Nov. 15, 1949 E. O. KEIZER 2,488,410

CONTROL CIRCUITS FOR ALTERNATING CURRENT TRANSMISSION NETWORKS

Filed Jan. 26, 1945 2 Sheets-Sheet 1

Fig. 1.

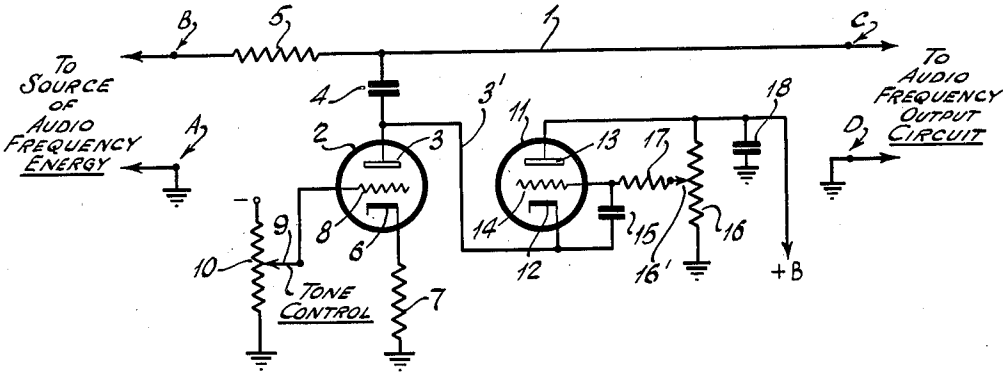
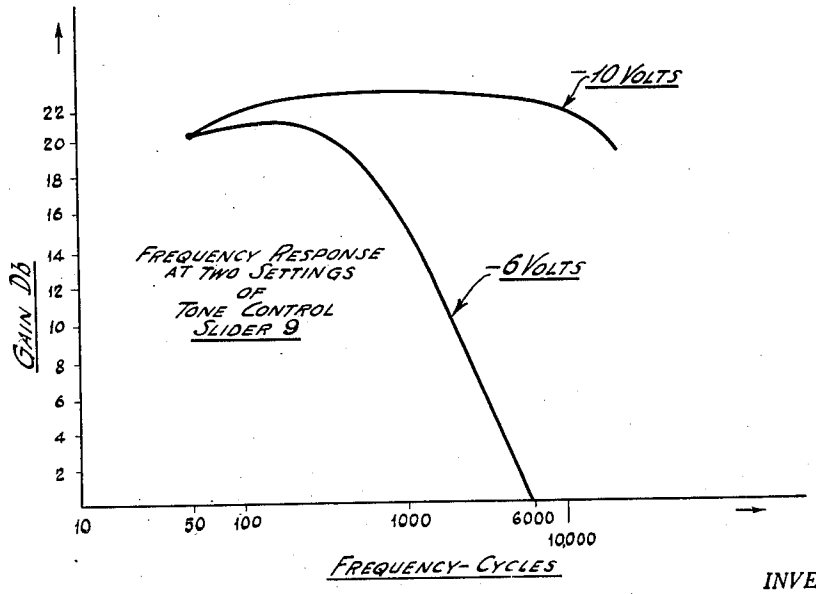



Fig. 2.




INVENTOR.
EUGENE O. KEIZER.

BY H. S. Grover

ATTORNEY.

Nov. 15, 1949 E. O. KEIZER 2,488,410

CONTROL CIRCUITS FOR ALTERNATING CURRENT TRANSMISSION NETWORKS

Filed Jan. 26, 1945 2 Sheets-Sheet 2

Fig. 3.

