

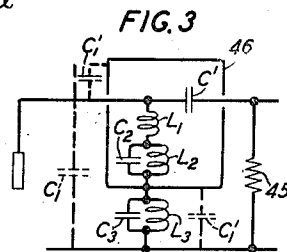
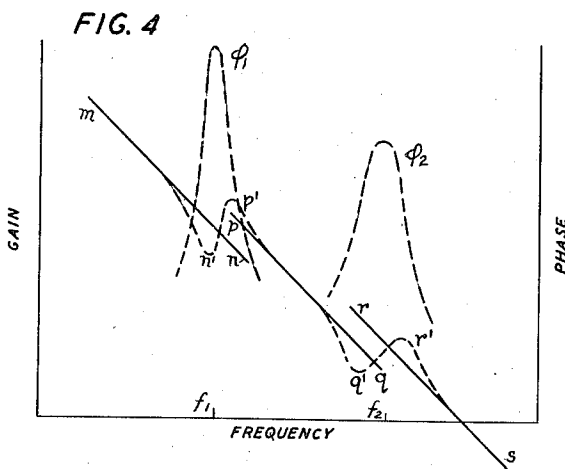
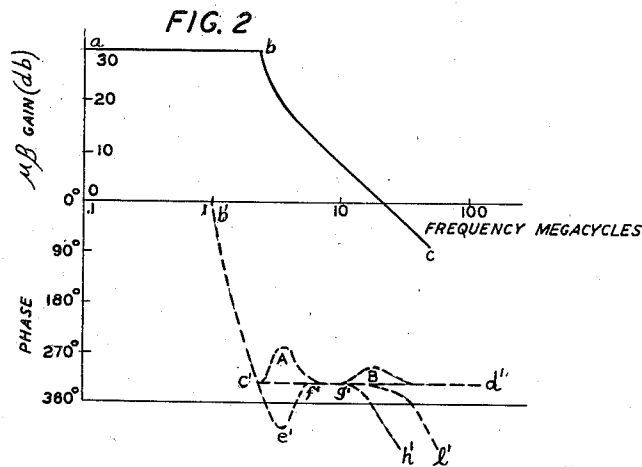
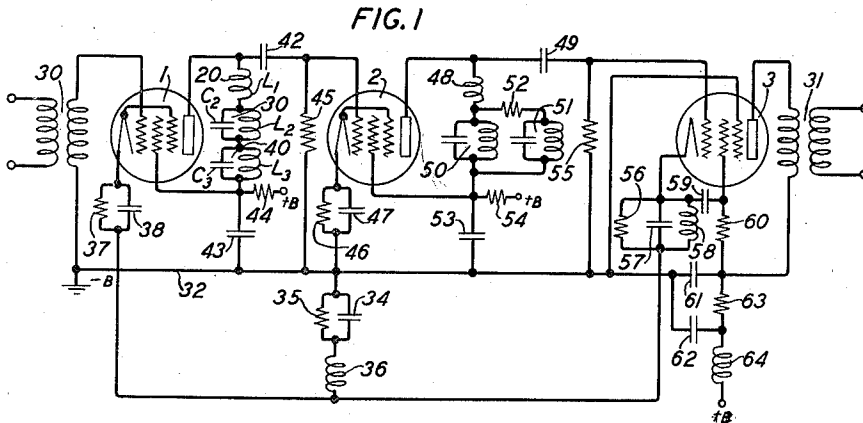
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2,231,374

NEGATIVE FEEDBACK AMPLIFIER

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NEGATIVE FEEDBACK AMPLIFIER

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The present invention relates to amplifier circuits, especially of the type suited to high frequency or broad-band amplification. While not limited to any particular frequency range or use, the amplifiers of the invention are especially applicable to multiplex carrier signaling or to television transmission over coaxial lines or similar means.

A general object of the invention is to increase the effectiveness of multistage tube circuits as amplifiers with stabilized feedback. This object is attained by means of a novel circuit arrangement which inherently increases the stability against singing at certain critical frequency ranges and which permits a higher over-all feedback gain to be realized in practice.

