

Aug. 22, 1939.

F. B. ANDERSON ET AL

2,170,046

NEGATIVE FEEDBACK AMPLIFIER

Filed April 15, 1938

2 Sheets-Sheet 1

FIG. 1

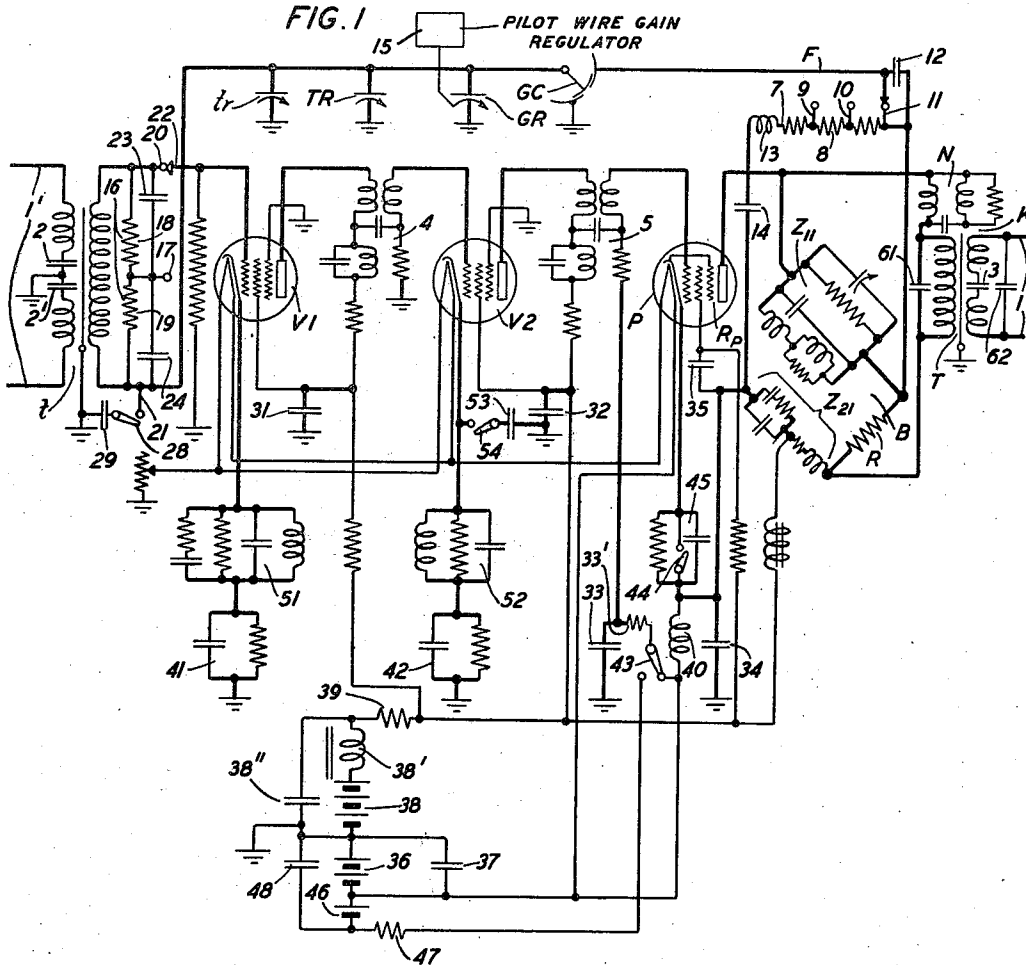


FIG. 4

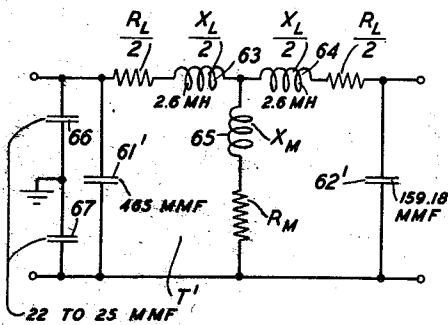
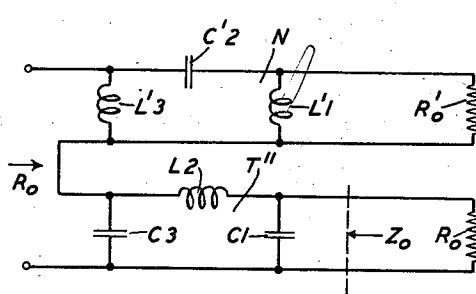


