April 16, 1940. J. F. FARRINGTON 2,197,239

STABILIZED TUNED SYSTEM

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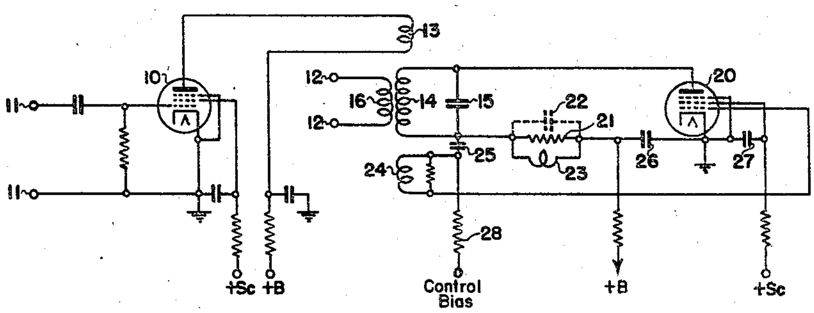
FIG. I.



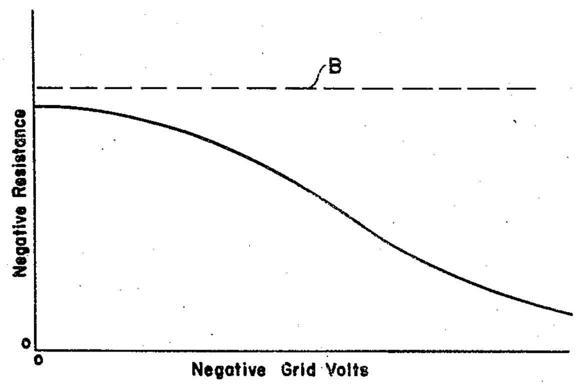


FIG. 3.

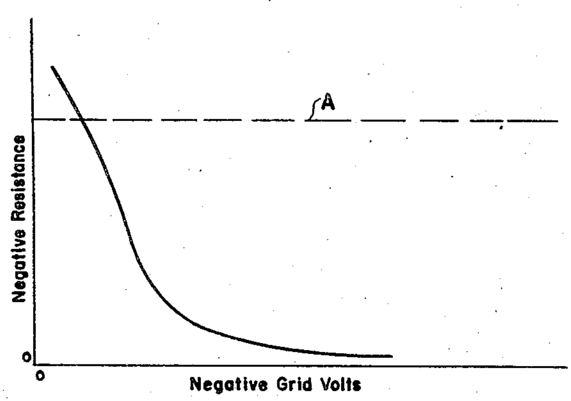


FIG. 2.

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STABILIZED TUNED SYSTEM

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12 Claims. (Cl. 178—44)

This invention relates to stabilized tuned systems; that is, tuned systems comprising regeneration to effect a sharply peaked resonance characteristic or a flat-topped characteristic with steeply sloping sides, in either case sharply selective against undesired signals, but which are stabilized against regenerative oscillations.

In many high-frequency signal-translating systems it is necessary to provide a very sharply selective circuit. Thus, such a selective circuit may be desired in order to select signals of a particular frequency or of a given band of frequencies from a source comprising signals of a wider range of frequencies. Such a circuit is of particular utility as a load circuit of a vacuum tube which is to be utilized as an amplifier for such selected frequencies. Simple tuned circuits have commonly been utilized in the manner described above. However, since it is not possible to construct reactive elements, together with conductors connecting the same, which have zero resistance, conventional prior art tuned circuits have not been as selective as is sometimes desired.

Regeneration has heretofore been utilized to provide a circuit which is more sharply selective than a simple tuned circuit. The effect of regeneration is effectively to introduce into the tuned circuit a negative resistance. Thus, as the magnitude of the negative resistance so introduced into the tuned circuit becomes comparable in magnitude to the inherent or actual resistance of the tuned circuit, the effective resistance is reduced to a very low value and the tuned circuit becomes very sharply selective. Such regenerative circuits commonly utilize vacuum tubes to provide regeneration. However, in such prior art circuits the amount of negative resistance so introduced into a tuned circuit varies rapidly with variations in transconductance of the regenerating tube. If the total effective resistance of such a system becomes negative, regenerative oscillation will result. Therefore, inasmuch as for a highly selective circuit it is necessary to reduce the effective resistance of the tuned circuit to a very low positive value while any resultant effective negative resistance causes the system to oscillate, such prior art systems may tend to be unstable and unsuitable for use in a system where it is desired to adjust the transconductance of the tube to adjust the gain of the system.

It is, therefore, an object of the invention to provide a stabilized tuned system in which the above-mentioned disadvantages of the arrangements of the prior art are eliminated.

