

June 10, 1941.

J. L. BARKER

2,245,176

COMPENSATING CIRCUIT FOR AMPLIFIERS

Filed March 4, 1939

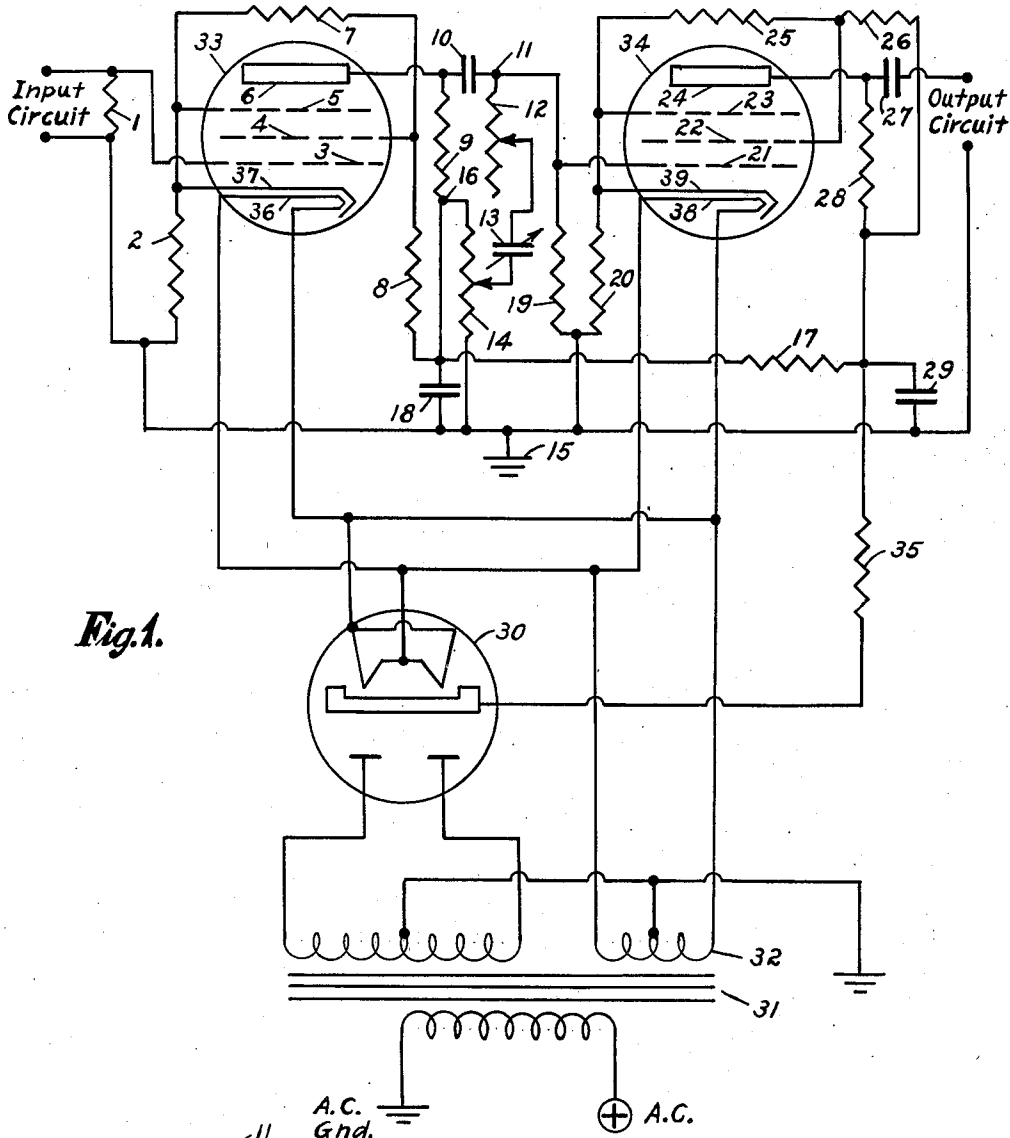
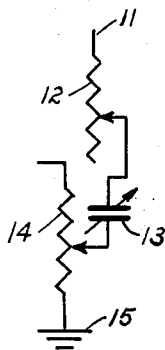


Fig. 1.