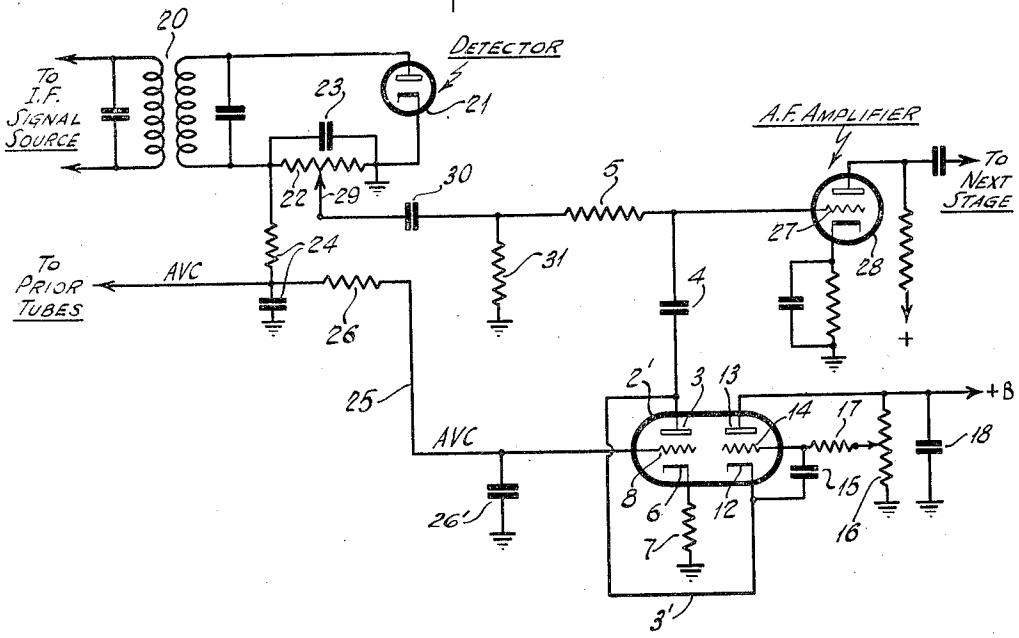
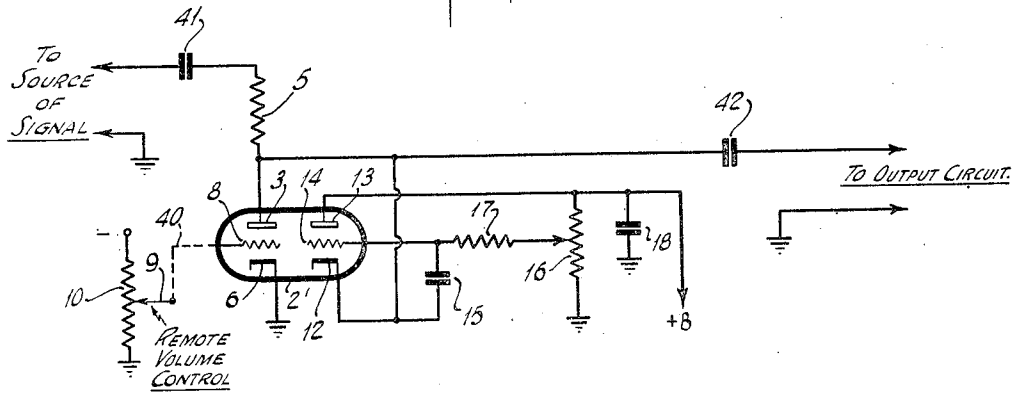



Fig. 4.




INVENTOR.
EUGENE O. KEIZER.

BY H. G. Brower

ATTORNEY.

Patented Nov. 15, 1949 2,488,410

# UNITED STATES PATENT OFFICE

2,488,410

## CONTROL CIRCUITS FOR ALTERNATING CURRENT TRANSMISSION NETWORKS

Eugene O. Keizer, Princeton, N. J., assignor to Radio Corporation of America, a corporation of Delaware

Application January 26, 1945, Serial No. 574,799

10 Claims. (Cl. 178—44)

1

My present invention relates generally to electronic control circuits, and more particularly to substantially distortionless circuits for the electronic control of amplitude and/or frequency response of an alternating current energy transmission network.