FIG. 5



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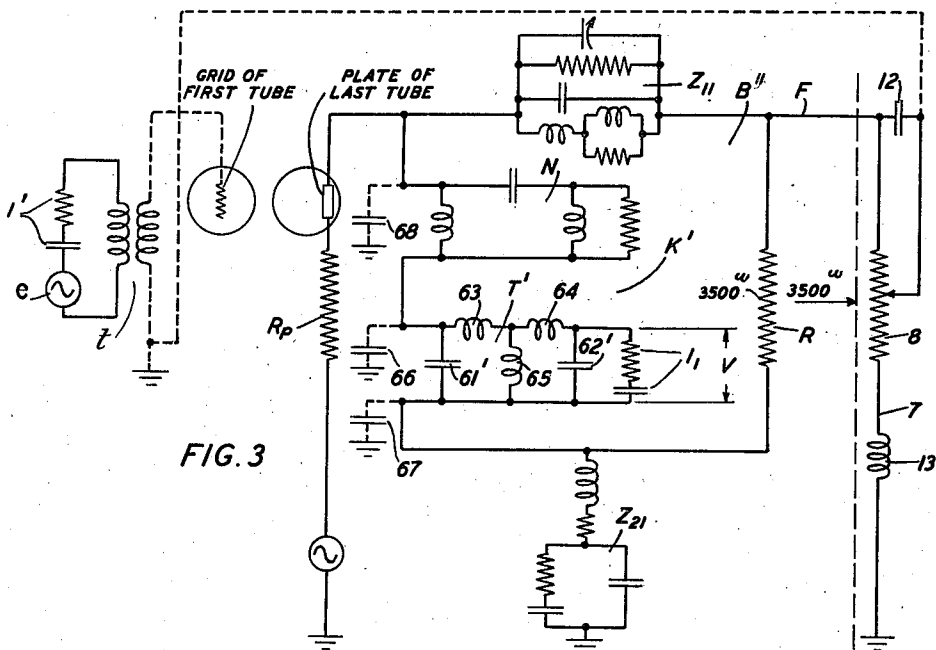
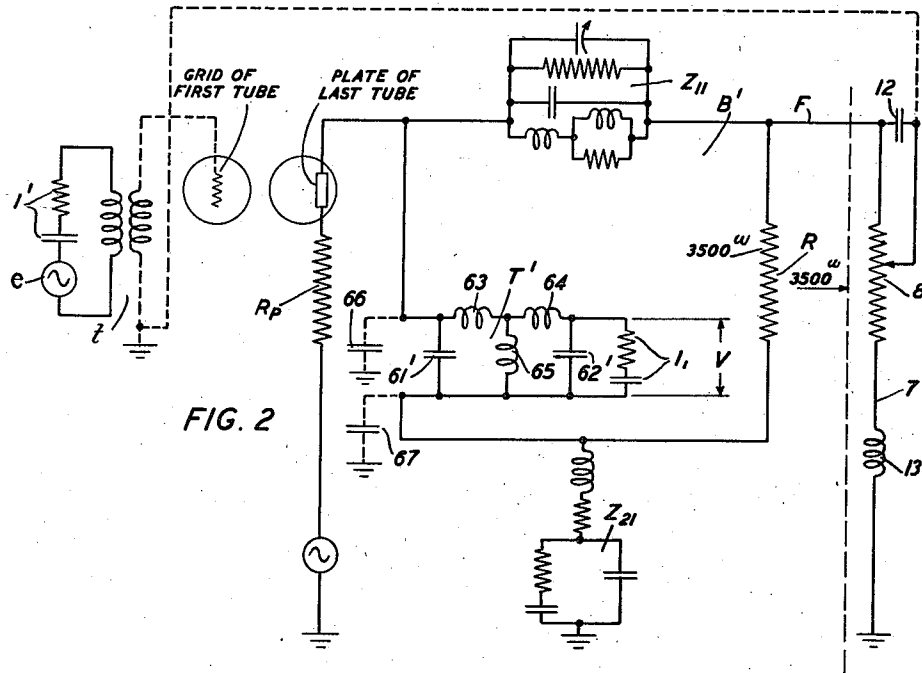
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2 Sheets-Sheet 2



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UNITED STATES PATENT OFFICE

2,170,046

NEGATIVE FEEDBACK AMPLIFIER

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Application April 15, 1938, Serial No. 202,180

13 Claims. (Cl. 179—171)

This invention relates to wave translating systems, as for example, systems for amplifying electric waves, and relates especially to such systems employing gain-reducing feedback for improving operation of the system for instance, amplifiers employing gain reducing feedback for reducing modulation in the amplifier, increasing the gain stability of the amplifier, or controlling the gain or the gain-frequency characteristic of the amplifier.

An object of the invention is to control feedback in such systems, for example, for reducing singing tendency of such amplifiers or increasing their margin against singing.

In accordance with the invention, where a negative feedback amplifier has a load circuit or attached circuit whose impedance outside the transmission band of the amplifier menaces the singing margin, there is associated with the amplifier and the circuit a network affording desirable loss and impedance characteristics for transmission between the amplifier and the circuit, yet giving the impedance faced by the amplifier a characteristic that avoids menace to the singing margin.

In one specific aspect the invention is applied to a negative feedback vacuum tube amplifier of the type that has an output bridge connecting the last tube of the amplifier to the amplifier output transformer and to the feedback path. That type is disclosed, for example, in Fig. 65 of H. S. Black Patent 2,102,671, December 21, 1937.

If, without feedback, the bridge arm containing the output transformer or load is conjugate to the feedback path, the transformer has no effect on the transmission from the tube to the feedback path, excepting effects of stray capacities to ground. In other words, excepting the latter effects, with passive balance of the bridge the feedback is independent of the transformer. However, the bridge is often purposely given passive unbalance. As brought out, for instance, in H. S. Black Patent 2,131,365, September 27, 1938, the purpose of giving the bridge the passive unbalance may be, for example, to reduce reflection to the load while working the tube into its optimum impedance from the standpoint of modulation. As there explained, the feedback can so change the amplifier output impedance as to produce a match between the amplifier output impedance and the load impedance while the tube works into its optimum value of load impedance, and this optimum value may be far different from the actual plate impedance in the tube.

For example, it may be a fifth or a tenth of the plate impedance in the case of a high impedance tube such as a pentode.

