

Jan. 20, 1942.

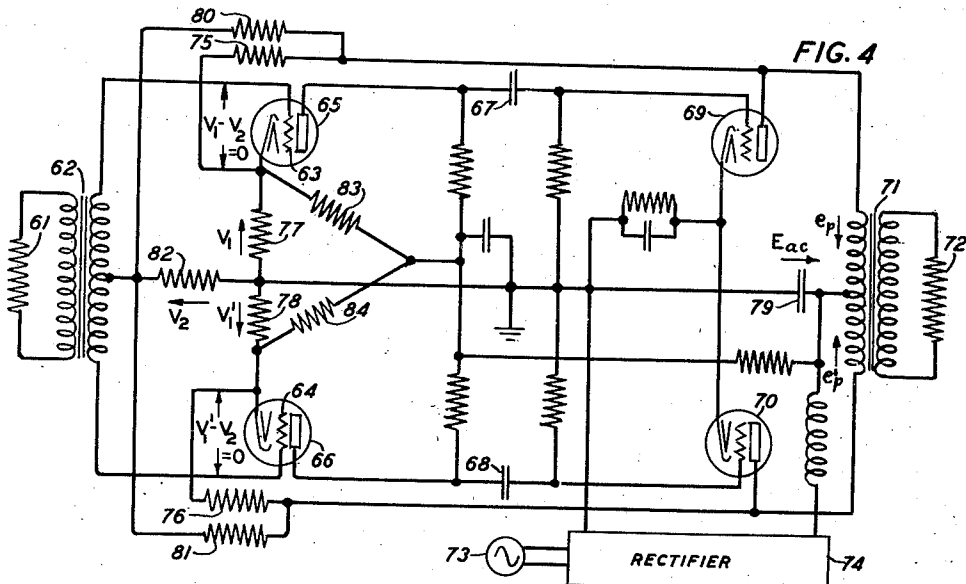
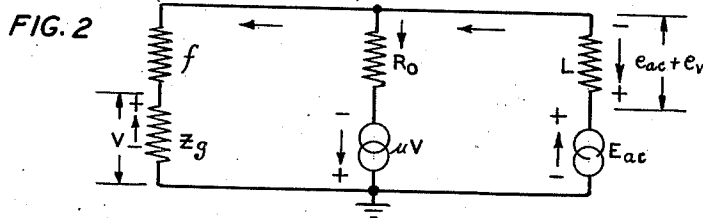
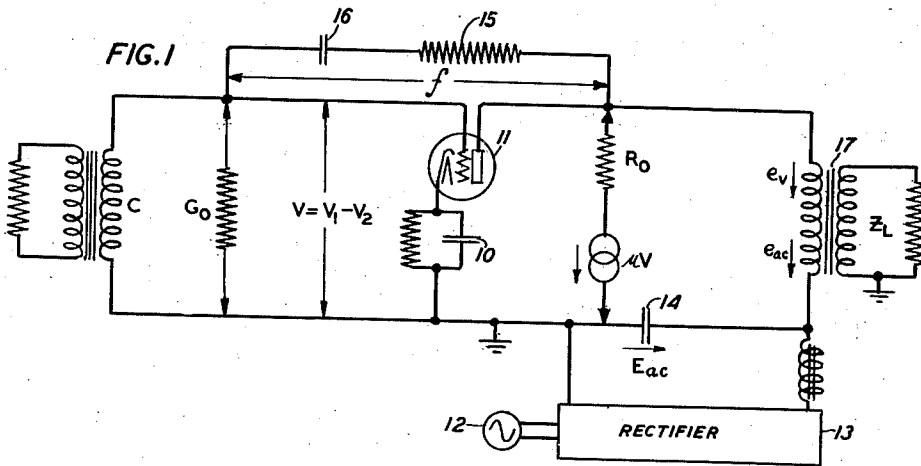
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2,270,295