In the past it has been proposed to vary the amplitude and/or frequency response of a wave transmission network by shunting the latter with a condenser in series with an electronic impedance consisting of the plate to cathode path of an electron discharge device, the conductivity of the plate to cathode path being variable. In such prior system there are various operating disadvantages which make it undesirable to use the system. For example, considerable control voltage is required to vary the impedance of the aforesaid plate to cathode path in order to secure a large change in alternating current impedance across the transmission network.

Accordingly, it may be stated that it is an important object of my present invention to provide in series with the plate voltage supply for the plate of the electronic control device a second electron discharge device whereby the effective impedance across the transmission network includes the impedances of both devices in parallel, a relatively small control voltage being now needed to secure relatively large changes in impedances across the transmission network.

Another important object of my invention is to provide an electronic control circuit for the frequency response of an audio frequency transmission network, wherein the electronic control circuit is capable of effecting a relatively sharp reduction of transmission of higher audio frequencies for relatively small changes in control voltage.

Another object of the present invention is to provide an automatic tone control for a radio receiver, wherein carrier-responsive control voltage is adapted to vary the effective impedances of a pair of electronic impedances connected in parallel across a signal transmission network of the receiver.

Still another object of my invention is to provide a remote electronic volume control device for varying the amplitude of signal transmitted over a signal transmission network, the electronic control device being fed with direct current voltage through a second electron discharge device.

Still other objects of my invention are to improve generally the efficiency and operation of electronic control circuits, and more especially

2

to provide control circuits of economical and reliable form.

Still other objects and features of the invention will best be understood by reference to the following description, taken in connection with the drawing, in which I have indicated diagrammatically several circuit organizations whereby my invention may be carried into effect.

In the drawing:

Fig. 1 is a circuit diagram of a manual tone control circuit employing the invention;

Fig. 2 graphically shows actual operating curves of a circuit including the invention;

Fig. 3 shows an automatic tone control circuit employing the invention; and

Fig. 4 is a circuit diagram of a remote volume control device embodying the invention.

Referring now to the drawing, wherein like reference characters in the figures denote similar circuit elements, Fig. 1 shows one form of my invention applied to an audio frequency signal transmission network. The function of my invention, in that case, is to control the frequency response of the audio frequency transmission network. However, the invention is not limited to the audio frequency range, nor to control of frequency response. Assuming, for the purpose of specific illustration, that A and B are the ground and high potential input terminals respectively of an audio frequency network, and that points C and D are the respective high potential and grounded output terminals, lead 1 connects the input and output terminal points B and C. The frequency response of the network may be varied by the circuit now to be described.

An electron discharge device, or tube, 2 is shown by way of example as a triode, although the invention is not limited to such type of tube. Tube 2 has its plate 3 connected by direct current blocking condenser 4 to the lead 1. The resistor 5 is inserted in lead 1 in series with the condenser 4. The cathode, or electron emitter element, 6 is connected to ground through the unbypassed resistor 7. The control grid 8 of tube 2 is varied in a negative potential sense, relative to ground, by connecting grid 8 to the adjustable slider 9 of potentiometer 10. The ungrounded end of potentiometer 10 is connected to the negative potential terminal of a source of direct current (not shown). The slider 9 functions as the actual tone control adjustment device, since its adjustment varies the conductivity of tube 2 and thereby varies the effective resistive impedance in series with condenser 4. The path

including condenser 4 and the plate to cathode impedance of tube 2 functions as a shunting path for the higher audio frequency components. The path including condenser 4, the plate to cathode impedance of tube 11, and the bypass condenser 18, also, functions as a shunting path for the higher audio frequency components.

The plate 3, in accordance with my invention, is connected to the +B terminal of a direct current supply (not shown) through the cathode to plate path of a second electron discharge device, or tube, 11. The cathode 12 of the tube 11 is connected by lead 3' directly to plate 3, the plate 13 being connected to the +B terminal. Control gril 14 of tube 11 is coupled to cathode 12 by condenser 15. The control grid 14 may, also, be connected to any desired point on the resistor 16 connected from plate 13 to ground. The grid 14 is connected to the slidable tap 16' of resistor 16 through resistor 17. The adjustment of the tap 16' on resistor 16 could, also, serve as the tone control. Condenser 18 bypasses the plate lead of tube 11 to ground. The triode electrodes of tubes 2 and 11, if desired, may be embodied in a single tube envelope, as in the case of a twin triode.