It is another object of the invention to provide an improved tuned circuit which is very sharply selective against undesired signals and stable in operation.

It is a further object of the invention to provide a stabilized tuned system comprising a tuned circuit and a regenerating vacuum tube, the system being stabilized against regenerative oscillation due to changes in the transconductance of the tube.

It is a further object of the invention to provide a tuned system in which the selectivity can be adjusted between broad and very sharp characteristics by regeneration without becoming unstable when a high degree of regeneration is utilized.

In accordance with the invention, a stabilized tuned system comprises a tuned circuit having a given effective positive resistance together with a vacuum tube coupled to the tuned circuit. There are included in the system means for providing regeneration in the tuned circuit, preferably comprising means for impressing on an input electrode of the tube a voltage derived from, and varying in phase and magnitude in accordance with, the voltage across the tuned circuit of the system to provide regeneration in the tuned circuit, and means for impressing on an input electrode of the vacuum tube also a degenerative voltage derived from, and varying in phase and magnitude in accordance with, the output current of the tube. The feed-back voltages, provided by the above-mentioned means, are so proportioned that their joint effect on the tuned circuit is that of an added negative resistance in the tuned circuit which approaches asymptotically a value not substantially greater than the value of the actual effective positive resistance included in the tuned circuit as the transconductance of the tube is increased; specifically, the circuit is so proportioned that the negative resistance is not greater than the positive resistance for any value of transconductance within the range of operation of the tube and so that for the higher values of transconductance utilized the negative resistance increases gradually with variations of transconductance of the tube.

When the circuit is proportioned in this manner, a very sharply selective resonance characteristic may be obtained with a single-tuned circuit for relatively high transconductance of the regenerating tube while, at the same time, the system is stabilized against regenerative oscillations due to variations in the transconductance of the tube. When coupled tuned circuits are used, as in an adjustable band-pass selector, the stabilized regenerative system may be used to control selectivity without danger of producing oscillations. In a preferred embodiment of the invention, the added negative resistance is made to approach asymptotically the approximate value of the actual resistance of the tuned circuit.

For a better understanding of the invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawing and its scope will be pointed out in the appended claims.

Fig. 1 of the drawing is a circuit diagram of a stabilized tuned system in accordance with the invention, utilized as a tuned circuit in the output circuit of a vacuum-tube amplifier; Fig. 2 illustrates the negative resistance-grid bias characteristic of analogous prior art regenerative circuit arrangements; while Fig. 3 illustrates the negative resistance-grid bias characteristic of the arrangement of Fig. 1.

Referring now more particularly to Fig. 1, there is shown a vacuum-tube amplifier 10 coupled between input terminals 11, 11 and output terminals 12, 12. The output circuit of vacuum tube 10 comprises a load circuit including a stabilized tuned system having an inductance 13 inductively coupled to an inductance 14 comprising with a condenser 15 a parallel-tuned circuit. Output terminals 12 are coupled to tuned circuit 14, 15 by means of an inductance 16 inductively coupled to inductance 14.

There is also provided a regenerating vacuum tube 20, the output electrodes of the tube being coupled across tuned circuit 14, 15 through a resistor 21. The inherent capacitance across resistor 21 is indicated by dotted-line condenser 22 and there is also connected across resistor 21 an inductance 23 effective to resonate with capacitance 22 at the frequency of tuned circuit 14, 15, thereby to neutralize the effect of the inherent capacitance 22. The circuit 22, 23 is heavily loaded by resistor 21 so that its impedance is substantially resistive and constant over a reasonable frequency range in the vicinity of its resonant frequency. In order to provide a positive feedback voltage to an input electrode of tube 20 for regeneration of circuit 14, 15 which varies in phase and magnitude in accordance with the voltage across circuit 14, 15, there is provided an inductance 24 inductively coupled to inductance 14 and included in the control or input-grid circuit of tube 20. In order to provide a negative or degenerative feed-back voltage to an input electrode of tube 20, the control-grid circuit including inductance 24 includes also the output circuit resistor 21. Suitable blocking condensers 25, 26, and 27 are also provided for the circuit of Fig. 1, while suitable operating potentials are applied to the electrodes of the tubes 10 and 20 from sources indicated at +Sc and +B. The bias potential of the input electrode of tube 20 may be adjusted by means of potentials applied to the control-bias terminal through a resistor 28 of high impedance as compared to resistor 21, and this tube may be adapted to operate over a predetermined-bias range including a bias corresponding to a relatively high value of transconductance of the tube.