Fig. 2.



INVENTOR.
JOHN L. BARKER
BY *Edward H. Barker*
ATTORNEY.

UNITED STATES PATENT OFFICE

2,245,176

COMPENSATING CIRCUIT FOR AMPLIFIERS

John L. Barker, Norwalk, Conn., assigner to Automatic Signal Corporation, East Norwalk, Conn., a corporation of Delaware

Application March 4, 1939, Serial No. 259,834

16 Claims. (Cl. 179—171)

This invention relates generally to high gain low pass electronic amplifiers and a control circuit for the same to compensate for changes in the voltage supplying the amplifier tube heaters and electrodes. More particularly the invention relates to such amplifiers employing pentode electronic tubes with condenser resistor coupling between the stages and to a supply voltage compensation circuit therein.

The direct current for operating such amplifiers is quite commonly supplied from an alternating current source through the use of a rectifier. It is well known that when the alternating voltage input to the rectifier varies from its usual value due to some disturbance such as a change in load at some other point on the power line supplying A. C. to the rectifier, the D. C. output of the rectifier will also vary. The output voltage of a low pass amplifier operating on a rectifier will vary when the direct voltage supplied to the amplifier tube heater and electrodes changes as a result of a disturbance in the alternating voltage feeding the rectifier. Where an amplifier is operated directly from a D. C. supply, any variation of the D. C. supply will similarly affect the output of the amplifier.

In electronic amplifiers designed to pass frequencies of more than about 30 cycles it is customary to use a filter in the D. C. supply circuit and have the coupling circuit between stages filter out any frequencies below this level, to minimize the effect of supply voltage changes. However, in amplifiers designed to operate on low frequencies from $\frac{1}{4}$ cycle up for example, such a D. C. filter will require condensers and inductances of large magnitude for filtering the D. C. supply to the tube electrodes. As the cathode heating circuits are normally supplied direct from the A. C. supply and the cathode temperature must be held quite constant to maintain stability of the output, it is ordinarily necessary to employ sensitive voltage or current regulators on the A. C. supply in such low pass amplifiers. The present invention provides a simple and inexpensive compensating circuit to avoid these difficulties.

The purpose of this invention is to maintain the output voltage of an amplifier reasonably constant even though the voltage source operating the electronic tubes of the amplifier is subject to fluctuation and the invention accomplishes this object without the use of the high capacity condensers and high inductance which would be necessary in a filter to do the same.

This invention is particularly adapted to be

used in connection with resistance-capacity coupled amplifiers when the time constant of the frequency pass of the amplifier is above the time constant of cathode electron emission changes in relation to supply voltage changes in the cathode heater circuit. Of course voltage or current regulator tubes can be employed for this purpose but they involve delicate adjustment, considerable expense and space. This invention is simple, inexpensive, and requires little space. In accordance with the invention a resistor associated with a capacitor and a potentiometer are connected with the coupling circuit between two of the pentode tubes of the amplifier. Both resistance and capacity may preferably be adjustable.

In a multistage amplifier the invention may of course be connected between any adjacent pentodes. It would be most effective to connect it between the first and second pentodes because its effect will then benefit by the amplification occurring in the subsequent stages. The effect of this invention is to control the voltage between the control grid and the cathode of the pentode in the next stage of amplification when the plate current from the preceding stage varies as a result of a fluctuation in the voltage supplying the electronic tubes. By causing the effect of this invention to suitably compensate for fluctuation in such plate current in the preceding amplifier stage an additional compensation can be set up which will neutralize similar effects occurring in following stages. In order to control the amount of this effect and to match the time constant of the electron emission of the cathode resulting from change in heater voltage the capacity and resistance of this invention are preferably made variable.

