April 29, 1941. V. M. COUSINS 2,240,286

AMPLIFIER

Filed Feb. 2, 1940

FIG. 1

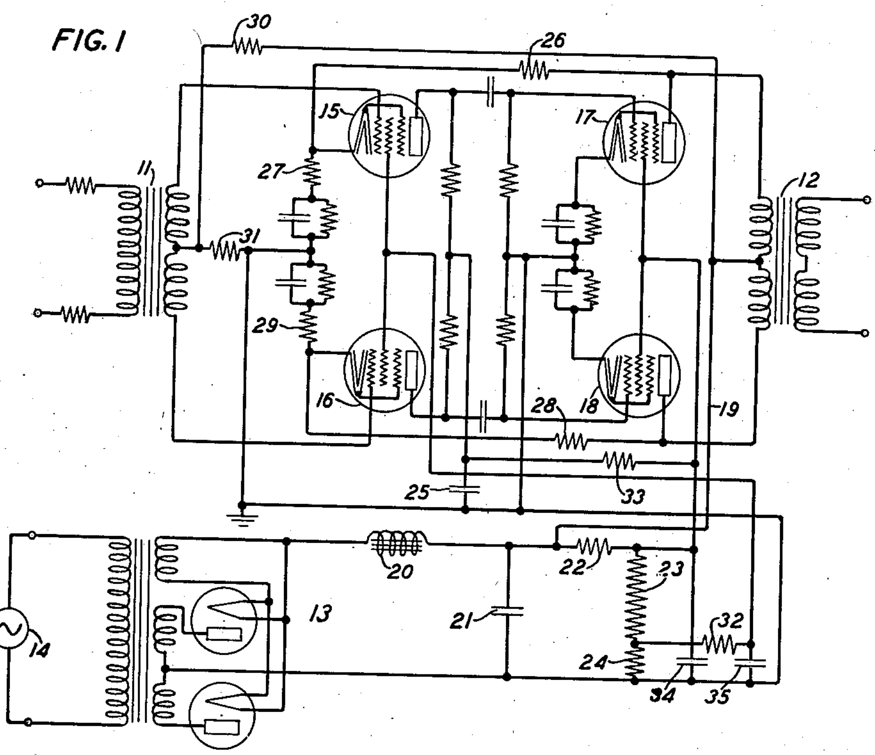
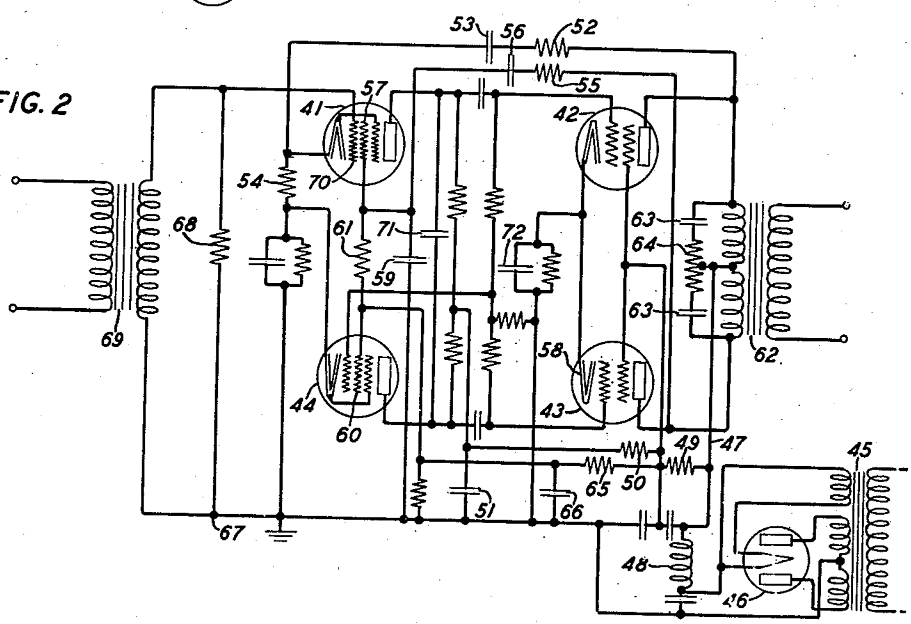


FIG. 2



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Patented Apr. 29, 1941

2,240,286

UNITED STATES PATENT OFFICE

2,240,286

AMPLIFIER

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Application February 2, 1940, Serial No. 316,926

6 Claims. (Cl. 179—171)

This invention relates to amplifiers and particularly to amplifiers using stabilizing negative feedback.