In order to explain the functioning of the circuit of Fig. 1, it is first assumed that the tube 11 and its associated circuit are replaced by a resistor inserted in lead 3' between plate 3 and the +B terminal. It is to be understood that condenser 18 is in the circuit, but resistor 16 is out of the circuit. It is, also, assumed that the cathode resistor 7 is not included in the circuit. In such case the alternating current impedance at constant frequency from point B to ground is affected by the control voltage on grid 8 of tube 2. As the grid becomes more negative the operating point of tube 2 approaches plate current cut-off, and the impedance through the tube becomes high.

However, the assumed load resistor in lead 3' provides a shunt path to ground through condenser 18. Since this assumed plate load resistor would be the upper limit of the impedance, it would be made very large. When the bias of grid 8 is made less negative the tube becomes more conductive thereby lowering the tube impedance. Now, the effect of having a large plate load resistor is to make the change of impedance relatively small with change in control voltage at grid 8. This is because even a small plate current would produce a very large voltage drop in the assumed resistor, thus greatly reducing the effective plate voltage of tube 2. So far as the shunt impedance of tube 2 is concerned, a reduction in plate voltage is equivalent to making the grid voltage more negative. Consequently, the desired decrease in tube impedance resulting from making the grid less negative is at least partially neutralized by the resulting reduction of the plate voltage, thus limiting the effective change of impedance. If a choke coil is utilized in place of the assumed plate load resistor series resonance of condensers 4 and 18 with the choke coil may be troublesome. Even with this latter arrangement considerable control voltage is required on grid 8 for a large change in alternating current impedance between points B and A.

If, now, there is inserted the tube 11 in place of the assumed plate load resistor it will be noted that the space current path of tube 11 is in series with the plate voltage supply for tube 2. The impedance of point B to ground now includes the impedances of tubes 2 and 11 in parallel. When the control voltage of grid 8 is made more negative, the resistance of tube 2 increases. This causes the cathode 12 to become more positive thereby increasing effectively the negative bias of grid 14. As a result the resistance of tube 11, and the impedance thereof, also, increase. When the the control voltage on grid 8 is made less negative the resistances of tubes 2 and 11 decrease. The two parallel impedance paths from blocking condenser 4 to ground thus change together and in the same direction as the grid bias of tube 2 is varied. In addition, the change of impedance in tube 11, which is the plate load impedance of tube 2, is now in such a direction as to overcome the undesired drop in plate voltage in the low impedance condition. That is, when the bias on grid 8 is made less negative to decrease the shunt impedance of tube 2, the simultaneous decrease of the impedance of tube 11 acts to minimize the voltage drop across it, and to maintain the plate voltage of tube 2 at a sufficiently high value that the maximum change in impedance can be achieved. A large change of impedance from point B to ground for small control voltage variation may thereby be obtained. For example, when using a pair of 6J5 tubes the impedance from point B to ground may be varied 100:1 for a three volt control voltage change.

To prevent distortion in the circuit the grid 14 and cathode 12 of tube 11 are closely coupled for alternating current, and condenser 15 is inserted for that purpose. Furthermore, resistor 17 is added between the grid 14 and the resistor 16 to ground, to make the alternating current path to ground a very high impedance path. Additionally, resistor 7, a cathode bias resistor, may be added to make the change of impedance less sharp if so desired. The grid 14 is connected to a potentiometer in the plate circuit of tube 11 whereby adjustment of the steady state bias voltage of tube 11 is provided, and thus of the region of control voltage at which large change of impedance occurs. In other words, adjustment of the slider 16' along resistor 16 provides a control over the range of control voltage at grid 8 at which large change of impedance occurs from point B to ground. In this form of the circuit the invention has wide applicability to any network where it is desired to provide a wide range of frequency response variation for a relatively small range of voltage variation at grid 8.