It is an object of this invention to provide a compensating circuit for an electronic amplifier employing high gain thermionic tubes to make the output voltage substantially independent of fluctuations which may occur in the voltage source energizing the amplifier tube heaters and electrodes.

It is a further object of this invention to provide an electronic amplifier in which the effect of fluctuations of the voltage source supplying the first stage with its consequent variation in voltage output of the first stage may not only be neutralized but may also be under compensated to neutralize similar effects which occur in the tubes of subsequent amplification stages.

It is another object of this invention to provide a high gain electronic amplifier of the type de-

scribed which is inherently compensated so that the output voltage is substantially undisturbed by ordinary minor fluctuations in the voltage source supplying the amplifier.

The invention can be better understood by referring to the accompanying drawing in which Fig. 1 shows a circuit for a resistance capacity coupled amplifier using two pentodes in the usual way well known in the art, but with the addition of a variable resistor 12, variable condenser 13 and a potentiometer 14 in accordance with the invention.

Fig. 2 shows a preferred form of circuit arrangement including the variable resistor, the variable condenser and the potentiometer which constitutes the improvement of my invention. This circuit connects into the circuit of Fig. 1 at points 11, 15 and 16.

The invention comprises a means whereby the output of a resistance-capacity coupled amplifier may be stabilized for cases where the lower frequency limit of the amplifier is near or below that which will not be filtered out in the power supply.

Referring to Fig. 1, the low limit of the frequencies handled by the amplifier is determined primarily by the value of the coupling condenser 10 and the leakage resistor 19. If it is desired to lower the frequency characteristic either 10 or 19 or both may be increased but if the frequency pass is lowered to the point where the time constant of this circuit is approximately within the range of the time constant of the plate current change resulting from change in the current in the filament or heater circuit, means such as my invention must be provided for eliminating the voltages which will appear as a result of the heater current change.

The amplifier of Fig. 1 comprises pentodes 33 and 34, which receive their electrode voltages from a power supply consisting of the A. C. supply transformer 31, rectifier tube 30 and filter condensers 18 and 29, and resistors 17 and 35. In order to control the change in voltage between plate 6 and ground resulting from variation in voltage across condensers 18 and 29 which will occur when the voltage of the A. C. source varies pentode tubes may be used in which suitable selection of electrode voltages can be made to minimize the change of the voltage from plate 6 to ground when the supply voltage across condenser 18 varies. In order to accomplish this a combination of self bias and fixed bias is used on pentode 33 by means of resistors 8, 7 and 2 which form a network which supplies the voltages for the screen grid 4, the suppressor grid 5, and the control grid 3 of the tube 33, and the cathode 37 of tube 33.

In order to prevent serious degenerative effects in the high gain amplifier the ratio of the current as drawn through the potential divider consisting of resistors 7 and 8 as compared to the total cathode current is made large, which provides a high ratio of fixed bias to self bias. The screen grid of the tube 4 will draw some current and alter the voltage at the junction of resistors 7 and 8, however this current is quite small compared to the current as determined by the value of the total potentiometer and therefore can be neglected.

The second stage of the amplifier comprising tube 34 is supplied with voltages in exactly the same manner as tube 33. However, the amount of filtering of the D. C. supply is not as critical.

The values of the several resistors and there-

fore the voltages applied to the elements of the tubes can be so selected that if the voltage across condenser 18 rises, the voltage change from the plate 6 of tube 33 to ground will be minimized. There will therefore be negligible change in the grid voltage of tube 34 and consequently little in the output voltage of tube 34 since tube 34 is also protected by the suitable choice of resistors.

Referring to Fig. 1, the normal operation of the apparatus to amplify signal voltage is as follows: The signal voltage is impressed on the input circuit shown in the upper left hand corner of Fig. 1. This voltage will appear across resistance 1 and also between control grid 3 and the cathode 37 of tube 33 which is connected to the top of resistance 2. If this voltage is such as to make the control grid potential more positive than formerly with respect to the anode the current flowing to plate 6 of tube 33 will be increased as is well known in the art. This increase of current will flow through resistance 9. The increase in voltage drop in resistance 9 will cause condenser 10 to become more negative. Condenser 10 having become more negative, control grid 21 of pentode tube 34 will also become more negative which will decrease the current flowing through tube 34 to plate 24 thereof.