An improved circuit arrangement for amplifiers of the kind referred to above is disclosed in application to J. M. West, Serial No. 218,300, filed July 9, 1938. In that circuit various improvements are made which permit a higher value of the $\mu\beta$ gain around the feedback loop while still maintaining a safe margin against singing. The purpose of this invention is to still further increase the permissible $\mu\beta$ gain around the loop circuit by maintaining the same margin against singing or, with the same value of $\mu\beta$ gain, to increase the margin against singing.

The invention will be better understood by reference to the following specification and the accompanying drawing in which:

Fig. 1 is a circuit embodying my invention;

Fig. 2 contains characteristic curves explanatory of my invention;

Fig. 3 is a detail of the circuit of Fig. 1; and

Fig. 4 contains additional explanatory curves.

Referring to Fig. 1, it is to be noted that it is the same as Fig. 9 of the said West application except for the coupling network between the first and the second tube. It will be noted that in Fig. 1 the external plate circuit of the first tube comprises an inductance L_1 in series with the parallel $L_2 C_2$ combination, in series with the parallel $L_3 C_3$ combination, these providing, as it were, a double trap circuit as later explained.

A detailed description of Fig. 1 need not here be given inasmuch as it appears in full in the said West application. My invention will, however, be made clear by reference to Fig. 2. In that figure, abc represents an ideal $\mu\beta$ gain curve for a negative feedback amplifier, such as that of the West application referred to. The portion ab represents the gain over the portion of the frequency spectrum in which transmission with flat and high gain is to be present, and bc is the

portion over which the gain around the loop falls off. In such a circuit there will be present certain unavoidable parasitic capacities, such as that between plates and ground. As the frequency impressed on the amplifier becomes higher and higher, these parasitic capacities become more and more significant and in the very high frequency region become controlling, rapidly reducing the gain of the amplifier. At very high frequencies the loss in gain increases at the rate of 6 decibels per octave per stage of amplification so that in a three-stage amplifier the curve bc will, in general, asymptotically approach a slope of 18 decibels per octave.

With this gain curve of Fig. 2 there is associated a phase curve $b' c' d'$ which gives the change in phase of the feedback voltage as a function of the frequency. The connection between the two has been pointed out in U. S. patent to Bode 2,123,178, July 12, 1938, and from the form of the gain curve one can predict quite definitely the form of the phase shift curve. While over the transmitting band region ab there will ordinarily be a negative feedback in the sense that the voltage fed back is opposite or nearly opposite in phase to the impressed signal, as one goes to frequencies above the transmitted band ab the phase of the fed back voltage is shifted and at a sufficiently high frequency may be turned over to be in phase instead of out of phase with the impressed voltage. In that case, if the gain through the $\mu\beta$ circuit is greater than unity, the amplifier is no longer stable but goes into oscillations. The curve $b' c' d'$ may be taken as a typical ideal phase shift curve. To avoid instability it is necessary that the curve shall not cross the 360 degree or the zero degree line until $\mu\beta$ becomes a loss. As shown in Fig. 2 there is a margin of safety against singing of 30 degrees over the portion $c' d'$.

With regenerative amplifiers using efficient transformer designs it is found that the phase curve is one which tends to fall very rapidly as one goes to frequencies just above the upper edge of the transmitting range at b and there is consequently a general tendency to exceed phase limits in this frequency range. There is also a tendency in the region of the high frequency cut-off to exceed the phase limits. More specifically, there is a tendency for the phase shift curve to follow a course such as the curve $b' c' e' f' g' h'$, passing to regions of excessive phase shift at two places, namely, one just above the upper edge of the transmitting range and one at the still higher frequencies in the region

where the parasitic capacities become controlling.

After these general considerations it may be stated that the purpose of my invention is to neutralize or to delay the build-up of phase shift as one goes to higher frequencies and I accomplish this by introducing circuit elements which will develop some helping phase shift as indicated by the areas A and B of Fig. 2 so that the resultant phase shift curve follows more closely the curve $b' c' f' g' l'$. More specifically, if at a suitable point in the $\mu\beta$ circuit, such as the coupling network between the first and second tubes, provision be made for circuit elements which at the two regions in question introduce helping phase, then there is a closer approach to the ideal condition. I have found that this can be accomplished by the insertion of two circuit elements shown in Fig. 1 at 20 and 40, the first of these consisting of an inductance L_1 and the second of the parallel combination $L_3 C_3$. These are in addition to the inductance 30 which is a coil of relatively high inductance L_2 for the purpose of supplying direct current voltage to the plate and inherently possessing parasitic capacities represented by C_2 . The impedance of L_2 is so high that its distributed capacitance is considered, for the purpose of simplicity, as controlling in the frequency ranges under discussion.