AMPLIFIER

Filed Feb. 2, 1940

3 Sheets-Sheet 1



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3 Sheets-Sheet 2

FIG. 3

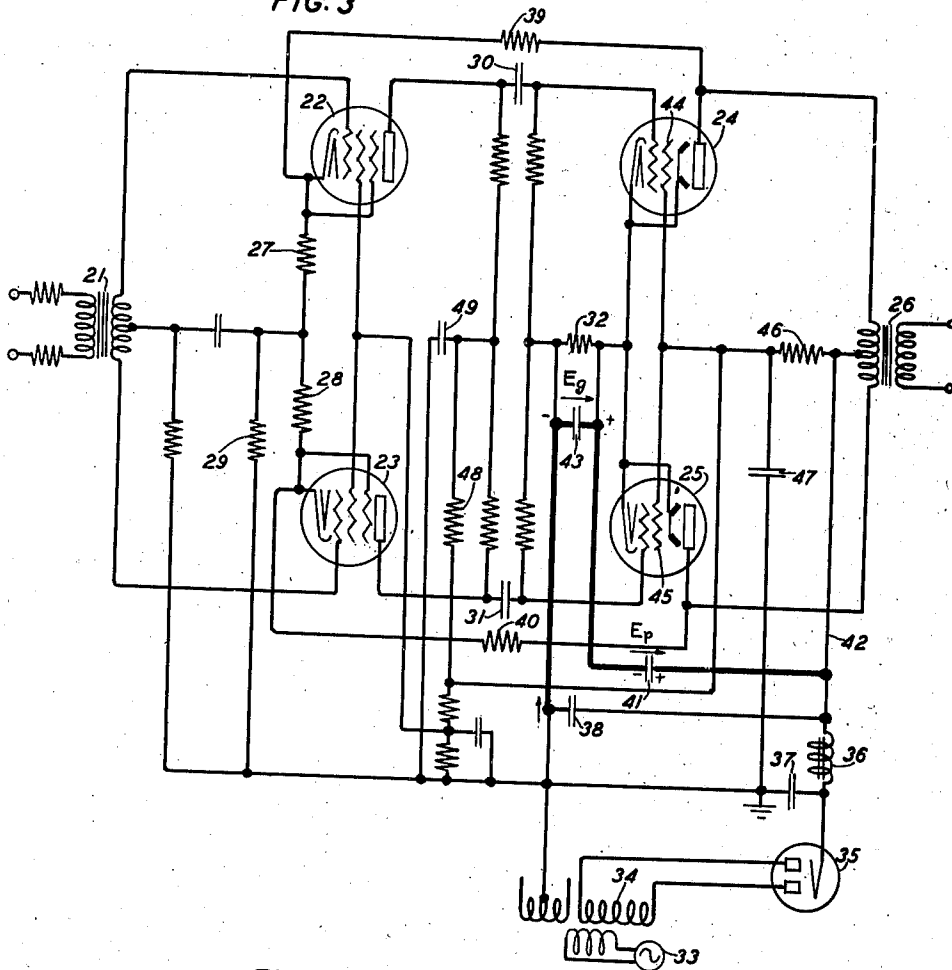
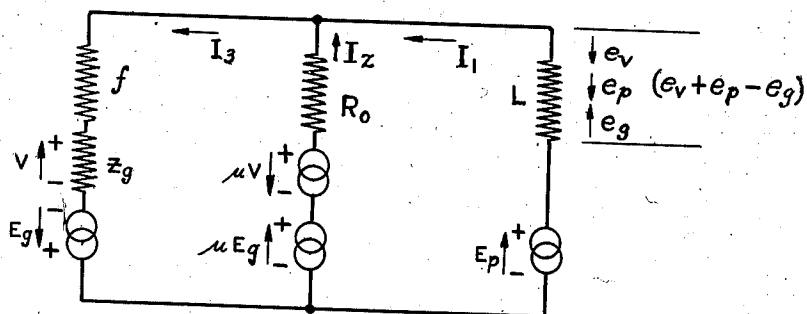