It is the usual practice to filter the power supply to the low level stages of an amplifier to a very high degree to prevent the introduction of noise components which would be amplified to excessive levels in passing through the later stages. This can be done quite economically because of the relatively low voltage and low current consumption of the low level stages. The output stage of an audio frequency amplifier, however, requires a high plate voltage and a large current for which filtering is relatively expensive, but in the output stage the filtering ordinarily need not be as complete as required in the prior stages.

In applying negative feedback to this conventional type of amplifier, it is frequently economical and desirable for circuit reasons to connect the feedback circuit to the primary side of the output transformer, that is, to the plate electrode of the output tube. While this type of feedback circuit largely eliminates the phase shift of the transformer from the feedback loop and, therefore, increases the margin of the circuit against instability, it has the disadvantage of producing a higher level of power supply noise in the output than when no feedback is used. The reason for this increase in noise is fully explained in a copending application of J. B. Harley, Serial No. 316,913, filed February 2, 1940, but, briefly stated, it is due to the fact that the noise potential drop in the output tube is fed back and amplified and produces across the output transformer a noise potential which is in phase with the noise potentials across the transformer due directly to the imperfectly filtered space current flowing through it.

It is the object of this invention to eliminate this excess noise in certain types of feedback amplifiers.

In accordance with the general features of the invention, the feedback amplifiers of the general type discussed above are provided with a second feedback path which impresses on the input circuit other noise potentials which oppose the effect produced by those in the signal feedback path and thereby reduce the noise to, or even below, the level obtaining in the amplifier without feed back.

In the case of a push-pull amplifier with a conventional feedback connection from the plate of each output tube to a push-pull circuit at a lower signal level, such, for example, as an input stage, the noise feedback may take the form of a mid-branch connection to a suitable impedance common to the input circuit of the input tubes. When a single input tube is used to drive push-pull output tubes through an inverter stage, the two signal feedback paths may be connected from the plates of the push-pull tubes to the input tube in such a way that both paths are effective as signal feedbacks and also effective in combination to limit the noise level to that obtained without any feedback.

In the drawing,

Fig. 1 is a push-pull feedback amplifier with means for reducing power supply noise according to the invention; and

Fig. 2 is an inverter tube amplifier with two signal feedback circuits which oppose each other with respect to power supply noise.

The amplifier of Fig. 1 comprises an input transformer 11, two push-pull stages of amplification, an output transformer 12 and the power supply unit 13 adapted to be energized in the usual manner from an alternating current source 14. The input tubes 15 and 16 are resistance-capacity coupled to the output tubes 17 and 18 and all four tubes are self-biased in the usual manner by means of resistors in the cathode circuits. The plate current supplied to the output tubes over the conductor 19 is filtered by the choke coil 20 and condenser 21 which reduces the ripple potential from the rectifier 13 to a value which is tolerable in this high level stage. The usual additional filtering is provided by resistors 22, 23, 24, 32 and 33 and condensers 34, 35 and 25 for the plate and screen currents of the input tubes 15 and 16 and the screens of the output tubes 17 and 18.

A stabilizing negative feedback path of the type shown in Patent 2,123,241 to Harley, July 12, 1938, extends from the plate of the tube 17 through a suitable resistor 26 to the cathode of tube 15, whereby signal currents in the output tube produce across the resistor 27 in the input of tube 15 a potential varying with the output to reduce the amplifier gain in the well-known manner. A similar path is provided from the plate of tube 18 through resistor 28 to develop a feedback potential across the resistor 29. Any ripple voltage across the condenser 21 in the output of the power supply filter will cause ripple currents to flow through the primary windings of the output transformer 12 and the tubes 17 and 18 to ground. Since the feedback paths are connected to the plates of tubes 17 and 18, the ripple potential drops across the tubes are fed back along with the signals to the tubes 15 and 16.

The phase relation of these components to the ripple current flowing directly from the power source to the transformer may be determined mathematically as in the Harley application referred to above, but it is also readily ascertained by considering the problem from the standpoint of the effect of the feedback action on the input impedance presented to the flow of ripple current in the output transformer. It is well known that a shunt feedback of the type under discussion here reduces the effective plate impedance of the tube from which the feedback takes place. As stated above, a certain ripple current flows through the transformer primaries and tubes 17 and 18, in the absence of feedback and since the feedback effectively reduces the impedance of the tubes, it will, therefore, increase the value of the ripple current in the transformer. In other words, the ripple components, due to the feedback action, must be in phase with the ripple current already flowing in the winding.