The passive unbalance may render the transmission from the tube generator to the feedback path dependent upon the impedance of the bridge arm that includes the output transformer, notwithstanding the fact that feedback may balance the bridge to a driving voltage originating in the load. Consequently, departure of the impedance of the transformer from its nominal resistance value may tend to affect the transmission from the tube generator to the feedback path, or in other words, may tend to affect the feedback or the propagation around the feedback loop, and as a result, the singing margin of the amplifier may be reduced. Such departure may occur at frequencies outside of the transmission band of the transformer, as for example, at frequencies far above the utilized frequency range or operating frequency range of the amplifier. Moreover, the effect of such departure on the feedback may be greatly increased by interaction of the impedance of the transformer with the impedances in other arms of the bridge. For example, the bridge may be an equalizer bridge of the type disclosed in A. L. Stillwell Patent 1,933,758, March 12, 1935, or in the above-mentioned Fig. 65 of H. S. Black Patent 2,102,671, and resonance may occur between a reactance introduced by the transformer and a reactance of one of the two inverse impedance arms used to effect equalization; and such resonance may further unbalance the bridge and may produce violent changes in the frequency characteristic of the impedance attached to the plate and cathode of the tube; and, as explained hereinafter, such further unbalance and such changes in frequency characteristic may increase the effect of the output transformer in changing the gain and phase of transmission around the feedback loop and reducing singing margin of the amplifier, especially where the plate impedance in the tube is high, as in the case of a suppressor grid pentode.

In accordance with a feature of the invention, the impedance of the output transformer is built out to a constant resistance for a range of frequencies including a wide range extending upwardly from the transmission frequency range of the amplifier, without unduly disturbing the transmission in the latter range. This avoids undesirable effects of the transformer on the operation of the amplifier, reducing the effect of the transformer in lowering the singing margin.

A further feature of the invention is that the

means used for building out the transformer impedance to a constant resistance is an appropriate impedance, resistive at frequencies well above the transmission band, connected in series between the transformer and the plate of the output tube. As explained hereinafter, this precludes objectionable resonance of the building out means with the capacity to ground in the transformer at these high frequencies and, moreover, is especially advantageous in that it removes the capacity to ground of the output coil from the plate of the tube and substitutes for that capacity a much smaller capacity.

Other objects and aspects of the invention will be apparent from the following description and claims.

Fig. 1 of the drawings is a schematic circuit diagram of an amplifier embodying the specific form of the invention referred to above; and

Figs. 2 to 5 show circuit diagrams facilitating explanation of the invention.

The amplifier of Fig. 1 is generally similar to that of Fig. 65 of the above-mentioned Patent 2,102,671, and is suitable, for example, as a line amplifier or repeater amplifier for amplifying carrier frequencies in the range from 12 kilocycles to 60 kilocycles transmitted over a nineteen-gauge non-loaded cable circuit comprising the incoming line 1' and the outgoing line 1. Condensers 2 and 2' in the input circuit and condenser 3 in the output circuit serve to make the amplifier impedances more nearly match the cable impedance, and also to make the line circuits of the amplifier an open circuit to direct current used, for example, for cable testing. Moreover, these condensers contribute loss for frequencies below the 12-60 kilocycle band, to facilitate meeting the requirement that the amplifier again be considerably less than the cable attenuation at these low frequencies for all gain settings of the amplifier. Further, the condensers 2 and 2' have equal capacities and have their junction grounded, to increase longitudinal balance of the system while helping to meet the requirement of impedance matching and the requirement of attenuation outside the transmission band.

The amplifier comprises suppressor grid pentodes V_1 , V_2 and P. The tubes are connected in cascade arrangement by interstage networks 4 and 5, which may be, for example, networks generally similar to the interstage networks of Figs. 15 and 16 of the copending application of H. S. Black, Serial No. 114,390, filed December 5, 1936, for Wave translation systems. The amplifier comprises an input transformer t , an output transformer T, a negative feedback path F, and output bridge B. The bridge connects the plate circuit of tube P to the feedback path and the output transformer in the general manner disclosed, for example, in Fig. 65 of the Patent 2,102,671 or in the above-mentioned Stillwell patent. The bridge serves as a transmission equalizer of the constant resistance type in the general manner explained in those patents, especially the Stillwell patent. The feedback path is in one arm of the bridge. The output transformer is in another arm. Of the remaining four arms, one contains the plate resistance R_p of tube P, a second contains resistance R, and the other two are inverse impedances Z_{11} and Z_{21} .

The feedback through path F reduces the amplifier gain, but gives great improvement in quality and stability and greatly reduces harmonic

distortion. The feedback path comprises a gain control potentiometer 7 including a potentiometer resistance 8 having tap conductors 9, 10 and 11.

Path F also comprises a condenser potentiometer of the type disclosed in the application of F. B. Anderson et al., Serial No. 44,050, filed October 8, 1935, for Voltage or gain control, issued as Patent 2,106,336, Jan. 25, 1938. This condenser potentiometer is formed of a flat gain control condenser GC, a flat gain regulator condenser GR, and two trimmer condensers TR and tr . The flat gain control condenser GC serves for varying the amount of feedback to adjust the flat gain of the amplifier through a range of 10 decibels, for example. The flat gain regulator condenser GR may be automatically operated, for example, by a pilot wire gain regulator system 15 such as that disclosed in F. A. Brooks Patent 2,075,775, April 6, 1937, for varying the amount of feedback in order to compensate for the flat portion of the variations in the line loss with line temperature.

The potentiometer 7 comprises a condenser 12, an inductance 13 and a stopping condenser 14. Condenser 12 and inductance 13 improve the high frequency phase margin of the amplifier against singing, for the potentiometer settings on taps 9 and 10; and the inductance 13 improves the high frequency phase margin for the setting on tap 11. The tapped resistance 8 supplies uniform losses over the 12-60 kilocycle band in the feedback loop, the capacity 12 and inductance 13 exerting little effect in that band; the capacity 12 contributes phase margin at high frequencies above that band; and the inductance 13 in the shunt arm of the potentiometer neutralizes some of the capacity bridging this arm and further improves the phase shift.

