

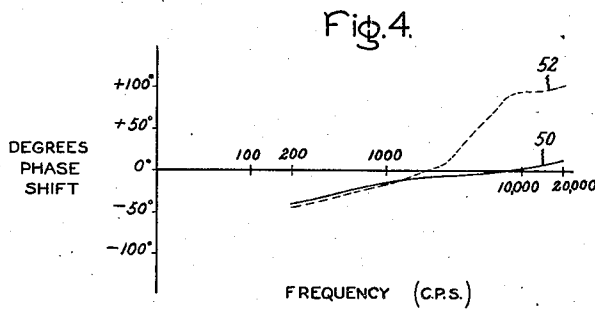
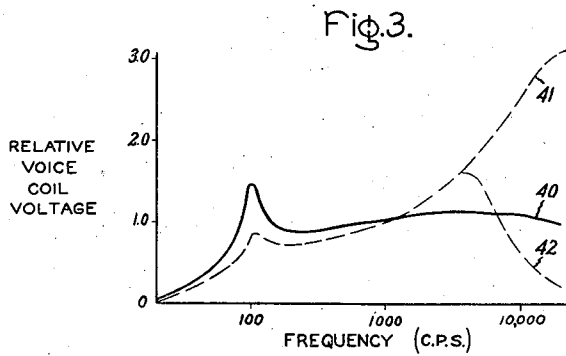
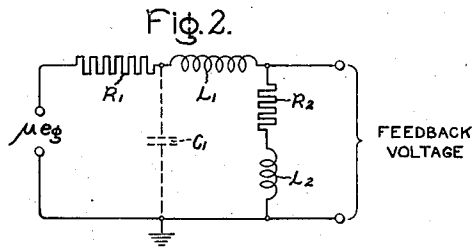
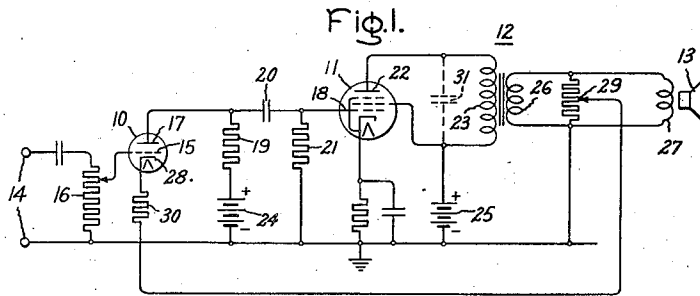
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AMPLIFYING SYSTEM

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AMPLIFYING SYSTEM

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15 Claims. (Cl. 179—171)

My invention relates to amplifying systems and particularly to a system for operation over a band of signal frequencies comprising an electron discharge amplifier which is transformer-coupled to a load device. For example, it may comprise an audio frequency amplifier coupled to a translating device, such as a loud speaker, by means of an audio coupling transformer.

In an audio frequency amplifying and reproducing system of the type wherein an audio frequency amplifier feeds an inductive load, such as the voice coil of a dynamic loud speaker, through a coupling transformer, reactive effects tend to accentuate the higher audio frequencies with consequent impairment of the fidelity of reproduction. These effects also cause a non-uniform phase shift through the coupling transformer at different frequencies within the high frequency portion of the audio spectrum. As is well known to the art, it is often desirable to provide a certain amount of degenerative feedback from the load device to some point in the amplifier preceding the final output stage for the purpose of stabilizing the operation of the amplifier and for improving its fidelity. However, unless the phase of the feedback voltage at these frequencies is maintained within limits, many of the advantages accruing from the use of negative feedback are lost. Even more serious, the higher frequencies may suffer such a large phase shift as to produce regeneration. Sustained oscillation or "singing" may even result if the regenerative voltages are of sufficient amplitude.

It is a primary object of my invention to provide means for rendering the frequency and phase characteristics of an amplifier of this general type more uniform, particularly at high frequencies within the operating range.

Another object of my invention is to provide an improved signal amplifier of the feedback type having means equalizing the phase shift over at least the higher frequency portion of the signal range.