FIG. 3A



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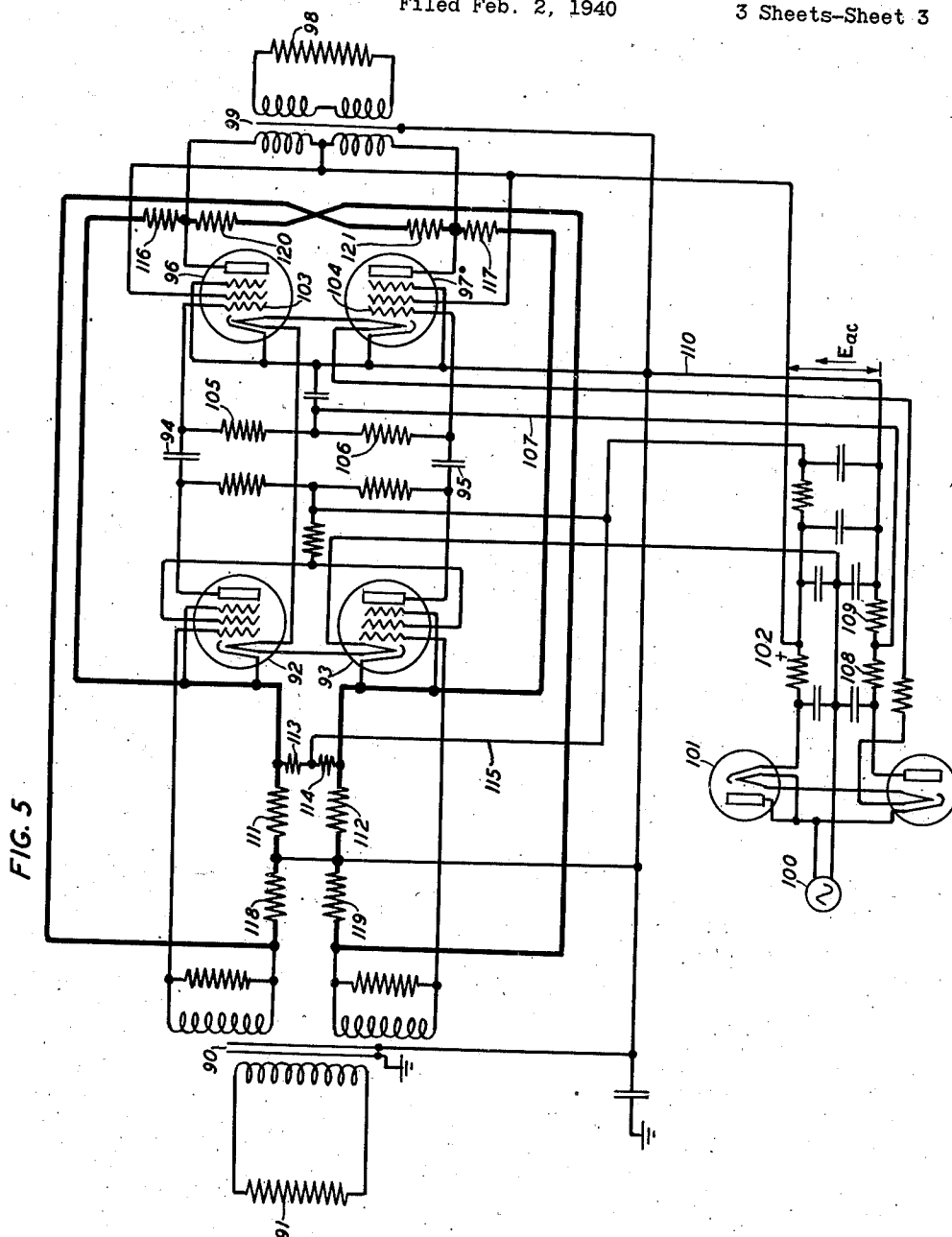
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AMPLIFIER

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3 Sheets-Sheet 3



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2,270,295

AMPLIFIER

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Application February 2, 1940, Serial No. 316,913

10 Claims. (Cl. 179—171)

This invention relates to amplifiers and particularly to amplifiers of the stabilized feedback type.

In the design of amplifiers it is common practice, for reasons of economy, to use power for the output stage which has a much higher line noise level than can be tolerated in the power used in the low level stages. Economy and circuit stability considerations often require that the feedback circuit be connected in such a way that the relatively high level noise of the output stage is fed back to a low level part of the circuit with a magnitude and phase which results in a higher noise level in the output than would obtain in the absence of feedback.

It is the object of this invention to balance out this excess noise without affecting the normal action of the feedback circuit in reducing noise and distortion from other causes.

In accordance with the general features of the invention the excess noise resulting from the use of negative feedback in the above manner is eliminated by introducing into the input circuit of the tube to which the feedback is applied, a second ripple potential of the proper magnitude and phase to balance the ripple potential reaching the tube over the feedback path. This may be done in various ways such as by dividing the ripple potential of the supply source in the proper proportions between the input and output circuits. In push-pull feedback amplifiers a second feedback connection from each output tube may be used to feed back both ripple and signal potentials in a positive sense to a mid-branch impedance common to the input tubes. The ripple potentials from the two tubes will be of the same phase and of the proper magnitude to balance out the ripple due to the first negative feedback connection but the signal potentials of the second feedback circuit will oppose each other and produce no net effect in a properly balanced circuit.

Alternatively, in push-pull amplifiers the second feedback circuit may be crisscrossed from the plate of each tube to the input of a preceding tube in the opposite side of the circuit. By using a separate impedance in the input circuit for each feedback circuit in each tube, both feedbacks may be negative as to signal currents with the two ripple components applied to each tube in phase opposition to each other.

The invention will be more clearly understood from the following detailed description and the accompanying drawings in which:

Fig. 1 is a typical stabilized feedback amplifier with an imperfectly filtered power supply;

Fig. 2 is a simplified equivalent of the circuit of Fig. 1;

Fig. 3 is a feedback amplifier with one means according to the invention for introducing into a low level part of the circuit a hum voltage which balances out the hum voltage fed back over the feedback path;

Fig. 3A shows a simplified equivalent of one side of the circuit in Fig. 3;

Fig. 4 is a push-pull amplifier with a positive feedback circuit for balancing out the hum voltage of the negative feedback circuit; and

Fig. 5 is a push-pull amplifier with two negative feedback circuits feeding back hum voltages which are applied to the amplifier in opposite phase so as to balance out in the input circuit.