Across the secondary winding of the input transformer is a terminating resistance 16 having a tap 17 that divides the resistance into two portions 18 and 19. The resistance 18 connects tap 17 and the high voltage terminal 20 of the winding. The resistance 19 connects the tap 17 and the low voltage terminal 21 of the transformer. A movable contact 22 connected to the grid of tube V_1 can be shifted from terminal 20 to tap 17 for reducing the flat gain of the amplifier. A condenser 23 shunts resistance 18; and a condenser 24 shunts resistance 19. The condensers 23 and 24 and the distributed capacity inherent in the secondary winding reduce the unfavorable high frequency phase shift that, especially with contact 22 on tap 17, the input transformer and its terminations introduce in transmission around the feedback loop, and thus increase the singing margin of the amplifier or its stability against self-oscillation of frequencies above the 12-60 kilocycle band.

When contact 22 is on tap 17, a switch 28 may be closed to connect a condenser 29 between the grounded shield of transformer t and terminal 21. This condenser serves to compensate for the effect of the capacity to ground associated with terminal 20 in such a way as to make the gain change due to a change in the setting of the GR condenser the same as it is with contact 22 on tap 20 and switch 28 open.

Condensers 31, 32, 33, 34 and 35 are stopping condensers or by-pass condensers, each of negligible reactance in the 12-60 kilocycle band.

Current for heating the filaments or heaters of the tubes is supplied from battery 36, which is by-passed by a condenser 37 for reducing cross-

talk between amplifiers to which the battery is common.

Plate and screen currents for tubes V_1 and V_2 are supplied, from battery 38 and a low-pass filter therefor comprising choke coil 33' and condenser 33'', through resistor 39 which serves to reduce cross-talk between amplifiers to which the battery is common.

Plate and screen currents for tube P are supplied from plate battery 38 and filament battery 36 in series, through the resistance 39. The plate current passes through a choke coil 40, the coil 40 preventing alternating current of tube P from flowing through the battery 36. The filament heating and space current supply system for the tubes is of the general type disclosed in the copending application of J. O. Edson et al., Serial No. 82,156, filed May 27, 1936, for Amplifiers, and in the above-mentioned Figs. 15 and 16 of the copending application of H. S. Black, Serial No. 114,390.

Grid biasing voltage for tube V_1 is obtained principally from the voltage drop across a network 41 in the cathode lead of the tube, this network consisting of a biasing resistor and a by-pass condenser therefor of relatively small reactance in the band.

Grid biasing voltage for tube V_2 is obtained principally from the voltage drop across a network 42 in the cathode lead of the tube, this network consisting of a resistor and a by-pass condenser therefor.

With switches 43 and 44 operated to the positions shown in the drawings, grid biasing voltage for tube P is obtained from voltage drop across a network 45 and the choke coil 40 which are in series with each other in the cathode lead of the tube. The network consists of a resistance shunted by a capacity and the choke coil is bypassed by the condenser 34. The biasing voltage is filtered by a resistor 33' and by the by-pass condenser 33. Switch 44 may be closed to short-circuit network 45 for a purpose referred to hereinafter; and then, in order to maintain the proper grid bias, the switch 43 is operated to the left to insert a grid biasing battery 46 in series with a resistor 47. The resistor 47 in series with the battery 46 prevents a short circuit on the grid lead to any of the amplifiers common to the battery from disabling the remainder of those amplifiers. A by-pass condenser 48 across batteries 36 and 46 serves to limit the impedance common to the biasing circuits of several amplifiers such as the one shown and so holds cross-talk due to such coupling within tolerable limits.

A network 51 in the cathode lead of tube V_1 provides local negative feedback around the tube, for improving the singing margin of the amplified in the general manner explained in D. D. Robertson Patent 1,994,486, March 19, 1935.

Networks 42 and 52 in the cathode lead of tube V_2 , which can be by-passed by a condenser 53 of negligible reactance in the transmission band of the amplifier by closure of a switch 54, and the network 45 in the cathode lead of tube P, which can be short-circuited by closure of switch 44, facilitate obtaining gain and phase conditions for transmission around the feedback loop that avoid singing for all adjustments of the movable contact of the potentiometer 7 on the taps 9, 10 and 11. For a given setting of the condensers GC and GR, the flat gain of the amplifier is at its maximum value when the contact is on tap 9, with contact 22 on terminal 20 of the input transformer and switches 54 and 44 closed. For a gain reduc-

tion from this maximum, the movable contact of potentiometer 7 is adjusted to tap 10 and switch 54 is opened. For a further gain reduction the movable contact is adjusted to tap 11, and switch 44 also is opened. For a further gain reduction contact 22 is adjusted to tap 17 and switch 21 is closed.

The suppressor grids of tubes V_1 and V_2 are connected to ground instead of to the cathodes of the tubes to increase the singing margin of the amplifier, as claimed in the copending application of F. B. Anderson, Serial No. 158,281, filed August 10, 1937, for Feedback amplifier circuit.

The output bridge B should not only have suitable transmission and impedance properties in the operating band of 12 to 60 kilocycles, but should have favorable phase properties for the feedback loop above the band notwithstanding the high generator impedance in the pentode tube P. In accordance with the invention, with the constant resistance output bridge configuration a satisfactory high frequency phase characteristic is obtained by associating with the load, including the output transformer T and its associated shunt capacities 61 and 62 referred to hereinafter, a network N to render the receiving impedance (i. e., the impedance of the bridge arm containing the load) a substantially constant resistive impedance over not only the operating frequency band, but also a wide frequency range above that band. In the drawings, that bridge arm is designated K and the network N is shown connected in serial relation with the primary winding of the transformer, between the plate of tube P and that winding. The high impedance R_p of the pentode P accentuates difficulties that the transformer and bridge constants contribute to stabilizing the feedback loop against oscillation at frequencies above the operating frequency band. However, such difficulties are overcome by network N, which builds the transformer with its associated shunt capacitances 61 and 62 out to a network K which has a constant resistance impedance.