Briefly, in accordance with my invention, the output coupling transformer is designed to have electrical constants which are so related to the electrical constants of the load that the phase shift through the transformer closely approximates the phase shift through the load over at least the high frequency end of the signal frequency range. As will appear more fully hereinafter, materially improved operating characteristics are thereby secured in an inexpensive manner and without utilizing additional corrective networks or circuit elements.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in which Fig. 1 diagrammatically represents an audio amplifying and reproducing system embodying the principles of my invention; Fig. 2 is an equivalent network diagram for a portion of the circuits of Fig. 1; and Figs. 3 and 4 are experimental curves showing the frequency and phase response characteristics of a particular amplifier system embodying my invention.

For the purposes of illustration, the audio frequency amplifying system of Fig. 1 is represented as having two thermionic amplifier stages 10 and 11 whose output is supplied through an audio frequency coupling transformer 12 to a loud speaker 13. The input terminals 14 of the amplifier are adapted to be energized from any suitable source of audio frequency signals having frequencies extending over a substantial band, not shown. For example, the circuits of Fig. 1 may comprise the final audio frequency and power amplifier stages of a conventional superheterodyne radio broadcast receiver. In this case, the terminals 14 will be coupled to the demodulated signal output of the second detector.

As illustrated, an adjustable fraction of the audio input signals is impressed upon the control grid 15 of the first triode amplifier 10 from the volume control potentiometer 16. Amplified signal potentials appearing upon the anode 17 of the triode 10 are supplied to the control grid 18 of the power amplifier 11, represented as a pentode, through the resistance-capacity coupling network comprising the anode resistor 19 for the triode 10, blocking capacitor 20 and grid resistor 21 for the pentode 11.

Anode operating potentials for the devices 10 and 11 are supplied from any suitable source, indicated conventionally by the batteries 24 and 25.

The amplified signals appearing upon the anode 22 of the pentode 11 are impressed on the primary winding 23 of the output coupling transformer 12. The secondary winding 26 is connected directly to the voice coil 27 of the loud speaker 13 which is conventionally represented as being of the dynamic type.

In the system of Fig. 1, the cathode 28 of the triode 10 is returned to ground through a portion of the potentiometer 29, which is connected across

the transformer secondary 26 and the voice coil 27, for the purpose of introducing a predetermined amount of feedback into the grid circuit of the amplifier 10. The polarity of the transformer windings 23 and 25 is so chosen that the feedback is negative, or degenerative. A resistor 30 is also included in the cathode circuit of the device 10 to provide the proper operating bias for the grid 15. It is also preferably unbypassed to provide some additional degeneration. This type of feedback connection, as well as its adjustment and operation, is familiar to those skilled in the art. As previously mentioned, its purpose is to improve the amplifier fidelity.

In the usual case, the anode impedance of the power amplifier 11 will be very high as compared to the impedance of the voice coil 27. In such case, the transformer 12 will have a relatively large step-down ratio in order to match these impedances properly.

In accordance with my invention, the output transformer 12 is provided with a leakage inductance related to the other circuit constants in a particular manner. Fig. 2 further illustrates the principles of my invention and shows the transformer circuits in their equivalent form when dealing with higher audio frequencies of the order of about 2,000 to 10,000 cycles, for example. It is unnecessary to consider the circuit characteristics at the lower audio frequencies since the primary inductance of the transformer predominates and eventually at zero frequency no power is transferred to the voice coil 27.

In Fig. 2, the anode voltage of the amplifier 11 applied to the transformer primary is indicated conventionally by μe_g , where μ is the amplification factor of the amplifier 11 and e_g is the signal voltage on the grid 13. The resistance R_1 includes all the primary circuit resistance. As a practical matter, it is almost entirely comprised by the internal plate or anode resistance of amplifier 11, which is very high for a power amplifier such as the pentode illustrated. The capacity C_1 is the effective capacity across the primary of the transformer. In a step-down transformer, this is principally the primary distributed capacity. In a step-up transformer, it would, of course, be principally comprised by the reflected secondary capacity. It is indicated by dotted lines since, as will be shown later, its effect will generally be negligible over the frequency range considered. The inductance L_1 represents the transformer leakage inductance referred to the primary side.

The secondary circuit resistance and inductance, comprised almost entirely by the resistance and inductance of the loud speaker voice coil, is represented in Fig. 2 by the resistance R_2 and series inductance L_2 . Where negative feedback is employed, as illustrated in Fig. 1, the voltage available for feedback is that appearing across R_2 and L_2 .