Since it is customary to think of negative feedback as reducing rather than increasing the noise in the output of amplifiers, the reason for the increase in power supply noise when using feedback circuits of certain types will first be explained with reference to the simple, single-tube, stabilized feedback amplifier shown in Fig. 1.

In Fig. 1 the vacuum tube 11 is energized from an alternating current source 12 by means of rectifier unit 13. A ripple or noise voltage E_{ac} due to imperfect filtering of the power supply appears across the condenser 14, its magnitude and direction at a given instant being represented by the associated arrow. A negative feedback circuit comprising a resistor 15 and a condenser 16 extends from the plate to the grid of the tube 11. With this circuit open the voltage E_{ac} will set up a ripple current through the transformer 17 and the tube and this circuit will produce a voltage drop e_{ac} across the primary of the transformer in the direction of the associated arrow and of a magnitude equal to

$$\frac{E_{ac}L}{R_o + L}$$

where L is the effective load impedance and R_o is the plate resistance of the tube.

The voltage e_{ac} will induce a voltage in the secondary winding of the transformer 17 and if the feedback path is connected to this latter winding instead of to the plate of the tube, as shown, this induced voltage will be fed back along with the signal output and reduced by the feedback action in the same proportion as the signal so that the ratio of power supply noise to signal in the amplifier output is not increased by this type of feedback connection.

However, when using large amounts of negative feedback over a very wide frequency range, the phase shift around the feedback loop varies widely with frequency and it becomes very difficult to keep the feedback from becoming positive, particularly for the very low and very high frequencies of the band of interest. When the feedback connection is made from the secondary of the output transformer, thereby including the transformer on the feedback loop, it is therefore imperative that the transformer have a very low phase shift over the whole band of frequencies which it transmits. Such a transformer is inherently expensive and any practical design will have sufficient phase shift to decrease materially the margin against instability. It is therefore common practice to connect the feedback circuit to the primary side of the output transformer as shown in Fig. 1 to reduce the effect of the transformer phase shift on the feedback circuit and make it practical to use a transformer of much cheaper construction.

The circuit of Fig. 1 may be represented by the simplified equivalent circuit of Fig. 2 and in accordance with feedback amplifier theory as explained, for example, in Patent 2,102,671 to Black, December 21, 1937. The attenuation constant for the voltage E_{ac} applied to the grid of the tube 11 in terms of the equivalent circuit of Fig. 2 is, to a close approximation:

$$A_t = \frac{Z_s}{\frac{L}{R_0}(R_0 + f + Z_s) + (f + Z_s)}$$

and the usual feedback attenuation constant β is:

$$\beta = \frac{Z_s}{\frac{R_0}{L}(L + f + Z_s) + (f + Z_s)}$$

in which

$$Z_s = \frac{G_0 C}{C + G_0}$$

G_0 is the grid circuit impedance of the tube.

C is the effective input impedance externally of the tube.

R_0 is the internal impedance of the plate circuit of the tube.

L is the effective load impedance, and

f is the impedance of the feedback circuit.

The condensers 10 and 14 are usually of large capacity and low impedance at hum frequencies as compared with R_0 and L and are therefore neglected in this discussion.

The hum or ripple voltage V_1 applied through the feedback path to the grid circuit due to the power supply hum voltage E_{ac} is

$$V_1 = E_{ac} A_t$$

This voltage at the grid is amplified by the tube and modified in the usual manner by feedback action as a result of which a component voltage V_2 of opposite polarity appears at the grid.

$$V_2 = \frac{-\mu\beta}{1 + \mu\beta} V_1$$

in which μ is negative due to the phase shift of the tube.

The effective hum voltage V at the grid is therefore $V_1 - V_2$ and the resulting voltage in the plate circuit is μV as indicated in Fig. 1. This latter voltage produces a potential drop (e_v) in

the output transformer which is very nearly equal to

$$\frac{\mu V L}{R_0 + L}$$

when, as in the usual case, the feedback impedance f is large. The potential drop e_v is in phase with the potential e_{ac} due directly to the ripple voltage E_{ac} across the power supply and the total hum voltage in the output load circuit is therefore $e_v + e_{ac}$.

It will therefore be seen from the foregoing analysis that in a stabilized feedback amplifier of the type shown the feedback action increases the magnitude of the noise or ripple current in output circuit due to an imperfectly filtered plate supply voltage.