Fig. 2 shows an output bridge B' which is substantially the output bridge B with the network N omitted and with the transformer T, capacities 61 and 62, and line 1 replaced by a substantially equivalent circuit. In this latter circuit the capacity 61 is represented by equivalent capacities 61', 66 and 67, the capacities 66 and 67 being capacities to ground of the primary winding of the transformer and having values of 22 to 25 mmf. each, for example, the capacity 62 is represented by its equivalent capacity 62'; the line 1 is represented by its equivalent impedance 1; an inductance 63 represents the transformer primary leakage inductance; an inductance 64 represents the transformer secondary leakage inductance; and an inductance 65 represents the transformer mutual inductance. The network comprising elements 61', 62', 63, 64, 65, 66 and 67 is designated T'.

Where the transformer T, which may have, for example, a nominal impedance of 3,500 ohms on the primary side and 140 ohms on the secondary side, must have a large mutual inductance so that its modulation will be small, a fairly large leakage inductance results, as for example, a leakage inductance of approximately 5.2 millihenries. In a circuit such as that of Fig. 2, the transformer T with small inherent capacities and relatively large leakage inductance would have its transmission characteristic unsatisfactory in the 12-60 kilocycle band, and would have its im-

pedance unsatisfactory both in this band and outside of the band, especially above the band. To improve the transmission and impedance in the band, condensers can be added on each side of the transformer building out the inherent capacities to the capacities 61 and 62 which may respectively have, for example, values of 477.5 mmf. and 3,980 mmf., so that the equivalent structure, neglecting the mutual inductance, is a full section of mid-shunt terminated constant K low-pass filter. (In the equivalent circuit as shown in Fig. 2, on a 3,500 ohm basis, the capacity 62' would be 159.2 mmf., or 3,980 mmf. divided by the impedance ratio 3500/140 of the transformer. Of this 159.2 mmf. capacity 62', only some 10 mmf., for example, is transformer capacity; and similarly, of the 465 mmf. capacity 61', only some 30 mmf., for example, is inherent transformer capacity.) However, though the transformer with capacities 61 and 62 has good transmission and impedance characteristics in the 12-60 kilocycle band, its impedance above the band is unsatisfactory in the circuit of Fig. 2, particularly as the capacities 61', 62', 66 and 67 produce resonances with the leakage inductance of the transformer and the inductance of the arm Z_{21} of the output bridge. These resonances may upset the performance of the output bridge and cause great deviation from the loop gain and loop phase characteristics that would be obtained if the bridge arm containing the output transformer were a constant pure resistance. Some idea of the effects of these resonances may be gathered from consideration of the voltage existing between plate and cathode of the output tube at the entrance to the output bridge in response to a unit driving electromotive force acting on the output tube. This plate-to-cathode voltage will depend upon the external impedance between plate and cathode, that is, the impedance attached to the plate and cathode. This impedance will decrease as series resonance occurs between the low side capacity 62' of the transformer (and the line capacity) and the leakage inductance 63, 64. This resonance may occur in the neighborhood of 150 kilocycles, for example. The resistance offered by the line l_1 will damp the resonance. The impedance increases as parallel resonance between the high side capacity 61' of the transformer and the leakage inductance 63, 64 and capacity 62' in series follows at a higher frequency, (for example, a frequency in the neighborhood of 200 kilocycles), decreases as series resonance occurs, for example, around 300 kilocycles, between 61' (together with 63, 64 and 62') and the inductance of the bridge arm Z_{21} ; and rises again as parallel resonance of this inductance occurs with the capacities to ground, 66 and 67 and others present in the equipment, for example, around 400 kilocycles. (Capacity 61' is much greater than capacities 66 and 67, so that capacities 66 and 67 may be considered tied together, or connected in parallel, at frequencies above the parallel resonance of capacity 61' and the leakage inductance.) These capacities predominate at higher frequencies, and the impedance drops as frequency increases.

The impedance-frequency characteristic of the external circuit between the plate and the cathode thus undulates as series and parallel resonances alternate. Impedance arising with frequency is associated with an inductive phase angle for the transmission from the tube to the feedback path, and the loss for such transmission decreases with frequency increase. Similarly, decreasing im-

pedance gives a capacitive phase angle (i. e., a negative phase angle) for transmission from tube to feedback path, and loss for such transmission increases with frequency with the phase angle thus negative. The higher the internal plate resistance of the tube, the less it damps the undulations. With the pentode tube the oscillations may be severe, causing the transmission and phase characteristics to deviate considerably from those for the case in which the output transformer and line present a constant pure resistance to the output bridge, and resulting in gain and phase characteristics for the feedback loop that menace the margin of the amplifier against singing or self-oscillations of the feedback loop.

To obviate such menace, the network N shown in Figs. 1 and 3 builds out the impedance of the transformer network or load (i. e., the impedance of the transformer with its associated capacities 61 and 62 and line l_1) so that the receiving network K presents to the output bridge an impedance which is a constant resistance, excepting distributed capacity. Network N is made in the form of a high-pass filter with a resistance termination, and is used as a two-terminal network in series with the primary winding of transformer T. Above 12 kilocycles the transformer with its associated capacities 61 and 62 is equivalent to a low-pass filter (whose cut-off is above 60 kilocycles), shown as the network T' in Fig. 2, since the admittance of the transformer mutual inductance represented at 65 in this equivalent network T' may be considered negligibly low above 12 kilocycles. The transformer with its associated capacities 61 and 62 is designed to make the resistance component of the impedance that this equivalent low-pass filter T' with its termination l_1 presents to the bridge substantially constant over the operating frequency band of the amplifier. The high-pass filter N added in series with the transformer T, or low-pass filter T', is substantially complementary to the low-pass filter T', being designed to cancel the reactance component of the impedance of the low-pass filter T' in the operating band of the amplifier and maintain the two-terminal impedance that the combination of the two filters presents to the bridge a constant resistance on up to frequencies where parasitic bridging capacities take toll.