The circuit for this coupling network may be represented as in Fig. 3. The usual blocking condenser C' is of such size that its importance is negligible at the frequencies here considered and the usual grid resistance 45 is so large that it does not act as an appreciable shunt for the remainder of the circuit. In this coupling circuit also it is contemplated that there may be a shield 46 enclosing the inductance L_1 , the circuit 30 and the coupling condenser C' . Furthermore, the shield is to be connected at the lower end of L_2 . In Fig. 3 also the parasitic capacities across the interstage circuit at this point, such as plate-ground capacitance, etc., are represented at C_1 .

This interstage coupling constitutes a double trap circuit where by the term trap circuit as here used is meant a circuit which introduces helping phase at a predetermined portion of the frequency spectrum. The manner in which these trap circuits function and perform the desired results will be better understood by reference to Fig. 4 in which the portion mn represents the gain curve for the combination of C_1 and C_2 in the region where the effects of the coils are negligible. More particularly in this instance the magnitudes of the inductances and the capacities are so chosen that at a frequency below the upper edge of the transmission band, that is, below the point b of Fig. 2, the impedance of L_1 and L_3 are both negligible; C_3 is a relatively large capacity and so far as frequencies in the region of b are concerned the capacitance C_2 is all that need be considered. As one approaches a certain frequency f_1 of Fig. 4 there is a damped series resonance of the elements L_1, C_2, Z_3 where Z_3 is the impedance of the $L_3 C_3$ combination and at f_1 is inductive. The damping would usually be provided by the dissipation present in the coils. This condition of series resonance modifies the curve mn to a form given approximately by mn' but the magnitude of the elements is so chosen that immediately following this dip the series combination just mentioned gives damped parallel resonance due to the presence of the parasitic capacitance C_1 . This combination modi-

fies the asymptotic gain curve mn to the curve $mn' p' q$ in which the portion pq is parallel to mn but shifted to slightly higher gain. The important thing at this point is that there is associated with this a change in phase given by a curve ϕ_1 which is of a size to neutralize the otherwise degrading phase around the $\mu\beta$ circuit.

Similarly in the region of f_2 a helping phase corresponding to the curve ϕ_2 is introduced, this being the region at which damped series resonance occurs for L_1, C_2, Z_3 , where Z_3 is now capacitive, which series resonance is followed immediately by damped parallel resonance of that combination with C_1 . The change in the gain curve from pq is represented by $pq' r' s$. It will be noted that this brings about a shift of the gain curve from pq to rs , which latter corresponds to the asymptotic curve for C_1 alone.

The effects thus described may be summarized as follows:

For frequencies below f_1 we have essentially C_1 in parallel to C_2 , this for the reason that at these frequencies the impedance of L_1 is negligible and L_3 is a virtual short circuit for C_3 . From f_1 to f_2 , C_1 is parallel to C_2 taken in series with C_3 , for in this region the impedance of L_1 is still not considerable but the impedance of L_3 has risen high enough so as to be practically out of the circuit. Above f_2 the impedance of L_1 is high and virtually opens the circuit for C_2 so that we essentially have C_1 alone. One method then of looking at the circuit is to state that the over-all improvement has come about through the elimination of the effects of the capacitance C_2 .

It is to be recognized that in a network of the kind described it is not necessary that the damped parallel resonance condition should follow closely on the series resonance condition described in connection with Fig. 4. This condition is desirable in one connection with my arrangement and, of course, is brought about by a definite and careful choice of the values assigned to L_1, L_3 , and C_3 . In general, the capacitance C_2 would be that inherent in the inductance L_2 although in some cases it might be desirable to supplement that distributed capacitance with additional capacitance. In general also it will be appreciated that the stiffness and the magnitude of the trap circuits can be modified to a considerable extent by suitable design.

