

Dec. 31, 1940.

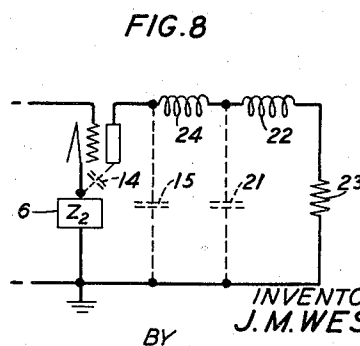
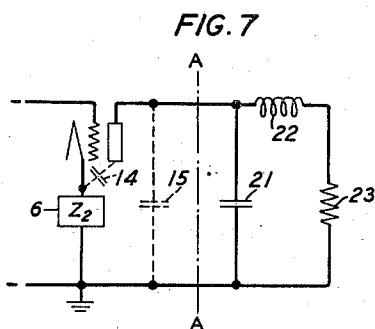
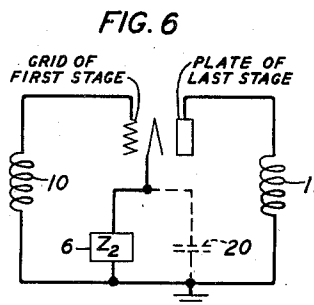
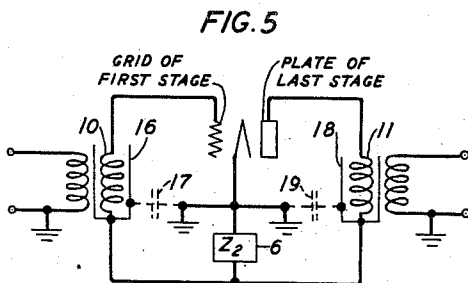
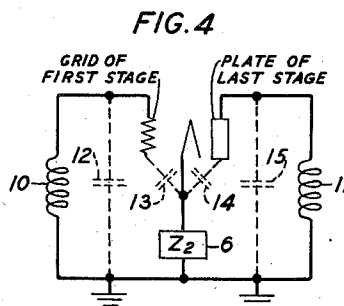
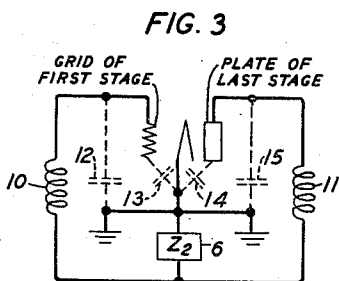
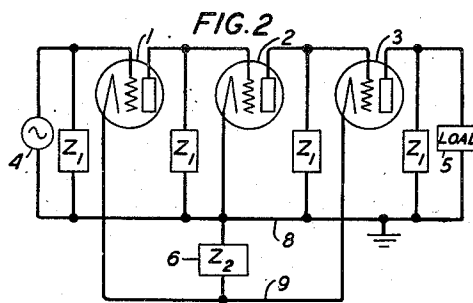
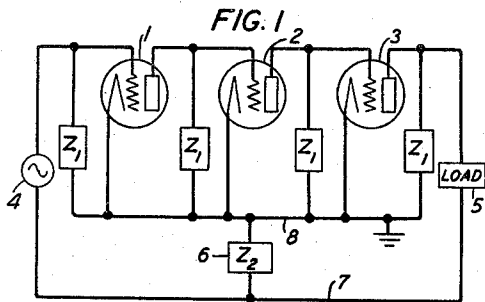
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2,227,048