Fig. 3 shows the network N inserted in series with the network T', but otherwise has the same circuit configuration as Fig. 2. In Fig. 3 the circuit representing the equivalent of the bridge B of Fig. 1 is designated B''. The capacity to ground of network N at its terminal connected to the plate of tube P is designated 68, and is considerably smaller than capacity 66, being approximately 12 mmf., for example.

The capacity 62 across the line winding of the transformer is made sufficiently small to insure that the series resonance of the leakage inductance and the line side capacity is highly damped by the line resistance so that the succeeding parallel resonance between these elements and the capacity 61 will be well damped. These series resonant elements are then effectively shunted out of the picture by the capacity 61 at frequencies above the frequency of the series resonance. The network N added in series with the output transformer holds up the impedance of the bridge arm containing the transformer at high frequencies, rendering the impedance substantially purely resistive to frequencies above 1000 kilocycles. The reciprocal filter N, being substantially a re-

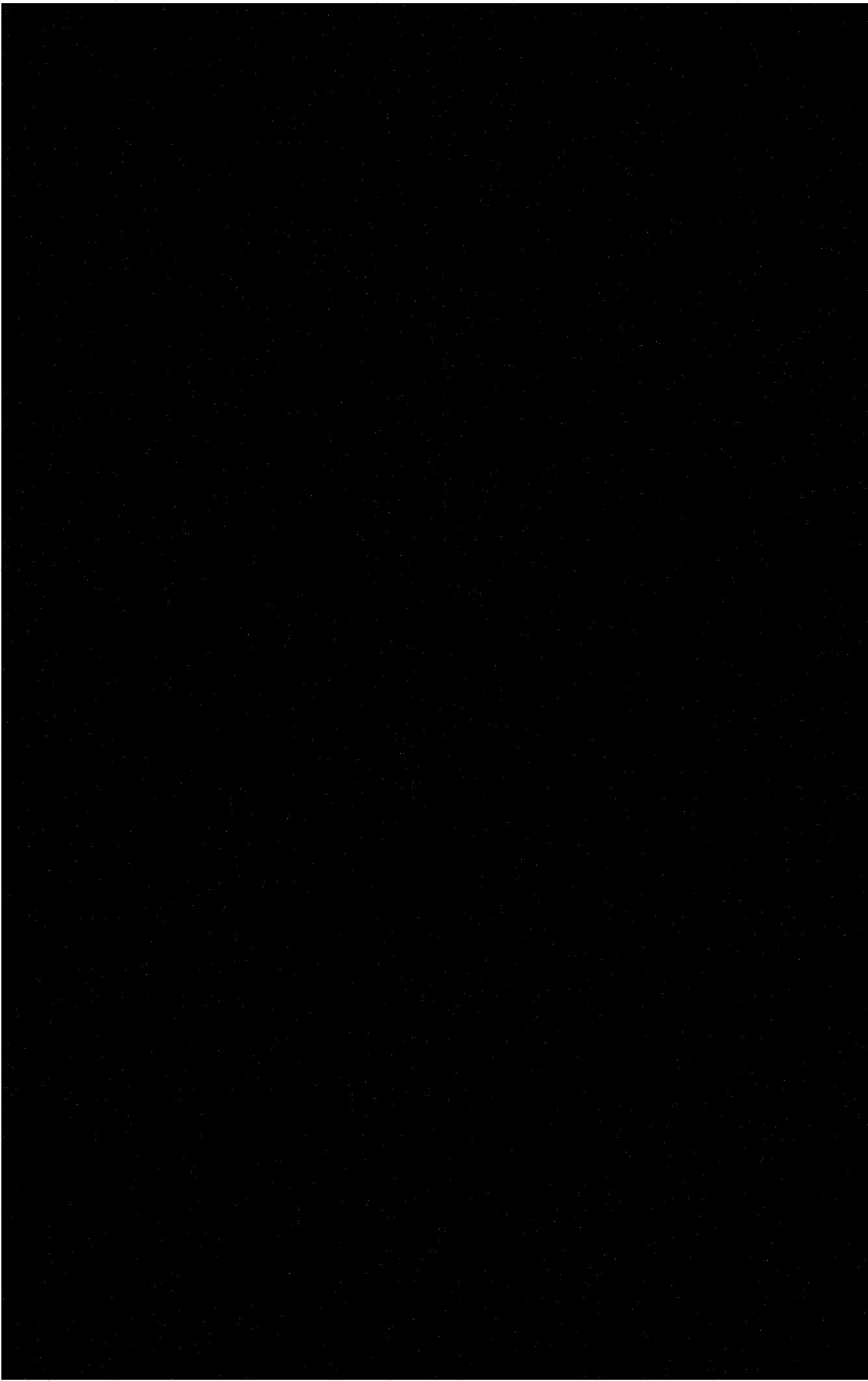
sistance at frequencies above the common cut-off of the two filters, cannot series resonate with the capacity across the arm Z_{21} of the output bridge, i. e. with the capacity to ground, 66, 67, of the output transformer. A highly advantageous feature of the circuit of Fig. 1, or the circuit of Fig. 3, with network N, as compared to the circuit of Fig. 2 with the network omitted, lies in the removal of the capacity to ground 66, 67, of the output coil from the plate of the tube and the substitution of a constant 3,500 ohm resistance (this 3,500 ohms being the impedance of the bridge arm that contains network N and the low-pass filter T'). The capacity 68 is introduced at the plate, but it is considerably smaller than the capacities 66 and 67 and an important net reduction of capacity results. In a particular amplifier, as shown in Fig. 1, this lifted 35 mmf. to ground off the plate, reducing the high frequency capacity approximately from 115 mmf. to 30 mmf. and resulting in substantial increase of gain for transmission from tube to feedback path and substantial favorable change in phase shift for such transmission. The capacity to ground, 66, 67, still parallel resonates with the inductance of the arm Z_{21} of the bridge, and should be made as small as practicable, especially since an attempt to eliminate this effect by inserting the network N between the transformer T and the arm Z_{21} has the disadvantage that the capacity to ground of the output coil is more detrimental when directly connected to the plate than when separated from the plate by a 3,500 ohm resistance as in the case of Fig. 1. Even in the case of Fig. 1, as can be readily seen by inspection of Fig. 3, when frequency increases to values at which the inherent capacities across the bridge arms Z_{11} and Z_{21} become very low impedances, two 3,500 ohm resistances, one the impedance of network N and low-pass filter T' and the other the impedance of bridge arm R, are paralleled across the 3,500 ohm termination F. Thus, a total resistance of about 1,200 ohms in parallel with the capacities to ground is shunted across the output of the tube. This reduction in impedance level means a reduction in gain for transmission from the tube to the termination F, and a negative phase angle for such transmission. Ordinarily, for forestalling the reduction in impedance level at the plate of the tube, locating the network N at the plate terminal of the primary winding is preferable to either locating it at the other terminal or splitting it and locating a part at each terminal. Similarly, connecting network N in series with the low-pass filter T' constituted by the transformer T and capacities 61 and 62, ordinarily is preferable to shunting across the input terminals of the low-pass filter a high-pass filter or network designed to build out the bridge arm containing the transformer to a constant resistance impedance, on account of the irreducible capacity inherently bridged across the primary winding of the transformer.