A physical advantage of the arrangement of my circuit arises from the fact that L_1, L_2, C_2 and the coupling condenser C' may be placed in a shield with the shield tied to the low end of L_2 . This reduces the parasitic capacitance to ground from L_1 and the coupling condenser C' , which capacitance to ground would ordinarily add to C_1 . With this shielding arrangement the new and reduced parasitic capacitance of these elements would now be represented by C_1' in Fig. 3. Also the capacitance of the shield to ground, represented by C_1'' , is across C_3 , which itself is relatively large and is therefore able to absorb this additional capacity.

It will be noted that in my circuit arrangement it has been possible to introduce a double trap circuit in one place in the $\mu\beta$ circuit, thus leaving greater freedom in design of other portions of the $\mu\beta$ circuit such, for example, as the complex interstage coupling between tubes 2 and 3 of Fig. 1. While the invention has been described in terms of the trap circuits functioning in the coupling network between the first and second tubes, it is to be understood that equiv-

alent trap circuits may be introduced in other parts of the $\mu\beta$ circuit with advantageous results either as a substitute for those described as between tubes 1 and 2 or as supplementing these, but in any case introducing helping phase.

What is claimed is:

1. In a multistage amplifier, a plurality of vacuum tube stages in tandem with feedback connection from the output of the last to the input of the first stage, said amplifier having a tendency to produce self-oscillation at a frequency above the utilized range due to shunt parasitic capacity, a coupling network between the plate of one tube and the grid of the next tube, the said network being made up of reactive elements proportioned to resonate with said parasitic capacity in the frequency region where said tendency is otherwise most pronounced, such resonance providing a helping phase shift in said frequency region sufficient to prevent oscillation production.

2. In a multistage amplifier, a plurality of vacuum tube stages in tandem with negative feedback connection, said amplifier having a tendency to produce self-oscillation due to shunt parasitic capacity at a plurality of separated frequency regions one of which is near the upper edge of the utilized range and the other of which is in the vicinity of the high frequency gain cut-off, a coupling network between the plate of one tube and the grid of the next tube, said network being made up of reactive elements proportioned to produce series resonance at or near each of said frequency regions and to produce together with said parasitic capacity parallel resonance at two frequencies closely adjacent said frequency regions, such resonance effects providing a helping phase shift in each of said frequency regions sufficient to effectively counteract said tendency.

3. In a multistage amplifier, a plurality of vacuum tube stages in tandem with negative feedback connection, a coupling network between the plate of one tube and the grid of the next tube, said network being made up of elements of such magnitude as to give rise to damped reso-

nance at two frequency regions, one of which is slightly above the transmitting region of the amplifier and the other of which is near the cut-off point of the amplifier, said coupling network consisting of an inductance in series with a parallel inductance-capacitance combination, the inductances and capacitances being of such magnitude as to give helping phase at the regions specified.

4. In a multistage amplifier, a plurality of vacuum tube stages in tandem with negative feedback connection, a coupling network between the plate of one tube and the grid of the next tube, said network being made up of elements of such magnitude as to give rise to damped resonance at two frequency regions, one of which is slightly above the transmitting region of the amplifier and the other of which is near the cut-off point of the amplifier, said coupling network consisting of an inductance in series with a parallel inductance-capacitance combination in series with a second inductance-capacitance combination, the inductances and capacitances being of such magnitude as to give damped resonance at the regions specified.

5. In a stabilized feedback amplifier for amplifying electrical waves extending over a band of frequencies and provided with a gain reducing stabilizing feedback path from a point of higher amplitude level to a point of lower amplitude level therein, said amplifier having the tendency to produce self-oscillation at a frequency near or above the uppermost frequency in said band due to parasitic capacity, a network of reactive impedances included in said amplifier certain of the impedances of which are proportioned to develop a series resonance in the vicinity of said frequency and certain of the impedances of which are proportioned to develop a shunt resonance with said parasitic capacity at a closely adjacent frequency whereby an increment of helping phase shift is produced at said frequency of such magnitude and sign as to counteract such tendency.

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