The elimination of this excess noise by dividing the ripple voltage of the power supply in the proper proportion between the grid and plate circuits of a feedback amplifier is illustrated by the circuit of Fig. 3. The circuit comprises two push-pull stages with an input transformer 21, input tubes 22, 23, output tubes 24, 25 and an output transformer 26. The input pentode tubes are self-biased by the cathode resistors 27 and 28, respectively, and by the resistor 29 in the common plate return circuit. These tubes are capacity coupled by condensers 30, 31 in the usual manner to the beam type output tubes which are biased by the resistor 32 in the common portion of the plate return circuit.

A stabilizing negative feedback circuit which is preferably of the type disclosed in Patent 2,123,241, granted to me July 12, 1938, extends from the plate of each output tube to the cathode of the corresponding input tube through resistors 39 and 40, respectively.

Power is supplied to both stages from the alternating source 33 through the transformer 34, rectifier 35 and filter network comprising the retard coil 36 and condensers 37, 38 in the usual manner. Any remaining ripple voltage due to imperfect filtering appears across the condenser 38 and produces in the output transformer ripple currents which are increased in amplitude by the feedback action as explained above. Since the circuit of Fig. 3 is of the push-pull type these currents will oppose each other in the two portions of the primary winding of the output transformer but in practice it is very difficult to maintain a perfect balance and some of this ripple current will ordinarily be effective in producing noise in the load circuit.

A portion of the ripple voltage existing across the condenser 38 is applied to the input circuit of the tubes 24 and 25 by means of a condenser 41 connected from the plate supply lead 42 to the cathodes of the tubes so that the ripple voltage is divided between the input and output circuits of the tubes in the ratio of the impedances of the condenser 41 and condenser 43 which bypasses the grid bias resistor 32. Since the impedance of condenser 43 is ordinarily small as compared with the impedance of resistor 32 the difference in phase between the potential drops across condensers 41 and 43 will be negligible and a resistor across condenser 41 is not necessary.

As indicated by the arrows on the drawings, the instantaneous ripple potential drop E_g across the condenser 43 increases the bias on the grids of the tubes while the potential drop E_p across condenser 41 is increasing the plate voltages.

These two potentials are therefore opposed in their effects on the plate current and by a proper choice of the relative impedances of the condensers 41 and 43 it is possible to produce a resulting ripple potential in the output circuit of each tube which will neutralize the excess noise potential due to feedback. While the circuit of Fig. 3 is of the push-pull type, the invention is, of course, equally applicable to single side circuits and the calculation of the ratio of the condenser impedances will therefore be based on

Therefore

$$\frac{1}{1+\mu\beta} = \frac{\frac{R_0}{L}(L+f+Z_g) + (f+Z_g)}{\frac{R_0}{L}(L+f+Z_g) + (f+Z_g) + \mu Z_g}$$

The power supply ripple voltage divides across C_{43} and C_{41} so that

$$\frac{E_g}{E_p} = \frac{C_{43}}{C_{41}} \text{ or } E_g = \frac{C_{43}}{C_{41}} E_p$$

$$\frac{e_p + e_g + e_v'}{1+\mu\beta} = \frac{\frac{R_0}{L}(L+f+Z_g) + (f+Z_g)}{\frac{R_0}{L}(L+f+Z_g) + (f+Z_g) + \mu Z_g} \left[\frac{E_p L}{R_0 + L} \right] \left[1 - \frac{C_{43}}{\mu C_{41}} + \frac{\mu R_0 Z_g}{(R_0 + L)(Z_g + f)} \right]$$

the constants of one side of the push-pull circuit.

In the following calculations the impedances C_{41} and C_{43} of the condensers 41 and 43 at hum frequencies have been neglected since these must be small compared to the output transformer impedance to obtain adequate filtering. The calculations are further simplified by assuming that, as in the usual case, the impedance of the feedback path is very large compared with the impedance of the load circuit.

The simplified equivalent of one side of the push-pull circuit of Fig. 3 is shown in Fig. 3A in which μ is the gain of the two stages in tandem. With the feedback circuit (f) disconnected, the voltage across the load impedance L (one-half the primary winding of the transformer 26) due to the ripple voltage E_p is

$$e_p = \frac{E_p L}{R_0 + L}$$

and the voltage across L due to E_g is

$$e_g = -\mu E_g \frac{L}{R_0 + L}$$

Since the impedance f is large compared to L , the values of R_p and e_g do not change appreciably when the feedback path is reconnected. Under this condition, neglecting for the moment the feedback action, there will be a voltage e_v' impressed on the load impedance L due to the voltage E_p being impressed on the input circuit through the feedback impedance f .