NEGATIVE FEEDBACK AMPLIFIER

Filed July 9, 1938

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

FIG. 9

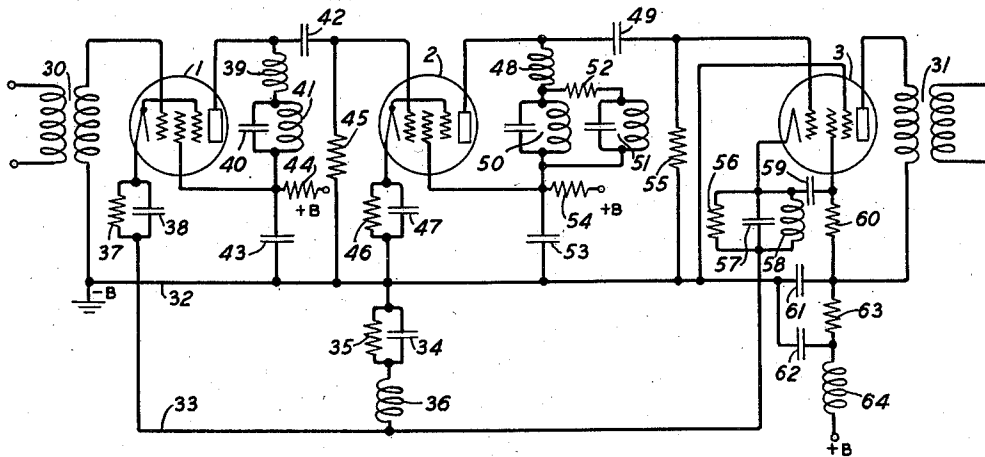
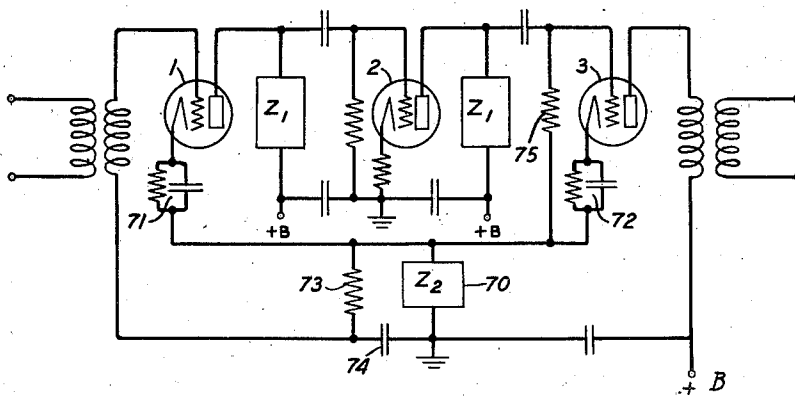


FIG. 10



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2,227,048

NEGATIVE FEEDBACK AMPLIFIER

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Application July 9, 1938, Serial No. 218,300

3 Claims. (Cl. 179-171)

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 applicable to multiplex carrier or television transmission over coaxial lines or similar media.

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 the invention by a novel circuit arrangement which inherently increases the singing stability at very high as well as at very low frequencies, and which permits a higher overall gain to be realized in practice.

In accordance with the specific embodiment to be disclosed herein, a three-stage amplifier has its input grid return and its output plate return connected to ground, while the cathodes of the first and third stages are off ground potential at frequencies of interest and are connected by a feedback path for waves of the frequencies of interest. In this way a negative or gain-reducing feedback is produced with several advantages including a reduction of the adverse shunting effects of parasitic capacities in the beta circuit and improved effectiveness of input and output transformers because of an improved disposition of the circuit capacities.

Where the term "ground" is used throughout the specification and claims, this includes but is not limited to earth since it may refer to an artificial ground such as a chassis or shield of the amplifier to which the various leads are returned as a body or surface of reference potential. Likewise, where three tandem stages are referred to in the claims these may comprise all or only part of the stages of the entire amplifier assembly.

The various features and objects of the invention will be more fully apparent from the detailed description of illustrative embodiments to follow, as shown in the attached drawings.

In the drawings, Figs. 1, 3 and 5 representing conditions according to the prior art are ranged alongside of Figs. 2, 4 and 6 which show in simplified schematic form certain improvements and advantages obtained by the invention; Figs. 7 and 8 are schematic diagrams of details according to the invention; and Figs. 9 and 10 are schematic circuit diagrams of specific amplifiers incorporating the invention.

A type of series feedback amplifier known in the art is shown in Fig. 1 and comprises stages 1, 2 and 3 connected in tandem relation by suitable

interstage impedances Z_1 . A feedback impedance Z_2 at 6 is connected between the common cathode lead 8, which is at ground potential, and the feedback lead 7 extending from the anode of stage 3 to the grid of stage 1. An input source 4 and output or load 5 are indicated.

A simplified similar diagram according to the invention, shown in Fig. 2, by comparison has the feedback lead 9 extending from the cathode of stage 3 to the cathode of stage 1, the feedback impedance 6 in this case forming the common return to ground for both of these cathodes.

The more favorable disposition of certain of the circuit capacities by the circuit of the invention may be seen from a comparison of Figs. 3 and 4. In Fig. 3 the capacity-to-ground of the grid lead of the first stage, indicated at 12, appears in shunt of the grid-cathode terminals, whereas in Fig. 4 this capacity appears across the input coil 10. Considering the feedback voltage from across the terminals of the feedback impedance 6, this voltage is partly shunted away from the grid in Fig. 3 by the capacity 12 while in Fig. 4 the capacity 12 is in series relation to the path extending up to the grid for the feedback voltage. The Fig. 4 circuit is thus more effective in applying the feedback voltage to the grid.