Resistor 5 is inserted in series with condenser 4 to provide a loss element across which attenuation can occur. Thus, proper operation can be obtained even if the impedance of the audio frequency source is low. That is to say, the signal which passes through condenser 4 and the tube impedances should be of nearly constant current, rather than constant voltage. Thus, the output voltage will be more dependent upon the impedance from the junction of resistor 5 and condenser 4 to ground. If the coupling condenser 15, which provides close coupling between grid 14 and cathode 12, were not present the impedance of tube 11 would be varied by the input signal, since the grid 14 would otherwise be at a fixed bias voltage and the cathode 12 would then vary up and down, changing the bias. With condenser 15 and resistor 17 in the circuit, the input signal which appears on cathode 12 is superimposed on the steady state bias voltage of grid 14 and does not affect tube 11, and thus distortion does not occur. That is, the cathode and grid of tube 11 are maintained at the same audio frequency potential by condenser 15.

Resistor 7 itself would normally not be used,

except in those cases where a degenerative action would be desired to make the tube impedance change less sharp. In such cases, a bypass condenser may be used, if so desired. It would, in general, have little effect, and for that reason was omitted. In the case where resistor 7 is so large as to become an appreciable fraction of the plate resistance of tube 2, then a small amount of distortion will appear which can be eliminated by using a bypass condenser. Resistor 17 is inserted into the circuit with the slider of potentiometer 16 for two reasons. The first, mentioned above, is to allow grid 14 to be closely coupled to cathode 12, rather than to be at a fixed voltage. The second reason is that condenser 15 and the lower part of resistor 16, in series with resistor 17, are a shunt across the signal in parallel with the tubes. In order that the maximum shunt impedance be high, resistor 17 must also be large.

In the case of Fig. 1, which shows a tone control circuit for an audio frequency voltage transmission system, the manual adjustment of slider 9, or slider 16', is utilized to control the frequency response characteristic of an audio frequency amplifier regardless of its use. The audio amplifier may be used in a radio receiver or a record reproducer, public address system and the like. While my invention is not restricted in any way to specific circuit constants, it is pointed out that the following constants may be utilized to provide a suitable tone control circuit for an audio frequency amplifier:

Resistance of resistor 5=50,000 ohms
Resistance of resistor 17=1 megohm
Capacity of condenser 4=0.005 microfarad (mfd.)
Capacity of condenser 15=0.05 mfd.

With these illustrative constants there may be secured variations in gain as shown in Fig. 2. Fig. 2 illustrates the frequency response of the audio frequency transmission system at two settings of the tone control slider 9. These two settings are for −6 volts and −10 volts respectively. These curves show that large changes in frequency response are possible for small changes of control voltage at grid 8. At 5000 cycles the curves of Fig. 2 show a difference of response of more than 20 decibels (db.).

Instead of a manually-adjustable tone control circuit there may be provided an automatic tone control circuit, wherein the control voltage for tube 2 is derived from variations in received modulated high frequency carrier energy. For example, the control voltage for the grid 8 of tube 2 could be derived from the automatic volume control (AVC) voltage of a radio receiver. In Fig. 3 I have shown a part of a radio receiver employing the present invention utilized as an automatic tone control circuit. Those skilled in the art of constructing radio receivers will be fully aware of the circuit details required for the complete receiver system. It is to be clearly understood that the invention is fully applicable to a receiver of amplitude modulated, frequency modulated or phase modulated carrier wave energy.

Merely by way of illustration, let it be assumed that the receiver shown is an amplitude modulated carrier wave receiver of the superheterodyne type usually employed in the broadcast band of 550 to 1700 kilocycles (kc.), and that numeral 20 indicates the intermediate frequency (I. F.) output transformer coupling the plate circuit of the final I. F. amplifier tube to the diode demodulator or detector tube 21. Each of the primary



and secondary resonant circuits of transformer 20 will, of course, be tuned to the operating I. F. value, which may be, for example, 455 kc. The stages preceding the transformer 20 will be the usual and suitable stages of a superheterodyne receiver, while the load resistor 22, bypassed by condenser 23 for I. F. currents, provides the AVC voltage and the audio frequency voltage.