$$e_v' = E_p \frac{R_0}{R_0 + L} \times \frac{Z_g}{Z_g + f} \times \mu \frac{L}{R_0 + L}$$

Neglecting the effect of feedback on its magnitude, the sum of e_p , e_g and e_v' is the total voltage across L due to the power supply noise

$$e_p + e_g + e_v' = E_p \frac{L}{R_0 + L} - \mu E_g \frac{L}{R_0 + L} + E_p \frac{R_0 Z_g \mu L}{(R_0 + L)^2 (Z_g + f)} = \frac{L}{R_0 + L} \left[E_p - \mu E_g + \frac{\mu R_0 Z_g E_p}{(R_0 + L)(Z_g + f)} \right]$$

The application of feedback reduces the voltage ($e_p + e_g + e_v'$) by a factor

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

Since μ is a negative quantity this factor becomes

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

in this case.

The attenuation factor β for the circuit of Fig. 3A is

$$\beta = \frac{Z_g}{\frac{R_0}{L}(L+f+Z_g) + (f+Z_g)}$$

Under the conditions that the hum voltage across the load L is reduced to zero

$$\frac{e_p + e_g + e_v'}{1 + \mu\beta} = 0$$

Therefore the expression

$$\left[1 - \frac{C_{43}}{\mu C_{41}} + \frac{\mu R_0 Z_g}{(R_0 + L)(Z_g + f)} \right] = 0$$

and

$$\frac{C_{43}}{C_{41}} = \frac{1}{\mu} + \frac{R_0 Z_g}{(R_0 + L)(Z_g + f)}$$

This expression, therefore, establishes the relative sizes of condensers 43 and 41 for the elimination of power supply noise in both sides of the amplifier of Fig. 3. In practice there will, of course, be a small residual noise voltage in each portion of the primary of the winding of transformer 26 but these residual voltages will largely cancel each other due to the push-pull connection and only the unbalance difference between these two small voltages will be effective in producing noise in the secondary winding.

The value of condenser 41 will ordinarily be determined on the basis that it forms a part of the main power supply filter and when this has been decided the value of condenser 43 is readily calculated from the above expression for the ratio of the condensers.

When all of the tubes of the circuit of Fig. 3 are properly balanced the noise voltages e_v and e_v' in the two sections of the primary winding of the output transformer will cancel each other and voltages e_g and e_g' will also be equal but opposite in phase. Due to the proportioning of the condensers 43 and 41 the voltages e_g and e_g' are each approximately equal to $(e_v + e_p)$. Under these conditions the level of the power supply

noise in the output circuit is not substantially affected by changes in the gain of either of the output tubes since such changes affect both the voltages e_v and e_g which are of opposite phase and the total voltage across each section of the transformer is substantially unchanged.

While the circuit is not so effective in compensating for unbalances in the driver stage, since the voltage E_g is applied only to the output stage, these tubes are individually self-biased and have high resistance plate loads and may be made less subject to gain variations.

In the circuit of Fig. 3 the voltages applied to the screens 44 and 45 of the tubes 24 and 25 are subjected to filtering by resistor 46 and condenser 47 in addition to the filtering in the plate

supply lead so that the power supply noise components in the screen grid current are negligible as compared with those in the plate current to these tubes. The resistor 46 and condenser 47 are also effective in reducing the ripple potentials in plate supply for the voltage amplifying tubes 22 and 23 and still further filtering for these plate currents is effected by resistor 48 and condenser 49.

The use of positive feedback to eliminate the excess power supply noise caused by the negative feedback is illustrated in the circuit of Fig. 4. In this amplifier signals from the sources 61 are impressed through the input transformer 62 on the grids 63 and 64 of the push-pull tubes 65 and 66 and from the plates of these tubes by means of the usual coupling condensers 67 and 68. A push-pull output transformer 71 connects the plate circuits of the output tubes to the load 72 and power for all of the tubes is supplied from the alternating source 73 by a conventional rectifier unit 74.

A stabilizing negative feed back connection including a high resistor 75 extends from the plate of the output tube 69 to the cathode of tube 65 and a similar path including the resistor 76 connects the plate of tube 70 to the cathode of tube 66 whereby negative feedback potentials are produced across the cathode resistors 77 and 78 and applied to grids 63 and 64, respectively.

The ripple voltage E_{ac} across the filter condenser 79 sets up noise currents which produce potential drops e_p and e_p' in the output transformer and due to the negative feedback connections additional noise components tend to appear in the output circuit as described above. There is, however, a second feedback path through resistors 80 and 81 from the plates of the output tubes to the grid end of resistor 82 in the common portion of the input circuits of the tubes 65 and 66.