Similarly, as to the capacity-to-ground 15 of the plate lead of the last stage, this appears in Fig. 3 in shunt relation to the feedback path while in Fig. 4 it appears in shunt to output winding 11 and in series relation to the path traversed by the voltage from the plate into the feedback path. The internal grid-to-cathode capacity 13 and internal plate-to-cathode capacity 14 are identified in these figures and distinguished from the external capacities to ground.

Since in the prior type of series feedback circuit of Fig. 1 the input and output transformers were not at ground potential, they presented a very considerable capacity-to-ground in shunt of the feedback path. These transformers are customarily shielded and the shields are indicated at 16 and 18, respectively, Fig. 5. The capacity-to-ground of the input transformer 10 and shield 16 is indicated at 17, while that of the output transformer winding 11 and shield 18 is shown at 19. From the standpoint of impressing a voltage from the anode upon the feedback path or from the feedback path upon the grid, each of these capacities is seen to have a deleterious shunting effect. In Fig. 6, by contrast, the input winding 10 and output winding 11 are at ground potential and the capacities 17 and 19 of Fig. 5 have been

exchanged, in effect, for the capacity 20 of the cathode-to-ground which is very small in comparison.

The advantage of reducing the capacity shunting effects as described in connection with Figs. 3 to 6 is more pronounced at high frequencies. The improvement secured by the circuit configurations illustrated in Figs. 4 and 6 renders the amplifier more stable against singing at very high frequencies (in the so-called asymptotic region) and permits use of higher gain in the useful band.

A known and recognized difficulty in the design of negative feedback amplifiers, particularly multistage amplifiers of high gain, is the tendency of the phase to turn over at some high frequency, usually far outside the useful band, at which the amplifier still has positive gain, so that singing or self-oscillation takes place. It has been shown by Bode in U. S. Patent 2,123,178, granted July 12, 1938, how the gain and phase trends may be controlled so as to prevent phase cross-over until after the frequency is passed at which the amplifier has lost all of its positive gain by the shunting effects of the parasitic capacities which become controlling in the very high frequency region. The circuit of the present invention is particularly stable against high frequency singing, partly for the reason apparently that the three-stage circuit, as shown in Fig. 2 for example, tends to break up into three separate stages at frequencies so high as to cause the interstage impedance to reduce effectively to shunt capacities. Consider the final stage 3, for example. This is part of the overall three-stage feedback loop but it also has local feedback from its own plate to its own grid through the feedback impedance 6. When the interstage shunt impedance disappears, therefore, stage 3 becomes a single stage feedback amplifier with a 90 degree phase margin and, therefore, very stable against singing. Similar analysis shows that the same thing occurs in regard to stage 1 and stage 2. The local feedback for stage 2 can be traced through the plate-cathode capacity of stage 1, the grid-cathode capacity of stage 3, and the capacity existing between the common cathode conductor of stages 1 and 3 and the cathode of stage 2. These afford a shunt capacity feedback coupling between the plate and grid of stage 2 resulting in the local feedback mentioned, at such high frequencies that the shunt capacities become controlling.

The circuit according to the invention, moreover, enables a more efficient transformer design to be used. There are two reasons for this. Were the circuit configurations of Fig. 5 to be used the capacities 17 and 19 would enter as limitations in design of the transformers. These capacities consist largely of the shield-to-low-winding capacity. If this capacity must be kept low, it imposes a limitation on the coupling and voltage ratio that can be used. With these limitations removed as indicated in Fig. 6, a higher voltage ratio can be used with consequent improvement in the signal-to-noise ratio and load capacity of the amplifier. The second reason permitting more advantageous transformer design may be seen by the aid of Figs. 7 and 8.

In Fig. 7 the elements to the right of the broken line A—A represent roughly an ideal transformer where resistance 23 is taken as the equivalent of the terminating resistance multiplied by the impedance ratio of the ideal transformer. That is, the leakage is indicated at 22 and the shunt capacity at 21. To the left of the line A—A are

shown the shunt capacities of the output tube as before. Filter theory shows that the value of 23, and thus the transformer impedance ratio, is inversely proportional to the sum of the three shunt capacities 14, 15 and 21 for a given frequency band provided the leakage inductance 22 is sufficiently small. It is found that by the circuit of the invention it is possible to add an impedance between capacities 15 and 21, as indicated in Fig. 8 by the added inductance 24, giving the effect of an added filter section. The value of resistance 23 is now much larger since it is inversely proportional to only the capacities 14 and 15. A group of impedance elements could be added in place of inductance 24, thus offering the possibility of building out to various types of filters or other networks.

This procedure is not permissible with the series type of feedback circuit of the prior art since it would seriously reduce the high frequency asymptotic gain.