The AVC voltage, for regulation of the gain of the various signal transmission tubes prior to transformer 20, is taken off from the ungrounded end of load resistor 22. The numeral 24 denotes a suitable resistor-condenser filter network 24 for preventing any fluctuating components from reaching the control grids of the various controlled transmission tubes. The function of the AVC circuit is well known. and it acts to maintain at the input circuit of diode 21 a substantially uniform amplitude regardless of wide signal amplitude variations at the receiver antenna. This is accomplished by utilizing the direct current voltage developed across resistor 22 for varying the gain of each of the controlled transmission tubes in a sense to oppose carrier amplitude variation at the receiver antenna. The direct current voltage across resistor 22 is substantially proportional to the carrier amplitude.

The AVC voltage is applied over lead 25, which includes the filter resistor 26 and may include filter condenser 26', to the control grid 8 of the first triode section of twin triode tube 2'. In other words, instead of using separate triode tubes as in Fig. 1, the triodes in Fig. 3 may be enclosed within a common tube envelope. The audio frequency signal voltage is applied to the control grid 27 of the audio frequency amplifier tube 28 over a path including the slider 29, the audio frequency coupling condenser 30 and the resistor 5. The resistor 31, connected from the output electrode of condenser 30 to ground, functions as a grid leak resistor. The remaining circuit elements of the tone control circuit are similar to those shown in Fig. 1, and for this reason they are represented by the same reference numerals. The construction and functioning of the audio frequency amplifier tube 28 and its associated circuit are well understood.

The operation of the circuit of Fig. 3 will be similar to that shown in Fig. 1, except that the variation in impedance across the input terminals of the audio frequency transmission line will be varied over a relatively wide range of values in response to the AVC voltage applied over lead 25 to grid 8. The receiver, with my present circuit embodied, would have the advantage of its full fidelity on strong stations, while on weaker stations where noise and "monkey chatter" begin to be troublesome the control bias on grid 8 would be less thereby resulting in the improvement and in signal to noise ratio of reduced fidelity. It will be noted that when the receiver is tuned between stations the relatively low magnitude of AVC voltage, developed in that instance, would result in a maximum reduction of the higher audio frequency response thus making inter-stage tuning much quieter. The potentiometer 16 could have its adjustable slider placed on the operating panel of the receiver in place of the conventional tone control whose function it would also replace, where the user would turn it naturally to reduce the noise on weaker stations. The user would then be setting the circuit to suit the prevailing noise lever, as well as his individual taste, although he would not necessarily be conscious of that fact.

Another use to which my invention could be put is in the case where it is desired to have a wide range of distortionless volume control from a remote point and without the necessity of bringing out audio frequency leads to the remote point of control. In that case the control voltage need only be direct current voltage, and the control leads can be thoroughly bypassed and filtered in case they are extended for long distances. In Fig. 4 I have shown a remote volume control circuit adapted to a signal transmission system. The source of signals may be, for example, audio frequency signals. Here, again, the tube 2' is a twin triode, say of the 6F8 type, and it is to be understood that the triodes may be replaced by screen grid or pentode sections, if desired. The cathode 6 is directly connected to ground, and the control grid 8 is shown connected by a lead 40, which may be of any desired length, to the control voltage supply potentiometer 10. Variation of the slider 9 along resistor 10 will vary the effective negative bias of control grid 8. The plate 3 in this case is connected directly to the resistor 5, the condenser 4 being omitted. Condenser 4 is omitted so as to prevent any change in frequency response, since it is desired to have the volume only varied. Numeral 41 indicates a signal coupling condenser, and numeral 42 denotes a coupling condenser at the output terminals of the signal transmission system.