It will now be apparent from inspection of Fig. 2 that if the phase of the feedback voltage is to remain the same as the voltage μe_g generated within the amplifier 11, it is necessary to have the following relation hold:

$$\frac{R_1}{L_1} = \frac{R_2}{L_2} \quad (1)$$

or solving for L_1 :

$$L_1 = \frac{R_1 L_2}{R_2} \quad (2)$$

In accordance with my invention, the trans-

former 12 is designed to have this value of leakage inductance. Next, having determined the proper value of leakage inductance L_1 , and knowing the primary inductance L_0 , the coupling coefficient k between the primary and secondary windings is easily determined from the well known relation:

$$k = \frac{2L_0 - L_1}{2L_0} \quad (3)$$

To demonstrate the practical application of these principles, the following values are given merely for the purpose of illustration. Assume that the amplifier 10 is a type 25L6G beam power tetrode with an anode resistance of 10,000 ohms. The remaining primary circuit resistance may be neglected. Hence, R_1 equals about 10,000 ohms. A conventional loud speaker might have a voice coil resistance of 3 ohms and an inductance of 200 microhenries. Therefore, assume that R_2 equals 3 ohms and L_2 equals 200 microhenries. In accordance with Equations 1 and 2, the leakage inductance L_1 referred to the primary side is made equal to .67 henry. An audio output transformer in current use has a primary inductance of 3.4 henries. Therefore, applying Equation 3, the coupling coefficient k should be made equal to about 0.9.

The presence of the capacity C_1 , shown in Fig. 2, tends to interfere with the desired phase relationships. However, in a practical transformer, this capacity will be quite low. For example, in a particular sample transformer, measurement showed this capacity to be only about 35 mmf. Using a value of L_1 of .67 henry, as given in the above illustration, the resonant frequency for the network formed by C_1 and L_1 is above 30,000 cycles per second. Hence, the effect of C_1 within the audio frequency range may be considered negligible.

The heavy curve 40 in Fig. 3 illustrates graphically the voltage-frequency characteristics of an improved amplifying system embodying my invention. This curve was plotted from experimental tests on a system of the general type illustrated in Fig. 1, except that the negative feedback connections were omitted. It will be observed that the voice coil voltage is quite uniform for frequencies within the range of about 200 cycles to more than 10,000 cycles per second. The hump in this curve, and in the other curves of Fig. 3, in the vicinity of 100 cycles, was due to mechanical resonance effects in the particular loud speaker used for the tests.

Conventional design practice has, to the best of my knowledge, led to the use of an output coupling transformer for this type of amplifying system which has a low leakage inductance, for example, of the order of .04 to .10 henry. In the usual case, when this type of transformer is employed to feed an inductive load, such as the speaker voice coil, a rise in voltage across the load at the higher audio frequencies occurs as a result of the secondary circuit inductance, the impedance of which rises with frequency. The curve 41 in Fig. 3 illustrates this effect graphically. It may be compared with curve 40, since it was derived under comparable test conditions, a conventional transformer of low leakage inductance being substituted for the transformer designed in accordance with my invention.

In order to limit this reactive rise in voltage across the load at higher frequencies, it has heretofore been proposed to place a capacitor of the

order of about .01 microfarad across the primary winding of the output transformer. The connection of such a capacitor 31 is indicated in dotted outlines in Fig. 1. The curve 42 in Fig. 3 demonstrates graphically the effect produced by the addition of such a capacitor across the primary winding of the conventional low leakage inductance transformer. It will be observed that the maximum voltage rise across the voice coil occurs at a lower frequency and that it is of materially reduced amplitude. The reasons for this effect are familiar to the art. Briefly, adding shunt capacity across the primary winding lowers the resonant frequency of the system. Furthermore, since the resistance of the load remains the same and since its inductive reactance is lower at this low resonant frequency as compared to the case with the capacitor absent, the circuit is more heavily damped and the rise in voltage at resonance is consequently less. However, it will further be noted that there is a serious attenuation of the higher audio-frequencies in the vicinity of 7,000-10,000 cycles per second and higher.