Fig. 9 is a diagram of a feedback amplifier in accordance with the invention designed for the range 400 to 4000 kilocycles. This amplifier gave a flat gain over this band of about 36 decibels, the gain reduction due to feedback being 30 decibels. This amplifier is given as one specific example, it being understood that the invention is capable of wide variation in many forms.

The input is at 30 and the output at 31. Each stage 1, 2 and 3 comprises a pentode tube. The ground line is at 32 and feedback connection 33 extends between the cathodes of stages 1 and 3. The feedback impedance comprises elements 34 (20 micro-microfarads), 35 (165 ohms) and 36 (1.1 μ henries). The cathode of stage 1 has bias resistor 37 (70 ohms) and by-pass capacity (200 micro-microfarads). The elements of the first interstage are as follows: 39 (15 millihenries), 40 (15 micro-microfarads), 41 (80 μ henries), 43 (.05 microfarad), 44 (500 ohms), 42 (50 micro-microfarads), 45 (50,000 ohms). The bias resistor of stage 2, 46 is 400 ohms by-passed by 47 (.004 microfarad). The elements of the second interstage are: 48 (458 μ henries), 50 (21.5 micro-microfarads), 458 μ henries, 51 (12.5 micro-microfarads, 75 μ henries), 52 (2800 ohms), 53 (.002 microfarad), 54 (500 ohms), 49 (50 micro-microfarads) and 55 (500,000 ohms). The cathode network of stage 3 comprises resistance 56 (800 ohms), capacity 57 (20 micro-microfarads) and inductance 58 (3.6 millihenries). Screen by-pass condenser 59 is .005 microfarad, and resistance 60 is 10,000 ohms. Condensers 61 and 62 are each .006 microfarad. Resistor 63 is 500 ohms and inductance 64 is 400 μ henries.

The operation of the circuit of Fig. 9 follows obviously from the preliminary figures and their description. The network 34, 35, 36 is common to the grid-cathode circuit of stage 1 and to the anode-cathode circuit of stage 3. Thus there is fed back to the first grid the voltage developed across this network by the flow of the output current of stage 3. In the specific embodiment of this figure, this feedback impedance (34, 35, 36) is also common to the output and input circuits of stage 1 and produces local negative feedback around that stage. Likewise it is common to the input and output circuits of stage 3 and produces local negative feedback around that stage. This latter local feedback is modified in the case of stage 3 by the action of the network 56, 57, 58 which is effectively in series

with network 34, 35, 36 for the third stage feedback. Both transformers 30 and 31 have their high windings at ground potential and the advantages set out in the description of Figs. 1 to 8 are realizable in this circuit.

In the circuit of Fig. 9 the main feedback impedance 34, 35, 36 passes direct current and contributes to the grid bias of stages 1 and 3 by the voltage developed across the resistance 35. The contribution to the biases can be removed, if desired, by inserting a stopping condenser 74 and grid leak 73 for the first tube, as in Fig. 10, and returning the grid leak 73 to the cathode side of the feedback impedance 70 instead of to ground. This permits any value of resistance to be used in the feedback impedance 70 since the voltage drop across it will not affect the biases of any of the tubes. Stages 1 and 3 now have individual bias resistors 71 and 72, respectively, which may be suitably by-passed by capacity. In Fig. 10 there is negative feedback from the output of stage 3 to the input of stage 1. Local negative feedback around stage 3 may be provided as usual by introducing impedance in the cathode lead in series with the bias network consisting of resistance 72 and its shunting condenser.

The invention is not to be construed as limited to the particular circuit details, dimensions or numerical values that have been given by way of example, since it is applicable generally to negative feedback amplifiers and is capable of wide variation in use. The scope of the invention is defined by the claims, which follow.

What is claimed is:

1. In a broad band amplifier using input and

output two-winding untuned transformers having broad band characteristics and having appreciable shunt capacity at the frequencies being amplified, three tandem stages, each including a space discharge device having a cathode, an anode and a control grid, the secondary winding of said input transformer being connected between the first stage grid and alternating current ground, the primary winding of said output transformer being connected between the third stage anode and alternating current ground, an alternating current connection traversed by the waves being amplified between the first stage cathode and the third stage cathode, an alternating current connection from the second stage cathode to ground, and a negative feedback impedance traversed by waves of said broad band of frequencies being amplified connected between said first and third stage cathodes and alternating current ground.

2. An amplifier according to claim 1 including a building out impedance included in series between the third anode and said primary winding, said building out impedance having an impedance value so related to the shunt capacities of the transformer and tube output as to increase the equivalent value of the terminating impedance of said output transformer within the transmitted frequency band.

3. An amplifier according to claim 1 in which the connection of the secondary winding of said input transformer to alternating current ground includes in series a condenser, and a grid leak resistance connecting the first grid to the first cathode.

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