The remainder of the circuit is substantially similar to that shown in Fig. 1. In that circuit the impedance from the lower end of resistor 5 to ground is controlled thereby controlling the bypassing of audio frequency signal voltage to ground. It is to be understood that the tone control circuit of Fig. 1 may, also be applied to a remote tone control system, and in that case the slider 9 and voltage supply source 10 would be located at a remote point from grid 8. It will be observed, however, that in the various modifications disclosed herein there exists a common factor of securing a relatively wide change in impedance for a relatively small change in control voltage at the grid 8 of the electron discharge device 2.

While I have indicated and described a system for carrying my invention into effect, it will be apparent to one skilled in the art that my invention is by no means limited to the particular organization shown and described, but that many modifications may be made without departing from the scope of my invention.

What I claim is:

1. In combination with an alternating current transmission network, a shunt path across the network including an electron discharge device provided with at least a cathode, control grid and plate, a second electron discharge device provided with at least a cathode, control grid and plate, a connection from the cathode of the second device to the plate of the first device, means connecting the plate of the second device to a positive potential source, thereby to apply a positive voltage to the plate of the first device, means for maintaining the grid of said second device at a predetermined direct current steady state bias potential, and for maintaining the grid and cathode of said second device at the same alternating current potential, and means including the control grid of said first device for varying the gain of said first device thereby to vary the internal impedances of both devices in the same sense.

2. In combination with an alternating current transmission network, a path across the network including an electron discharge device provided with at least a cathode, control grid and plate, a second electron discharge device provided with at least a cathode, control grid and plate, a connection from the cathode of the second device to the plate of the first device, means connecting the plate of the second device to a positive potential source thereby to apply a positive potential to the plate of the first device through the said connection, a resistor in the space current path of the first device between is cathode and ground, means including a second resistor of high impedance connecting the control grid of the second device to a source of fixed positive potential, means including the control grid of said first device for varying the gain of said first device thereby to vary the internal impedances of both devices in the same sense, and capacitor means closely coupling the grid and cathode of the second device.

3. In combination with an audio frequency transmission system, a path across the system including an electron discharge device provided with at least a cathode, control grid and plate, a second electron discharge device provided with at least a cathode, control grid and plate, a conductive connection from the cathode of the second device to the plate of the first device, means connecting the plate of the second device to a fixed positive potential means thereby to apply a positive voltage to the first device plate through the conductive connection, means including the control grid of said first device for varying the gain of said first device thereby to vary the cathode voltage of said second device, means establishing the control grid bias of said second device at a predetermined value so that the internal impedances of both devices are varied in the same sense, a condenser connecting the plate of the first device and thus the cathode of the second device to the high potential side of said system, and means for maintaining the cathode and the control grid of the second device at the same audio frequency potential.

4. In combination with a pair of signal input terminals and a pair of signal output terminals adapted for connection to a source of and a utilization circuit for audio frequency energy, respectively, a tone control circuit comprising an electron discharge device, said device having the cathode thereof grounded and its plate connected through a condenser to the high potential input and output terminals, means for varying the direct current control grid bias of said device over a range of negative voltage values, a second electron discharge device having its cathode-to-plate path in series between the plate of the first device and a positive potential source, means responsive to the steady state plate potential of the first device providing a control over the effective steady state grid-cathode voltage of said second device, and means including a capacitor connected between the grid and cathode of said second device for maintaining the effective potential therebetween at said steady state value.

5. In combination with a pair of signal input terminals and a pair of signal output terminals, a signal amplitude control circuit comprising an electron discharge tube, the tube having the cathode thereof grounded and its plate coupled by a condenser to the high potential signal input and output terminals, means for varying the steady state control grid bias of said tube over a range of negative voltage values, a second electron dis-

charge tube having a cathode, a control grid and a plate, and having its cathode-to-plate path in series between the plate of the first tube and a positive potential source, voltage divided means connected across said positive potential source, a resistor of high impedance connected between a selected point on said voltage divider means and the control grid of said second tube, and a condenser connected between the control grid and cathode of said second tube.