Since the current flowing into plate 24 of tube 34 passes through resistance 28 the voltage drop across resistance 28 will therefore be decreased by the decrease in the current going through it. Hence the voltage between condenser 27 and ground will be increased and the voltage of the output circuit at the upper right hand corner of Fig. 1 will be correspondingly increased. The change in current of the plate of both of the pentodes will be many times as great as the change in the grid control voltage which caused the change in the plate current as is well known in the art and therein lies the amplifying effect of the apparatus.

In a similar manner a decrease of voltage across the input circuit will cause a decreased voltage drop across resistance 1 which will be transmitted to the amplifiers in the manner described previously with respect to an increase in the voltage drop across resistance 1, but its effect will be reversed with respect to that formerly described so that the voltage at the output circuit will be decreased instead of increased. All of this is well known in the art and is not a part of my invention.

Since the purpose of an amplifier is to cause the output voltage to vary at some constant ratio with respect to variations in the input voltage, it is desirable to have the output voltage unaffected by any changes in the heater current in the tubes. My invention accomplishes this as follows.

Due to the fact that the heater circuits 36 and 38 of the tubes derive their energy from the same original source as condenser 18 their temperature will change if the voltage across condenser 18 changes due to voltage fluctuations in their common A. C. supply. When this happens the space current in tube 33 will change slowly and somewhat later than the voltage of condenser 18. The rate of change of the space current will be a function of the rate of change of the temperature of the cathode. For a given change of supply A. C. voltage, the change in plate current of the tube will very closely approximate an exponential relationship with respect to time due to the familiar cathode heating

time lag and the time constant of this exponential can be duplicated quite closely by means of a condenser-resistor network which has an analogous time constant. An increase of heater voltage will cause the space current in the vacuum tube to become larger thereby producing a larger drop across resistor 9 which will tend to make the plate 6 of tube 33 and condenser 10 at a lower voltage with respect to ground than they previously were. As the voltage of condenser 10 becomes lower it lowers the voltage of grid 21 of the next stage. It is this effect that my invention controls.

As the voltage on plate 6 goes down due to the increase in heater temperature as described above the voltage across condenser 18 will rise as a result of the same A. C. change that increased the heater voltage. This fact is used to supply a compensating voltage to condenser 10 to counteract the tendency of condenser 10 to become more negative as above described. By selecting the proper capacity for condenser 13 and the proper value for resistance 12 and the proper percentage of the voltage across potentiometer 14 it is possible to gradually apply a part of the voltage increase in condenser 18 to condenser 10 and to cause the grid 21 of tube 34 to remain at substantially a constant voltage with respect to ground despite variations in the voltage of the A. C. source.

The time constant of the electron emission change resulting from a change in the voltage supplying the heater coil of a standard pentode tube is on the order of four seconds. Experiments have shown that if condenser 13 has a capacity of 4 microfarad and resistance 12 is of the order of 10 megohms, the time constant of this condenser and resistance circuit is about four seconds which gives proper time balance between the change in heater temperature in the tube and the application of the compensating voltage as above described. The range of tube time constants for different types of tubes that might be employed may be from less than one second up to thirty seconds for example, and it will be obvious to those skilled in the art that proper values for resistance 12 and condenser 13 can be readily chosen to match these time constants in accordance with the well known rule that the time constant of a resistance-capacity circuit is the product of the resistance and capacity.

If the voltage of the alternating current source supplying transformer 31 were to be decreased instead of increased all of the effects just described would be reversed. Therefore the current change in tube 33 being reversed and the counteracting effects of condenser 13 and resistance 12 being reversed they would still offset each other and keep the voltage of the output circuit constant. Similarly, the temperature of the heater 38 in tube 34 would be gradually decreased but the voltage of control grid 21 thereof would be gradually increased to compensate thus again maintaining the output circuit voltage constant.