In considering the operation of the system of Fig. 1, it will be seen that the regenerative feedback circuit to the control grid of tube 20 including inductance 24 is effective to provide regeneration in a manner well understood in the art, and that this feed-back voltage varies in phase and magnitude in accordance with the voltage across tuned circuit 14, 15. It wil also be seen that resistor 21 provides a means for impressing on an input electrode of tube 20 a degenerative voltage derived from, and varying in phase and magnitude in accordance with, the output current of the tube. The joint effect of the two feed-back means of Fig. 1 is to introduce a negative resistance into tuned circuit 14, 15.

The negative resistance characteristic of comparable circuits of the prior art is shown by Fig. 2. If it is assumed that the tuned circuit of prior art arrangements, corresponding to tuned circuit 14, 15 of the invention, has an actual resistance of a magnitude indicated by the dotted line A of Fig. 2, it is apparent that any value of negative resistance of a greater magnitude introduced into the tuned circuit causes oscillation. Furthermore, it is seen that the grid voltage-negative resistance characteristic of such prior art systems is very steep in the region of its intersection with the positive resistance curve of the circuit, thus causing such a system to be very unstable for any appreciable variation in transconductance of the feed-back tube in such region.

The negative resistance characteristic of the circuit of Fig. 1, proportioned in a manner to be hereinafter described, is illustrated in Fig. 3. Thus, if the dotted horizontal line B of Fig. 3 represents the magnitude of the effective positive resistance of tuned circuit 14, 15, it will be seen that, for any value of negative grid voltage or transconductance of tube 20, the magnitude of the negative resistance introduced by regeneration cannot exceed that of the actual resistance of the circuit. The system is, therefore, stable against changes in grid voltage or variations in transconductance of vacuum tube 20.

The following equations are applicable to the system of Fig. 1 and are utilized in proportioning the constants of the system to secure the characteristic illustrated in Fig. 3:

$$e=\left[r+j\left(\omega L-\frac{1}{\omega C}\right)\right]i+\frac{ji_p}{\omega C}=[r+jX]i+jyi_p=Z_i+jyi_p \quad (1)$$

$$i_p=ge_g=j\omega Mgi-Rgi_p=\frac{j\omega Mgi}{1+Rg}=j\frac{mgi}{1+Rg} \quad (2)$$

$$e=\left[Z-\frac{myg}{1+Rg}\right]i=\left[\left(r-\frac{myg}{1+Rg}\right)+jX\right]i \quad (3)$$

From (3) the effective resistance of tuned circuit 14, 15 is

$$r_{eff}=r-\frac{myg}{1+Rg} \quad (4)$$

In the foregoing equations

L = value of inductance 14,
C = value of capacitance 15,
r = actual series resistance of tuned circuit 14, 15,
R = value of resistor 21,
M = mutual inductance between inductances 14 and 24,
e = value of series driving voltage introduced into tuned circuit 14, 15 by coupling between 13 and 14,
e_g = input voltage of tube 20,
i = current which flows in tuned circuit 14, 15,
$y=\frac{1}{\omega C}$, the reactance of capacitor 15,
m = mutual reactance between 14 and 24,
g = transconductance of tube 20,
i_p = plate current of tube 20.
$-\frac{myg}{1+Rg}$ = value of the negative resistance effectively introduced in tuned circuit 14, 15 by means of vacuum tube 20.

When $Rg>>1$, the negative resistance

$$-\frac{myg}{1+Rg}$$

approaches

$$-\frac{my}{R}$$

and is substantially independent of g, the transconductance of tube **20**.

Therefore, the total effective resistance of tuned circuit **14**, **15** approaches

$$\left(r-\frac{my}{R}\right)$$

which is a constant, that is, independent of the transconductance of tube **20**. Therefore, by properly proportioning the circuit impedances r, m, y, and R so that

$$\left(r-\frac{my}{R}\right)$$

is positive, the total effective resistance of tuned circuit **14**, **15** remains positive and oscillation is avoided.