In the amplifier of Fig. 1, the two-terminal network N connected in series with the output transformer network T' eliminates the shunting of the transformer capacity-to-ground across the output tube and at the same time builds out the transformer arm of the constant resistant equalizer bridge to a substantially constant resistive impedance over the operating frequency band of the amplifier and over a higher frequency range, for example, twenty times the operating band. Thus, the building-out network holds up the gain of the transmission from the tube to the feed-

back path at high frequencies and reduces the phase shift of such transmission due to the distributed capacity to ground on the tube plate and the associated equipment, and gives the feedback loop smooth gain and phase characteristics suitable for stabilizing the amplifier against singing at high frequencies. At the same time, as explained hereinafter, the building-out network causes the impedance of the transformer as viewed from line 1, or the impedance of the amplifier as viewed from line 1, to have a desirable value, as for example, a value of 140 ohms approaching a match of the line impedance over the operating frequency range.

The transformer T with its associated capacities 61 and 62 may be referred to as the transformer network. Since this transformer network is designed for transmission only over the operating frequency band of the amplifier and to offer some discrimination outside of this band, its impedance can be designed to approach pure resistance over only this band. As indicated above, to build out this network to a network presenting a 3,500 ohm resistance to the amplifier at frequencies from 12 to 1000 or more kilocycles and presenting substantially a constant 140 ohm resistance to line 1 over the operating frequency band of 12 to 60 kilocycles, the transformer network is regarded as a low-pass filter over the 12 to 1000 kilocycle range and an appropriate complementary high-pass filter N is connected in series with it. A series combination of complementary high-pass and low-pass filters can be made to have an impedance which is a constant resistance from zero to infinite frequency at the end where the filters are connected together, as disclosed, for example, in E. C. Norton Patent 2,076,248, April 6, 1937. Such combination is shown, for instance, in Fig. 2 of that patent. Fig. 4 herein shows the equivalent network of transformer T with its associated capacities 61 and 62, on a 3,500 ohm basis. In Fig. 4, X_m and R_m indicate the reactance and resistance components of the mutual impedance of the transformer; and X_L and R_L indicate the leakage reactance and resistance. From Fig. 4 it can be seen that a low-pass filter structure employing a series inductance shunted at each end by a capacitance, as in filter 12 of Fig. 2 of the Norton patent, can absorb the equivalent network T' of the transformer T with its associated capacities 61 and 62, neglecting the mutual impedance, which, as indicated above, has relatively small admittance above 12 kilocycles.

Therefore, the network of Fig. 4 is treated as the low-pass filter of a series combination of high-pass and low-pass filters of which the high-pass filter is the network N and the low-pass filter is designated T'', this combination being shown on a 3,500 ohm basis in Fig. 5, and the constants for the elements of the combination network are chosen in accordance with the teaching of the Norton patent to give a network whose input impedance would be a constant resistance from 0 to infinite frequency in the ideal case; and then the input impedance of the actual network, comprising the building-out network N and the transformer T with its associated capacities 61 and 62, is very nearly a constant resistance from 12 to 1000 kilocycles, since the mutual impedance of the transformer over this range is so large as to have little effect upon this input impedance. In each of the filters T'' and N of Fig. 5, the first branch, that is, the branch adjacent the resistance R_0 or R_0' , is in shunt rather than in series as in filters 12 and 13 of Fig. 2 of the Norton



the network and the load circuit as viewed from the loop suitable for stabilizing said system against said singing.

2. A wave translating system comprising an amplifier having a negative feedback loop and a circuit for connection to said loop including an impedance corrective network, said circuit without said network having its impedance outside the operating frequency range of the amplifier so differ from its impedance within that range as to cause objectionable singing tendency of the loop outside that range, and said network giving the impedance of said circuit as viewed from the loop a value that reduces said singing tendency.

