phase characteristics, and means operating in response to initiation of a sing condition in said amplifier for controlling the characteristics of said network to in turn so modify the gain and phase characteristics of the feedback loop as to maintain the sing current at negligibly low amplitude and to maintain the loop gain within the utilized frequency band at least as high as when operating with unconditional stability.

10. A negative feedback amplifier operating with conditional stability to secure a greater feedback factor in the used band than is obtainable with unconditionally stable operation comprising means for operating said amplifier with unconditional stability at relatively low values of tube gain, means operative at somewhat higher tube gain for allowing said amplifier to start to sing at a frequency much higher than any utilized frequency while maintaining the circuit completely stable at all lower frequencies, and means utilizing the sing current to control both the loop gain and loop phase shift characteristics to convert the circuit to conditionally stable operation with full tube gain while maintaining the amplitude of the sing at too low a value to interfere with amplifier operation.

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