These noise currents will, of course, be of opposite phases in the two sections of the primary winding of the transformer, due to the push-pull connection, and will, therefore, tend to cancel each other in their effects in the level of the noise in the output circuit. In practice, however, there is never a perfect balance in the transformer itself or in the amplifier stages and, since the ripple voltages pass through both stages in passing around the feedback loop, all of the unbalances of the amplifier may tend to increase the effective unbalance at the output transformer and thereby increase the noise in the associated load circuit.

In this circuit, however, the mid-point of the primary winding of the output transformer is connected through resistor 30 to the grid end of resistor 31 in the common portion of the input circuits of the tubes 15 and 16, thereby impressing on both of these circuits a potential proportional to the ripple potential across the condenser 21 and of a polarity such as to oppose the ripple potentials across the resistors 27 and 29 in the input circuits of these tubes. By proper choice of the values of resistors 30 and 31, the ripple potential developed across resistor 31 may be made just sufficient to balance the ripple potentials across resistors 27 and 29 so that no increase in output noise results from the use of negative feedback. It may even be possible in some cases to reduce the noise level further by developing across resistor 31 a slightly greater potential which will also neutralize the ripple voltage drop which exists in the output transformer in the absence of feedback. This mid-branch connection also serves another very useful purpose. The condenser 21 in the filter network is ordinarily of large capacity and hence of very low impedance for signal frequencies. At extremely low frequencies, below the band of interest, however, potentials of considerable magnitude may be developed across this condenser and impressed on the input circuit through the signal feedback paths in such phase as to produce low frequency oscillations. In this circuit these low frequency potentials are also fed back over the mid-branch connection and impressed on resistor 31, thereby introducing a compensating effect which stabilizes the circuit against troubles of this type.

The circuit of Fig. 2 comprises a single input tube 41, push-pull output tubes 42 and 43 and an inverter tube 44 coupling the tube 41 to the tube 43 in the well-known manner. The amplifier is energized from a conventional power supply unit comprising a transformer 45 adapted to be connected to an alternating current line, a rectifier 46 and suitable filter elements for reducing the amplitude of the ripple components in the rectifier output. The plate circuits of the output tubes are energized over conductor 47 which is connected to the choke coil 48 but the current for the plate circuits of the tubes 41 and 44 is subjected to further filtering, in accordance with the usual practice, by the resistors 49, 50 and the condenser 51. The screen currents are similarly filtered by resistor 65 and condenser 66.

As pointed out above, when the stabilizing negative feedback is applied to an amplifier by means of the feedback connection from the plate of the output tube, it ordinarily results in an increase to the noise level and requires additional circuit connections for balancing out this increase in noise. Applicant, however, uses feedback connections of this type in the circuit of Fig. 2 in such a way that the noise is kept at at low level without any additional circuit features. One feedback path comprising resistor 52 and condenser 53 connects the plate of tube 42 to the cathode of tube 41 so that a voltage proportional to the output of tube 42 is developed across the resistor 54 and a second feedback path, comprising resistor 55 and condenser 56, connects the plate of tube 43 to a second grid, such as the screen grid 57 of the tube 41, and extends back to the cathode 58 of tube 43 through resistor 61, condenser 66 in the power supply filter and the by-pass condenser 72 in the output stage. The potential variations developed across the resistor 61 are effective to vary the potential of the screen grid 57 but the screen grid 60 of the inverter tube 44 is maintained substantially at ground potential for signal currents because of the low impedance of condenser 66. The resistors 52, 54 and 55, 61 are so proportioned with respect to the characteristics of the tube 41 and its associated circuits that the two feedback paths produce substantially equal reductions in the gain of the amplifier. While condensers 53 and 56 have been shown in the feedback paths, they are not essential and, if desired, they may be omitted if the necessary changes are made in the values of the resistors 52, 55, 54 and 61. If used, they may be preferably of such capacity as to have appreciable impedance only for frequencies up to about 100 cycles per second so as to reduce the feedback at these frequencies and thereby improve the low frequency response of the amplifier. The primary of the output transformer 62 is shunted by a network, comprising two condensers 63, 63 and a resistor 64, which protects the output tubes from damage and reduces the noise due to the transient currents which may be set up when either output tube is biased to cut-off by a signal of abnormally high level. In order to be effective for these purposes, the condensers 63, 63 are usually low enough in impedance to have some undesirable shunting effect on the higher signal frequencies. This high frequency attenuation may be compensated conveniently by making condenser 59 of sufficient capacity to reduce the feedback applied to the screen grid 57 by a corresponding amount in this part of the frequency range.