Due to the ripple voltage E_{ac} noise currents will flow through the upper winding of transformer 71 and resistor 75 producing a potential drop V_1 in the resistor 77 and similarly noise currents through the lower winding of the transformer and resistor 76 produce a potential drop V_1' in resistor 78. The voltage E_{ac} , however, also produces currents through resistors 80 and 81 to ground through resistor 82 which give rise to a potential drop V_2 across this latter resistor. In a balanced circuit of this type the potentials V_1 and V_1' will be equal and by proper choice of resistors 80, 81 and 82 the potential V_2 may be made of the same value so as to neutralize V_1 and V_1' in the grid circuits of the tubes 65 and 66 as indicated in the drawings.

Signal potentials will, of course, also be impressed back through resistors 80 and 81 to the resistor 82 in a positive sense but they are of opposite phases due to the push-pull connection and in any reasonably well-balanced circuit they will substantially neutralize each other and have no appreciable effect on the gain of the amplifier. A further margin against instability from the use of positive feedback is provided by the fact that since resistor 82 is common to the two positive feedback paths, the positive feedback current in each of the resistors 80 and 81 is just one-half of the current in each negative feedback resistor. Phase shifts in the feedback paths are reduced to a minimum by the elimination of both the usual blocking condensers and grid bias resistor by-pass condensers.

The value of the resistors 77 and 78 is determined by feedback considerations as explained above and in cases where they do not provide sufficient self-bias for the tubes 65 and 66 the necessary additional bias may be readily obtained by connecting the cathodes of the tubes to the power supply through resistors 83, 84. These resistors will ordinarily be large as compared with resistors 77 and 78 and their effect on the circuit at noise frequencies need not be considered.

The circuit of Fig. 5 comprises an input transformer 90 impressing signals from the source 91 on the input circuits of the push-pull pentode tubes 92, 93 which are capacity coupled by condensers 94, 95 to the push-pull output pentode tubes 96, 97. The output circuits of these tubes are delivered to the load 98 through the transformer 99 and the amplifier is supplied with power from the alternating source 100 through a rectifier 101 and a resistance-capacity filter network 102. The rectifier may be of the voltage doubler type which may be used without a transformer and connected directly to the power source thereby reducing the cost and weight of the amplifier and eliminating inductive pick-up which is one common source of power supply noise in the signal circuit.

The control grids 103 and 104 of the tubes 96 and 97 are connected through resistors 105 and 106, respectively, and conductor 107 to the junction between resistors 108 and 109 in the filter 102 and the cathodes of the tubes are connected by conductor 110 to the other terminal of resistor 109 so that the drop in this resistor serves as the grid bias for the tubes. Since the plate current of the output tubes is large compared with the plate current of the tubes 92 and 93, the output tubes operate substantially as if they were entirely self-biased. The tubes 92 and 93 are biased in part by the potential drop due to the plate current flowing in the resistors 111 and 112, respectively, but since the value of these resistors is determined primarily by feedback considerations, additional grid bias is obtained by increasing the flow of direct current through them by means of high resistors 113 and 114 and the conductor 115 to the positive side of the filter 102 as in the case of the amplifier of Fig. 4.

A stabilizing negative feedback connection, including resistor 116, extends from plate of tube 96 to the cathode of tube 92 and a similar path including resistor 117 connects the plate of tube 97 to the cathode of tube 93 to complete the feedback circuit. Signal energy fed back over this circuit will develop across resistors 111 and 112, respectively, potentials which are applied through resistors 118 and 119 and the windings of the input transformer 90 to the grids of the tubes 92 and 93 to reduce the gain of the amplifier in the well-known manner.

A second negative feedback circuit comprises resistors 120 and 121, respectively connecting the plates of the output tubes to the grid ends of the resistors 118 and 119 in the input circuits of the tubes 92 and 93 but it will be observed that in this case the plate of tube 96 is connected to the input of tube 93 on the other side of the push-pull circuit and that the plate of tube 97 is similarly cross-connected to the input of tube 92.

The resistors 111, 112, 118 and 119 are preferably all of the same value and resistors 116, 120, 117 and 121 are also of the same value so that the two feedback paths each carry one-half of the total feedback required for gain reducing

purposes. The ripple potential E_{ac} is applied to all four of the feedback connections and since the paths are all of the same impedance the ripple potential developed across resistor 118 will balance the ripple potential across resistor 111 so that no noise potential is applied to the grid circuit of tube 92 over the fed back connections. Similarly the ripple potentials across resistors 119 and 112 will be equal but of opposite polarity in the grid circuit of tube 93. This circuit, therefore, permits the use of negative feedback without increasing the noise level and it has the additional advantage that the signal feedback is negative in both circuits thereby avoiding any sacrifice of the margin against instability.