When negative feedback is employed, the phase relationships between the amplifier signal voltages and the feedback voltages are particularly important. The solid line curve 50 of Fig. 4 shows the degrees phase shift at different frequencies, between the grid voltage impressed on the grid 18 of amplifier 11 and the load voltage, in the case of the particular system embodying my invention previously described in connection with the curve 40 of Fig. 3. Similarly, the curve 52 was obtained from the same apparatus as the curve 42 of Fig. 3, wherein a low leakage inductance transformer, with the primary winding shunted by a .01 mfd. capacitor, was employed. It is seen that the phase shift closely approximates zero over the range of higher audio frequencies of from about 1,000 to 20,000 cycles per second in the case of the curve 50, whereas, there is a substantial positive phase shift within this upper range in the case of the curve 52.

It will thus be apparent from the foregoing specification that I have provided an improved amplifying system which has highly desirable frequency and phase characteristics and which is simple in design and economical in construction. While I have shown a particular embodiment of my invention, it will of course be understood that I do not wish to be limited thereto since various modifications may be made, and I contemplate by the appended claims to cover any such modifications as well within the true spirit and scope of my invention.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An electrical network comprising, in combination, a transformer having primary and secondary windings, a first circuit comprising said primary winding and a source of signals having components included within a band of signal frequencies, said transformer having leakage inductance L_1 referred to its primary side and said circuit having resistance R_1 , a second circuit comprising said secondary winding and an inductive load device having inductance L_2 and resistance R_2 , said inductances and resistances being proportioned substantially according to the relation,

$$\frac{R_1}{L_1} = \frac{R_2}{L_2}$$

over at least a portion of said frequency band.

2. In combination with a source of electrical energy having components included within a range of signal frequencies, a load having inductance and resistance, a transformer having a primary winding connected with said source and a secondary winding connected with said load, said load being of such a character that it tends to increase its impedance with frequency and thereby cause a rise in load voltage at higher frequencies within said range, and means to render the voltage-frequency characteristics of said load more uniform within said range comprising means providing said transformer with a leakage inductance referred to the primary side which makes the ratio of leakage inductance to primary circuit resistance substantially equal to the ratio of inductance to resistance of said secondary load circuit over at least a portion of said range.

3. In combination, a source of audio frequency signals, an inductive and resistive load device, means comprising an audio frequency transformer for coupling said device to said source, said device being of such a character that it tends to cause a rise in load voltage at high audio frequencies because of its impedance, and means to render the voltage-frequency characteristics of said device more uniform over the audio range comprising means providing said transformer with a leakage inductance referred to its primary side which makes the ratio of leakage inductance to primary circuit resistance substantially equal to the ratio of secondary circuit inductance to secondary circuit resistance at said high audio frequencies.

4. An electrical network comprising, in combination, a source of signal energy having components within the audio frequency range, a load device having inductance and resistance, an audio frequency transformer having a primary winding connected with said source and a secondary winding connected with said device, the transformer leakage inductance referred to the primary side being proportioned with respect to the primary circuit resistance to provide a phase shift through said source and said transformer closely approximating the phase shift through said load device over a substantial band of higher audio frequencies within said range.

5. In an electron discharge amplifier for operation over a range of signal frequencies, a load device having inductance and resistance, a transformer having a primary winding connected to the amplifier output and a secondary winding connected to said device, the transformer leakage inductance referred to the primary side being proportioned with respect to the primary circuit resistance to provide a phase shift through said source and said transformer closely approximating the phase shift through said load device over a substantial band of higher frequencies within said range, and means for feeding back at least a portion of the voltage developed across said load device upon the input to said amplifier.

6. In an audio frequency amplifier having an output stage including an electron discharge amplifying device, a transformer having primary and secondary windings, a first circuit comprising said primary winding and the anode circuit of said device, said transformer having a leakage inductance L_1 referred to its primary side and said circuit having a resistance R_1 , a second circuit comprising said secondary winding and an inductive load device having inductance L_2 and resistance R_2 , said inductances and resistances

being proportioned substantially according to the relation,

$$\frac{R_1}{L_1} = \frac{R_2}{L_2}$$

over at least a high frequency portion of the audio frequency spectrum, and means for feeding back at least a portion of the voltage developed across said load device upon the input of said amplifier.

7. In combination, an audio frequency amplifier having an output amplifying device of relatively high anode impedance, a relatively low impedance load having inductance and resistance, a step-down transformer connecting said output device to said load, said device being of such a character that it tends to have its impedance rise with frequency and thereby cause a non-uniform phase shift at different frequencies in the upper range of the audio frequency spectrum, and means to render the phase shift substantially uniform over said range comprising means providing said transformer with a relatively high leakage inductance referred to its primary side which makes the ratio of leakage inductance to primary circuit resistance substantially equal to the ratio of secondary circuit inductance to secondary circuit resistance at frequencies within said range.