Since the signal feedback potential in the two paths are of opposite phases by virtue of the connections to the plates of the push-pull output tubes and are applied to the cathode and screen grids, respectively, of tube **41**, they will both operate to reduce the gain of the circuit. The ripple current in these paths due to imperfect filtering of the power supply, will, however, be of the same phase and will, therefore, produce equal and opposite effects on the plate current of the tube **41** and thereby prevent any increase in the noise level.

It is well known that the phase shift around the feedback loop of a negative feedback amplifier increases with frequency and may finally become positive at some frequency which is preferably above the range of interest. When an amplifier, such as the circuit of Fig. 2, is designed to transmit a wide frequency band, this positive feedback may be sufficient to produce instability at frequencies of the order of 50 kilocycles. It has been found that this type of instability is effectively prevented in this circuit by connecting a condenser **71** directly between the plates of the input and inverter tubes. In this particular circuit a condenser of 50 micro-microfarads greatly improves the stability of the circuit without introducing appreciable loss at audio frequencies.

While the invention has been described for purposes of illustraiton with reference to particular circuits, it will be understood that these circuits may be modified in various ways. The general principle of using a plurality of negative feedback circuits which oppose each other with respect to power supply noise is, of course, not limited in its application to circuits of the push-pull type but may be applied to amplifiers in general.

In the circuit of Fig. 2 the feedback to the screen grid **57** of the tube **41** may instead be applied, if desired, to the control grid **70** by inserting a suitable resistor between the lower end **67** of the input shunting resistor **68** and ground and connecting the feedback circuit to the point **67**. While this modification would be quite satisfactory if the amplifier is always used with an input transformer, as shown, it would not be desirable for an amplifier which may be resistance-capacity coupled in the ordinary manner to a driver stage, since in that case the impedance of the driver tube would be effectively in shunt to the added feedback resistor and any changes in the tube impedance would destroy the balance between the two feedback paths.

Other possible modifications of these circuits will occur to those skilled in the art but the invention is intended to be limited only by the scope of the following claims.

What is claimed is:

1. In an amplifier, two vacuum tubes having input and output circuits connected in push-pull relation, a vacuum tube input stage having a grid circuit connected to a source of signals and a plate circuit connected to the push-pull tubes, a source of direct current for the amplifier having undesirable noise components, an impedance in the push-pull output circuit, a connection from the direct current source to the mid-point of the impedance, a negative feedback circuit from at least one point on the impedance to the input stage whereby the noise components are fed back along with the signals and amplified and assume in the output impedance a larger value than they would have in the absence of feedback and a path from another point on the impedance to the input stage for impressing thereon noise components for neutralizing the effect produced by the noise components in the feedback path.

2. In an amplifier, input and output stages each having two vacuum tubes connected in push-pull relation, a source of direct current for the amplifier having noise components, plate electrodes in the output tubes, an output impedance connected between the electrodes with its mid-point connected to the source of current, negative feedback signal paths extending from the electrodes to the input circuits of the input tubes and impressing thereon along with the signal noise components from the source which are normally amplified and increase the noise level in the output of the amplifier and a feedback connection from an intermediate point on the output impedance to both of the input circuits impressing thereon noise components opposing the noise components in the feedback paths in their effects on the noise level of the amplifier.

3. In an amplifier, an input tube, push-pull output tubes, means including an inverter tube coupling the input tube to the output tubes, plate electrodes in the output tubes, an output impedance connecting the electrodes, a source of direct current having undesired noise components, a connection between the source and the mid-point of the impedance and two feedback paths from the plate electrodes to the input tube carrying signal energy of different phases and noise components of substantially the same phase and means for utilizing the signal energy in both paths to reduce the gain of the amplifier and for causing the noise components of one path to oppose the effect on the input tube produced by the noise components in the other path.

4. An amplifier according to claim 3 in which the input tube has a signal grid and at least one other grid and one of the feedback paths is connected to the other grid.

5. An amplifier according to claim 1 having a resistance-capacity network shunting the output impedance for protecting the output tubes from excessive transient voltages and a capacity shunting one of the feedback paths and selectively reducing the amount of feedback at high frequencies to compensate for the loss at high frequencies produced by the resistance-capacity network.

6. An amplifier according to claim 3 in which the input tube and the inverter tube have plates and cathodes connected in push-pull relation with a condenser of very small capacity connected directly between the plates and stabilizing the amplifier against singing at super-audible frequencies.

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