During the described changes in the tube current and voltage brought about by changes in the voltage of the alternating current source any signal voltage applied to the input circuit resistance #1 would of course be amplified and appear in the output circuit just as if the voltage of transformer 31 were not changing.

By properly adjusting potentiometer 14, the capacity of variable condenser 13 and of variable

resistance 12 the compensation effect thereof can be made greater in raising the voltage of condenser 10 than the effect of plate current in tube 33 is in lowering it. Or, if desired, the compensation effect of condenser 13 and resistance 12 can be made to be less than the effect of increased plate current in tube 33. By adjusting potentiometer 14, condenser 13 and resistance 12 so that their compensation effect is not quite sufficient to counteract the increased current in plate 6 of tube 33, the control grid 21 of tube 34 can be caused to become slightly more negative gradually as the temperature of the heater coil of the tube 34 gradually rises. Thus when the gradual rise in temperature of heater in tube 34 tends to produce more electrons which would increase the current in plate 24 of tube 34, the increase in the negative potential of control grid 21 tends to decrease the flow of electrons to plate 24. These two actions counteract each other and cause the voltage of the output circuit to remain substantially constant.

A low pass amplifier of the type described is useful in connection with the detection of moving magnetic objects such as vehicles in a highway. A well known method of such detection is to place a coil of wire on a magnetic core adjacent to the path of traffic so that vehicles passing will generate a wave of electromotive force in the coil which can be connected to the input of an amplifier. Such waves will have a very low frequency characteristic and low electromotive force for low traffic speeds, which require a low pass, high gain amplifier, of a high degree of stability as provided in accordance with the present invention. Such a low pass, high gain amplifier is also useful to amplify the output of a photo-electric cell, arranged to detect relatively slow changes in light intensity on the photo-electric cell, as for example changes caused by varying density of smoke passing before the photo cell.

The form of the invention described and illustrated herein is to be considered as but one embodiment, and it will be appreciated that changes may be made in the construction of the unit or alterations in the design thereof or rearrangement of the parts without departing from the spirit of the invention as defined by the claims.

I claim:

1. In an electronic amplifier employing a thermionic tube having the conventional control grid, hot cathode, anode and screen grid and an output circuit connected to the anode, means for minimizing voltage changes in the output circuit produced by changes in the voltage supply for the heater and anode, cathode and screen grid electrodes, said means comprising a circuit having a time constant substantially equal to the time constant of thermionic emission in relation to heater supply voltage changes and connected from the voltage supply to a point in the anode circuit.

2. In an electronic amplifier employing a thermionic tube having the conventional control grid, hot cathode, anode and screen grid and an output circuit connected to the anode, a control circuit for minimizing voltage changes on the output circuit produced by changes in the voltage supply heating the cathode, and supplying the other electrode voltages, said control circuit comprising resistance and capacitance connected between the voltage supply and the anode, and hav-

ing a time constant substantially equal to the time constant of thermionic emission in relation to heater supply voltage changes.

3. In an electronic amplifier employing a thermionic tube having the conventional control grid, hot cathode, anode and screen grid and an output circuit connected to the anode, a control circuit for minimizing voltage changes on the output circuit produced by changes in the voltage supply heating the cathode, and supplying the other electrode voltages, said control circuit comprising a potentiometer connected across the voltage supply and a resistance and capacitance connected between said potentiometer and the anode circuit, and said control circuit having a time constant substantially equal to the time constant of thermionic emission in relation to heater supply voltage changes.

4. In a multistage electronic amplifier employing thermionic tubes having a control grid, a screen grid, an anode and a cathode and a coupling circuit connecting the anode of one stage with the control grid of a following stage, a control circuit for minimizing the effect of power supply voltage variations on the signal output of the amplifier, said control circuit comprising a resistance and a capacitor connected in series between the power supply and the anode of one of the stages, and having a time constant to match substantially the time constant of thermionic emission of the cathode in relation to changes in supply voltage for the cathode heater and the anode.