What is claimed is:

1. In combination, an amplifier having an input circuit including a source of signals and an output circuit including an output impedance, a vacuum tube in the amplifier having a grid, an anode and a cathode, a source of direct current for the amplifier having noise components, connections from the source of direct current to the cathode and through the output impedance to the anode, a negative feedback circuit from the anode and cathode to a point in the amplifier between the tube and said signal source, whereby undesired noise components are fed back along with the signal currents and amplified to produce in the output impedance a noise level greater than would exist in the absence of feedback, and means for impressing on the grid of the tube noise potentials from the current source equal in magnitude but opposite in phase to the noise components impressed thereon by the feedback circuit.

2. In an amplifying system, a vacuum tube having a grid, a cathode and a plate, an input circuit connected to the grid and cathode, an output circuit connected to the plate and cathode and including an output impedance, a source of current having undesired noise components connected to the cathode and to the plate through the impedance, a negative feedback path connected to the plate of the tube and feeding back noise components along with the signal and two condensers connected directly in series across the source of current dividing the noise component potentials of the source between the input and output circuits of the tube, the ratio of the impedance of the condenser in the input circuit to the impedance of the condenser in the output circuit being substantially equal to

$$\frac{1}{\mu} + \frac{R_0 Z_g}{(R_0 + L)(Z_g + f)}$$

to balance out in the input circuit the noise components fed back over the feedback path.

3. In an amplifier, the combination with a vacuum tube having an input circuit connected to a source of signals and an output circuit including an output impedance, a source of current having undesired noise components connected to the tube through the impedance and a negative feedback path connected to the output circuit between the tube and the impedance and feeding back to the input circuit, along with signals, noise components in such phase as to increase the noise level in the output circuit above the noise level in the absence of feedback, of means for deriving from the source of current and applying to the input circuit of the vacuum tube a noise component voltage of such phase and magnitude as to balance out the excess noise voltage in said input circuit produced by the feedback path.

4. In an amplifying system, a source of signals, a voltage amplifying tube and an output tube connected in tandem to the source and having input and output circuits, a source of current having undesired noise components connected to the tubes, means for reducing the noise components of the current for the voltage amplifying tube, a negative feedback circuit connected to the output circuit of the output tube and feeding back to the voltage amplifying tube, along with the signal, noise components from the current source of such phase and magnitude as to increase the noise level in the output circuit above the level existing in the absence of feedback, and means for applying to the input circuit of the output tube a noise potential from the current source for balancing out in said input circuit the potential produced therein by the noise components in the feedback path.

5. In an amplifying system, an input circuit, an output circuit, two input vacuum tubes having input circuits connected in push-pull to the input circuit, two output vacuum tubes connected in push-pull between the input tubes and the output circuit, a source of current for the tubes, a separate impedance in the input circuit of each input tube and an impedance common to the input circuits of the input tubes, negative feedback connections from the plates of the output tubes to the separate impedances, and a positive feedback connection from the plate of each output tube to the common impedance.

6. A system according to claim 5 in which the separate impedances are each substantially equal to the common impedance and the impedance of each positive feedback connection is substantially equal to twice the impedance of each negative feedback connection.

7. A system according to claim 5 in which the impedance and feedback connections are so related that the signal currents in the positive feedback connection are substantially one-half the value of the signal currents in the negative feedback path.

8. In an amplifying system, a source of signals, an output impedance, a plurality of tandem, push-pull, vacuum tube amplifying stages having input and output electrodes connecting the source to the impedance, a source of current for all the tubes having noise components and supplying current to the output electrodes of the tubes of the last stage through portions of the impedance and separate negative feedback paths from the output electrodes of each tube in the last stage to the input electrode of each tube in the first stage.

9. In an amplifying system, a source of signals, an output impedance, an input stage comprising two push-pull tubes each having a grid and a cathode, an output stage comprising two push-pull tubes each having a plate, said stages being in tandem and connecting the source to the impedance, a source of current for the tubes supplying current to the plate electrodes through the impedance, two resistors in series between the grid and cathode of each input tube, connections from the junctions of the resistors to the source of current, and negative feedback connections from the plate of each output tube to the grid of one input tube and to the cathode of the other input tube.

10. An amplifying system comprising a push-pull, vacuum tube input stage, a push-pull, vacuum tube output stage, a source of signals connected to the input stage, an output impedance

connected to the tubes of the output stage, a source of current having noise components connected to the tubes of the output stage through portions of the impedance, two feedback paths from the output tubes to each input tube, said paths carrying signal currents of opposite phases and noise components from the current source of

the same phase, and means in the input circuit of each input tube for reducing the gain of the amplifier in accordance with the sum of the signal currents in the two paths and for balancing out the effect of the noise components in each input tube.

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