3. A negative feedback amplifier comprising a closed feedback loop, a load circuit for connection to said feedback loop whose impedance at frequencies outside of the operating frequency range of the amplifier departs from its impedance within said range in a manner that produces objectionable singing tendency of the amplifier at said frequencies outside of said range, and an impedance corrective network interposed between said feedback loop and said load circuit, the attenuation produced by said network in transmission from said feedback loop to said load circuit having its value for frequencies of said range low relative to its value for said frequencies outside of said range, and the impedance of said network and said load circuit faced by said feedback loop at said frequencies outside of said range having a value that substantially reduces said singing tendency.

4. A wave amplifying system having a negative feedback loop, a load circuit for connection to said loop, and means for preventing self-oscillation of said loop at frequencies above the frequency range utilized in said load circuit, said means comprising a high-pass filter network having an input impedance, the resistive component of which varies with frequency inversely to the resistance of said load circuit and the reactive component of which is equal and of opposite sign to that of said load circuit, and means for connecting said network between said loop and said load circuit with said input impedance serving as a two-terminal impedance in series with said load circuit.

5. A wave translating system comprising an amplifier, a feedback path forming therewith a loop producing negative feedback in the operating frequency range of the amplifier, a transmission circuit attached to said loop including a load circuit and an impedance corrective network interposed between said load circuit and said loop, said transmission circuit without said network having impedance whose value affords stability against amplifier singing in said range but produces objectionable tendency of the amplifier to sing at a frequency outside said range, said network causing the impedance of said transmission circuit presented to said loop to afford stability of the amplifier against said singing outside said range, and said network having its loss for transmission from said loop to said load circuit low for the frequencies of said range compared to its loss for said frequency outside said range.

6. A wave translating system comprising wave amplifying means having a negative feedback loop, a load circuit for connection to said loop whose impedance outside the frequency range utilized in said load circuit produces objectionable singing tendency of said loop, and a network interposed between said loop and said load circuit producing substantial change in the value of the

impedance into which said loop works in transmitting to said load circuit to reduce said singing tendency while producing relatively little effect upon transmission from said loop to said load circuit in said frequency band.

7. A wave amplifying system comprising an amplifier having a negative feedback loop, a load circuit for connection to said loop whose impedance outside the frequency range utilized in said load circuit causes singing around said loop, and a network interposed between said loop and said load circuit for giving the impedance into which said loop works in transmitting to said load circuit a value that prevents said singing while producing substantially no loss in transmission from said loop to said load circuit in said frequency band, said network comprising a ladder type structure the product of whose series and shunt impedances and corresponding impedances in said load circuit is constant independent of frequency.

8. A wave translating system comprising an amplifier having a forwardly transmitting path and a feedback path for providing negative feedback in the amplifier, a transmission circuit for connection to said amplifier, a transformer circuit interposed between said amplifier and said transmission circuit, and means for connecting said forwardly transmitting path to said feedback path and to said transformer circuit and rendering the impedance facing said forwardly transmitting path a constant resistance over a frequency range that includes the operating frequency band of the amplifier and is a number of times as wide as said band, said means comprising a network connected to said transformer circuit that has its reactance equal and opposite to that of said transformer circuit over said frequency range and has its resistance varying inversely to that of said transformer circuit over said range.

9. A wave translating system comprising an amplifier, a feedback path for producing negative feedback in said amplifier, a circuit for connection to said amplifier, a transmission equalizing bridge circuit connecting said amplifier to said feedback path and said first-mentioned circuit, an output transformer for said amplifier having one winding in a branch of said bridge and an inductively related winding in said first-mentioned circuit, and a reactive impedance device in said branch for building out the impedance of said branch to a constant resistance over the operating frequency band of said amplifier and over a wide frequency range above the operating frequency band of said amplifier.

10. A negative feedback amplifier having an output transformer circuit and a high-pass filter with its input end in serial relation with the primary winding of said transformer for building out the input impedance of said circuit to a substantially constant resistance over and above the operating frequency band of the amplifier, said filter having its cut-off frequency sufficiently above said band to render the output impedance of said circuit a substantially constant resistance for the frequencies of said band.

11. The method of controlling the phase shift of propagation around the feedback loop of a negative feedback amplifier having an unbalanced output bridge circuit working into a load impedance that causes objectionable singing tendency of the amplifier at frequencies above the operating frequency band of the amplifier,

which comprises building out the load impedance to a substantially constant resistance receiving circuit over a wide frequency range above said band and at the same time maintaining transmission from said amplifier to said load impedance substantially unaltered in said band.

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12. A wave translating system comprising an amplifier, a feedback path for producing negative feedback in said amplifier, a circuit for connection to said amplifier, an unbalanced bridge network connecting said amplifier to said feedback path and to said circuit with said circuit in one branch of said bridge network and said feedback path in a branch which would be conjugate at bridge balance, the unbalance of said bridge network rendering the feedback dependent upon the impedance of said circuit and said circuit having its impedance at frequencies above the operating frequency band of said amplifier of such value as to produce objectionable singing tendency of said amplifier, and an impedance corrective device connected in said one branch that substantially reduces said singing tendency without material deleterious effect upon trans-

mission between said amplifier and said circuit in said band.

13. An amplifier comprising a high impedance pentode output tube, a feedback path for producing negative feedback in said amplifier of output waves from said tube, a load circuit for connection to said amplifier, an unbalanced output bridge circuit for said amplifier comprising said tube, said path and said load circuit, said feedback lowering the amplifier output impedance presented to said load circuit in the operating frequency band of the amplifier and the impedance of said load circuit producing objectionable singing tendency of said amplifier at frequencies above said band, and an impedance corrective device connected to said load circuit for substantially reducing said singing tendency, the attenuation of said device for transmission from said amplifier to said load circuit having its value for frequencies of said band low relative to its value for said frequencies above said band.

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