5. In a multistage electronic amplifier employing thermionic tubes having a control grid, a screen grid, an anode and a cathode, and employing resistance-capacity coupling between stages, a control circuit for minimizing the effect of power supply voltage variations on the signal output comprising a resistance and a capacitor connected in series between the power supply for the tube of one stage and the control grid of the tube in the next subsequent stage, and said control circuit having a time constant to match substantially the time constant of thermionic emission of the cathode in relation to changes in supply voltage for the cathode heater and the anode.

6. In a multistage low frequency electronic amplifier employing thermionic tubes having a control grid, a screen grid and an anode-cathode circuit, and having a resistance in series with a voltage supply in the anode-cathode circuit of one tube in one stage and a condenser connected between the anode end of said resistance and the control grid of the tube of the next subsequent stage, and a resistance between the latter control grid and its associated cathode, and also having a resistance and condenser connected in series between the screen grid of the first mentioned tube and its associated cathode, a connection between the first mentioned resistance and the point of connection of the last mentioned condenser and resistance, a control circuit for minimizing the effect of supply voltage changes on the signal output, said control circuit comprising a resistor and a capacitor connected in series between the said control grid of said next stage and said point of connection, on the voltage supply providing the electrode voltages of said first tube.

7. In an electronic amplifier as in claim 6, said control circuit being adjusted to under compensate for the effects of supply voltage variations in the first stage of amplification in order

that such under compensation will be effective on the next succeeding stage to compensate for similar supply voltage variations on the said next stage without providing an additional control circuit in said next stage.

8. A high gain low frequency thermionic amplifier including two pentode tubes, an input circuit to the control grid of the first tube, an output circuit including the anode of the second tube, resistance-capacity coupling between the tubes, voltage supply for the heaters and the other electrodes of the tubes, a combination self bias and fixed bias arrangement for the control grids of the tubes selected to provide a high ratio of fixed bias to self bias and to provide a relatively fixed proportion of supply voltage at the screen grid, and a compensating circuit for minimizing the effect of supply voltage changes on the output circuit, said compensating circuit comprising resistance and capacitance connected in series between the control grid of the second tube and the voltage supply for the electrodes of the first tube.

9. A high gain low frequency multistage thermionic amplifier comprising a pentode tube for each stage, an input circuit connected between the control grid of the first tube and ground, and a resistance connected between the cathode of each tube and ground, a resistance and condenser connected in the order named between the screen grid of each tube and ground, resistances connected between the respective suppressor grids and the screen grids of the respective tubes, a power supply having one side connected through a resistance to a point between the last named condenser and resistance and the other side connected to ground, heater circuits for said tubes connected to said power supply, resistances connected between the anode of each tube and the respective last mentioned points for each tube, a condenser connected between the anode of the first tube and the control grid of the second tube, a high resistance connected between the control grid of the second tube and ground, a potentiometer connected across said power supply, a circuit including a resistance and a condenser connected between the control grid of said second tube and a point on said potentiometer and an output circuit between the anode of said second tube and ground.

10. A high gain low frequency amplifier including a thermionic tube having an anode, a cathode, a control grid and a screen grid connected to control the anode-cathode current, an input circuit connected to the control grid, an output circuit connected to the anode, a power supply providing a voltage for the output circuit and providing heating current for the cathode and having slight relatively slow variations in average voltage value, a resistance and a capacitor connected in series across the power supply, an impedance connected in said output circuit between said anode and the point of connection of said capacitor and said resistance, a potentiometer connected in shunt with said capacitor, and another capacitor and resistance connected between said potentiometer and the output circuit at the anode, whereby the output circuit will be compensated for any variations in the thermionic emission of the cathode caused by such voltage variations of the power supply.