6. In combination with an audio frequency current transmission network, a path shunted across the network and including frequency discriminating impedance means in series with a first electron discharge device provided with at least a cathode, control grid and plate, a second electron discharge device provided with at least a cathode, control grid and plate, a conductive connection from the cathode of the second device to the plate of the first device, means connecting the plate of the second device to a positive potential source thereby to apply a positive voltage to the plate of the first device, a direct current connection including a resistor from the control grid of the second device to a source of predetermined positive potential, and an alternating current connection between the cathode and grid of said second discharge device, and means including the control grid and the cathode of said first device for varying the gain of said first device thereby to vary the internal cathode to plate impedances of both devices in the same sense.

7. In combination with a signal transmission line, a shunt path across the line including an electron discharge device provided with at least a cathode, control grid and anode, a second electron discharge device provided with at least a cathode, control grid and anode, a direct current connection from the cathode of the second device to the anode of the first device, direct current means connected to the anode of the second device and to the anode of the first device through the anode to cathode path of the second device in series with said connection, means including the control grid of said first device for varying the gain of said first device thereby to vary the internal impedances of both devices in the same sense, and means responsive to the plate voltage variation of the first device providing a control over only the effective steady state bias voltage of the control grid of the second device.

8. In combination with a pair of audio signal input terminals and a pair of audio signal output terminals, a signal control circuit comprising an electron discharge device having at least a cathode, control grid and plate, the cathode thereof being grounded and its plate being coupled by a condenser to the high potential signal input and output terminals, said condenser having a relatively low impedance to audio signals of a relatively high frequency and a relatively high impedance to audio signals of a relatively low frequency, means for varying the control grid bias of said device over a range of negative voltage values, a second electron discharge device having at least a cathode, control grid and plate, direct current connection means for connecting the cathode-to-plate path of the second device in series between the plate of the first device and a positive potential source, and means responsive to the plate voltage variation of the first device providing a control over only the effective steady state bias voltage of the control grid of said second device, the audio frequency potentials of the cathode and grid of said second device being maintained equal at all times.



9. In a radio receiver system of the type having an audio signal transmission network, and a shunt path across the network including, in series, frequency discriminating impedance means and an electron discharge device provided with at least cathode, control grid and plate, electrodes, the improvement comprising a second electron discharge device provided with at least cathode, control grid and plate electrodes, a direct current connection from the cathode of the second device to the plate of the first device, means connecting the plate of the second device to a positive potential source thereby to apply a positive potential to the plate electrode of the first device through a series path including the cathode-to-plate path of the second device, means including a resistor for applying a selected positive bias potential to the grid of said second device, a condenser having a low impedance to said audio signals connected between the cathode and grid electrodes of said second discharge device, and signal-carrier responsive means for varying the gain of said first device thereby to vary the internal impedances of both devices in the same sense.

10. A variable resistance network for controlling the effectiveness of a shunting element connected across a source of alternating current in series with said network which comprises an electron discharge device provided with cathode, grid and plate electrodes, the plate-to-cathode path of said tube being connected in series with said element across said source; a second discharge device having cathode, grid and plate electrodes, a source of fixed positive potential; means including the cathode-to-anode path of said second device for applying said positive potential to the plate of said first device; means for applying a predetermined steady-state bias voltage to the grid of said second device; means for applying substantially equal alternating current voltages from said source to the cathode and grid electrodes of said second device; and means for applying a predetermined bias potential to the grid of said first device for controlling the effective resistance of said network.

EUGENE O. KEIZER.


## REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

| Number | Name | Date |
|---|---|---|
| 1,849,189 | Holden | Mar. 15, 1932 |
| 2,028,511 | Lewis | Jan. 21, 1936 |
| 2,112,595 | Farnham | Mar. 29, 1938 |
| 2,148,030 | McLennan | Feb. 21, 1939 |
| 2,318,075 | Hollingsworth | May 4, 1943 |
| 2,321,269 | Artzt | June 8, 1943 |
| 2,369,952 | Devine | Feb. 20, 1945 |
| 2,378,620 | Chatterjea et al. | June 19, 1945 |