8. In combination, an audio frequency amplifier having an output amplifying device of relatively high anode impedance, a relatively low impedance load having inductance and resistance, a step-down transformer connecting said output device to said load, said device being of such a character that it tends to have its impedance rise with frequency and thereby cause a non-uniform phase shift at different frequencies in the upper range of the audio frequency spectrum, means to render the phase shift substantially uniform over said range comprising means providing said transformer with a relatively high leakage inductance referred to its primary side which makes the ratio of leakage inductance to primary circuit resistance substantially equal to the ratio of secondary circuit inductance to secondary circuit resistance at frequencies within said range, and means for feeding back at least a portion of the voltage developed across said load device upon the input to said amplifier.

9. An electrical network comprising, in combination, a source of electrical energy having components extending over a band of frequencies, an inductive and resistive load device, means for energizing said load device from said source through series inductance, said inductance being proportioned with respect to the internal resistance of said source in substantially the same ratio as the inductance and resistance of said load device, whereby the voltage across said load device is substantially constant over a wide band of frequencies, and means for feeding back upon said source at least a portion of the voltage developed across said load device.

10. In combination, a source of signal voltages having components extending over a band of signal frequencies, an inductive load device, said source having a high internal resistance as compared to the impedance of said load device, means for energizing said load device from said source through series inductance, said inductance being proportioned with respect to said internal resistance to provide a phase shift through said source and said inductance closely approximating the phase shift through said load device at high fre-

quencies within said range, whereby the voltage developed across said load device is substantially constant over a wide band of frequencies, and means for feeding back upon said source at least a portion of the voltage developed across said load device.

11. In an electron discharge amplifier for operation over a band of signal frequencies, the combination of an electron discharge device having an anode and a cathode, an inductive and resistive load device effectively coupled to said anode and cathode through means providing series inductance in circuit therewith, said inductance bearing a ratio to the internal resistance of said discharge device substantially equal to the ratio between the inductance and resistance of said load device, whereby the voltage developed across said load device is substantially constant over a wide band of frequencies, and means for feeding back upon the input of said amplifier at least a portion of the voltage developed across said load device.

12. An audio amplifying and reproducing system operating over the audio frequency band comprising, in combination, a thermionic amplifier of high internal anode impedance, a resistive and inductive load comprising the energizing coil of a sound reproducer, said load being of very low impedance as compared to said amplifier, said load being effectively coupled to said amplifier through means providing series inductance in circuit therewith, said inductance bearing a ratio to said internal anode impedance substantially equal to the ratio between the inductance and resistance of said load, whereby the voltage developed across said load device is substantially constant over a wide band of frequencies, and means for feeding back upon the input of said amplifier at least a portion of the voltage developed across said load device.

13. An electrical network comprising, in combination, a source of electrical energy having components extending over a band of frequencies, an inductive load device, and a transformer having a primary circuit including said source and a secondary circuit including said load device, the effective series inductance included between said source and said load device, referred to the primary side of said transformer, being proportioned with respect to the primary circuit resistance in substantially the same ratio as the inductance and resistance of said load device.

14. In combination, a source of signal energy adapted to supply voltages extending over a range of signal frequencies, a reactive load, said source having a very high internal impedance as compared to the impedance of said load, and a step-down transformer having a primary circuit including said source and a secondary circuit including said load, said load being of such a character that it tends to cause a rise in load voltage over a band of higher signal frequencies within said range, the effective series inductance included between said source and said load, referred to the primary side of said transformer, being proportioned with respect to the primary circuit resistance to provide a phase shift between said source and load closely approximating the phase shift through said load over said band of higher signal frequencies.

15. In combination, an electron discharge amplifier, means for supplying signal voltages to the input of said amplifier extending over a band of signal frequencies, an inductive and

resistive load, said amplifier having a very high internal resistance as compared to the impedance of said load, a step-down transformer having a primary circuit including said source and a secondary circuit including said load, the effective series inductance included between said amplifier and said load, referred to the primary side of

said transformer, being proportioned with respect to the primary circuit resistance in substantially the same ratio as the inductance and resistance of said load, and means for feeding back at least a portion of the load voltage upon the input of said amplifier in degenerative phase.

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