11. In a high gain low frequency amplifier including a thermionic tube having a hot cathode, an anode and a control grid, an input circuit connected to the control grid, an output circuit

connected to the anode, and a common voltage supply for the cathode heater and for the anode, said voltage supply having very low frequency variations of appreciable value; compensating circuit means for minimizing the effects of supply voltage variations on the output of said amplifier, said circuit means including capacitance and resistance connected in series between said power supply and the anode and having a time constant substantially equal to the time constant of thermionic emission of the cathode in relation to variations in the supply voltage.

12. In a high gain low frequency amplifier including a thermionic tube having a hot cathode, an anode and a control grid, and a common voltage supply for the cathode heater and the anode, said voltage supply having very low frequency variations of appreciable value; a potentiometer across said voltage supply, and a circuit including capacitance and resistance in series between a tapping point on said potentiometer and said anode, said circuit having a time constant of substantially the same order as the time constant of changes in thermionic emission of the cathode in response to changes in supply voltage.

13. In a high gain low frequency amplifier including a thermionic tube having a hot cathode, an anode and a control grid, a power supply transformer having one winding supplying the voltage for the cathode heater and a second winding supplying voltage for the anode, a rectifier having its input connected with the second winding, an impedance connected across the output of the rectifier, a circuit connecting the anode and cathode and including said impedance to supply voltage to the anode, and a circuit including resistance and capacitance in series connected between said impedance and the anode to balance potential changes in anode voltage resulting from changes in the heater supply voltage from the first winding against potential changes in anode voltage resulting from changes in the anode supply voltage from the second winding.

14. In a high gain low frequency pass amplifier including a thermionic tube having a hot cathode, an anode and a control grid, a power supply transformer having one winding supplying voltage for the cathode heater and a second winding supplying voltage for the anode, a rectifier having its output connected with the second winding, a resistance and a capacitor connected in series across the output of the rectifier, a circuit including other resistance connecting the anode to the cathode via said capacitor, a potentiometer connected across said capacitor, and a circuit including another resistance and another capacitor connected between the anode and

a tap on said potentiometer, to compensate anode voltage against changes in supply voltage by balancing effect of heater winding voltage changes against effect of voltage changes in the second winding.

15. In a high gain low frequency amplifier having two stages and including a thermionic tube having a hot cathode, an anode and a control grid in each stage, an input circuit to the control grid of the first stage, a circuit including capacitance in series between the anode of the first stage and the control grid of the second stage, a circuit including capacitance and resistance in series between the anode and cathode of the first stage and connected on the anode side of the last mentioned capacitance to one terminal of a voltage supply, circuits including resistance connecting the control grids and the cathodes of the two stages to the other terminal of the voltage supply, a voltage supply for the cathode heater of the first stage having a source of power common to said anode-cathode voltage supply, and a circuit including capacitance and resistance in series between said anode-cathode voltage supply and the control grid of said second stage, whereby the effect on the control grid of the second stage of changes of electron emission of the cathode from slow variations in the heater voltage supply will be substantially balanced against the effect of corresponding variations in the anode-cathode voltage supply.

16. In a high gain low frequency amplifier having two stages and including a thermionic tube having a hot cathode, an anode and a control grid in each stage, an input circuit to the control grid of the first stage, an output circuit from the anode of the second stage, a circuit including capacitance in series between the anode of the first stage and the control grid of the second stage, a circuit including capacitance and resistance in series between the anode and cathode of each stage and connected on the anode side of the last mentioned capacitance to one terminal of a voltage supply, circuits including resistance connecting the control grids and the cathodes of the two stages to the other terminal of the voltage supply, a voltage supply for the cathode heaters of the two stages having a source of power common to said anode-cathode voltage supply, and a circuit including capacitance and resistance in series between said anode-cathode voltage supply and the control grid of said second stage, whereby the effect on the output of changes of electron emission of the cathode from slow variations in the heater voltage supply will be substantially balanced against the effect of corresponding variations in the anode-cathode voltage supply.

JOHN L. BARKER.