It is, therefore, seen that, by means of the relationship described above, it is possible to proportion the constants of the circuit of Fig. 1 so that the joint effect of the two feed-back means in the feed-back circuit is an added negative resistance in the tuned circuit which approaches asymptotically a value not substantially greater than the value of the resistance r of tuned circuit **14**, **15**; actually, the circuit is so proportioned that within the range of variation of transconductance of tube **20** the negative resistance is less than r, the actual resistance of tuned circuit **14**, **15**. The value of negative resistance so introduced may be made to approach very nearly the value of resistance r without impairing the stability of the system. In this manner, tuned circuit **14**, **15** has a very sharply selective resonance characteristic for relatively high values of transconductance of the tube **10** and the system is stabilized against regenerative oscillation. It will be seen that the value of negative resistance inserted in the tuned circuit may be varied by a variation of the transconductance g of tube **20** and it will be understood that the circuit constants may be so proportioned that the added negative resistance in the tuned circuit is approximately equal to, but not greater than, the value of the given resistance over a substantial portion of the transconductance range. While the resonant circuit **14**, **15** has been shown in the embodiment of Fig. 1 in the output circuit of tube **20**, it will be apparent to those skilled in the art that tuned circuit **14**, **15** may be coupled in the input circuit of tube **10**. While the invention has been illustrated with reference to a single sharply tuned circuit, it will be understood that the invention is equally applicable to systems comprising a plurality of coupled tuned circuits. Thus, the invention is particularly useful in that type of variable band-pass selector circuit comprising a plurality of coupled tuned circuits and having a vacuum tube coupling the circuits to provide regeneration to narrow the pass band with increasing values of transconductance of the coupling tube.

While there has been described what is at present considered to be the preferred embodiment of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, means for coupling said sets of electrodes to said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said degeneration being so proportioned with respect to said regeneration that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches a value not greater than the value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply selective resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

2. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches a value not greater than the value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply selective resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

3. A stabilized tuned system comprising, a tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply peaked resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

4. A stabilized tuned system comprising, a tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, said vacuum tube being adapted to operate over a predetermined-bias range including a bias value corresponding to a relatively high value of transconductance of said tube, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube

a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which is approximately equal to but not greater than the value of said given resistance over a substantial portion of said bias range, whereby said tuned circuit has a very sharply peaked resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

5. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, said output electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply peaked response characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

6. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, said output electrodes being coupled to said tuned circuit, means for impressing on one of said input electrodes a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on said one of said input electrodes of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply selective response characteristic for relatively high values of transconductance of said tube and said system is stabilized against regenerative oscillation.

7. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, a circuit common to an input set of electrodes and said output electrodes and including a resistor to provide a negative feed-back voltage, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration, the feed-back voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply selective response characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

8. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, one of said sets of electrodes being coupled to said tuned circuit, means comprising an inductance inductively coupled to said tuned circuit for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply selective response characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

9. In a high-frequency amplifier for amplifying signals with sharp selectivity against undesired signals including a vacuum tube, a load circuit for said tube including a stabilized tuned system comprising, a tuned circuit having a given resistance, a second vacuum tube having input and output sets of electrodes, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said second tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an output electrode of said second tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on their tuned circuit is that of an added negative resistance in said tuned circuit which approaches a value substantially equal to the value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply peaked resonance characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

10. A stabilized tuned system comprising, a tuned circuit including a parallel-connected inductance and capacitance and having a given resistance, a vacuum tube having input and output sets of electrodes, a circuit common to an input set of electrodes and said output electrodes and including a resistor, said output electrodes being coupled to said tuned circuit through said resistor, means comprising an inductance inductively coupled to said inductance of said tuned

circuit for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, said resistor comprising means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said voltages being so proportioned that their joint effect on said tuned circuit is that of an added negative resistance in said tuned circuit which approaches the approximate value of said given resistance with increasing transconductance of said tube, whereby said tuned circuit has a very sharply peaked resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

11. A stabilized tuned system comprising, at least one tuned circuit having a given resistance, a vacuum tube having input and output sets of electrodes, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in accordance with the output current of said tube to provide degeneration, said circuit being so proportioned that

$$r-\frac{myg}{1+Rg}$$

is positive for relatively high values of transconductance of said tube, where the various parameters have the significance defined in the specification, whereby said tuned circuit has a very sharply selective resonant characteristic for relatively high values of transconductance of said tube and the system is stabilized against regenerative oscillation.

12. A stabilized tuned system comprising, a tuned circuit having a given resistance, a vacuum tube having a predetermined maximum value of transconductance and input and output sets of electrodes, a circuit common to an input set of electrodes and said output set of electrodes and including a resistor, one of said sets of electrodes being coupled to said tuned circuit, means for impressing on an input electrode of said tube a positive feed-back voltage derived from and varying in accordance with the voltage across said tuned circuit to provide regeneration in said tuned circuit, means including said resistor for impressing on an input electrode of said tube a negative feed-back voltage derived from and varying in phase and magnitude primarily in accordance with the output current of said tube to provide degeneration, said circuit being so proportioned that the product of the value of said maximum transconductance and the value of said resistor is much greater than unity and the negative resistance introduced into said tuned circuit is approximately equal to said given resistance for relatively high values of transconductance of said tube, whereby said tuned circuit has a very sharply peaked resonant characteristic for values of transconductance of said tube approaching said maximum value and the system is stabilized against regenerative oscillation.

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