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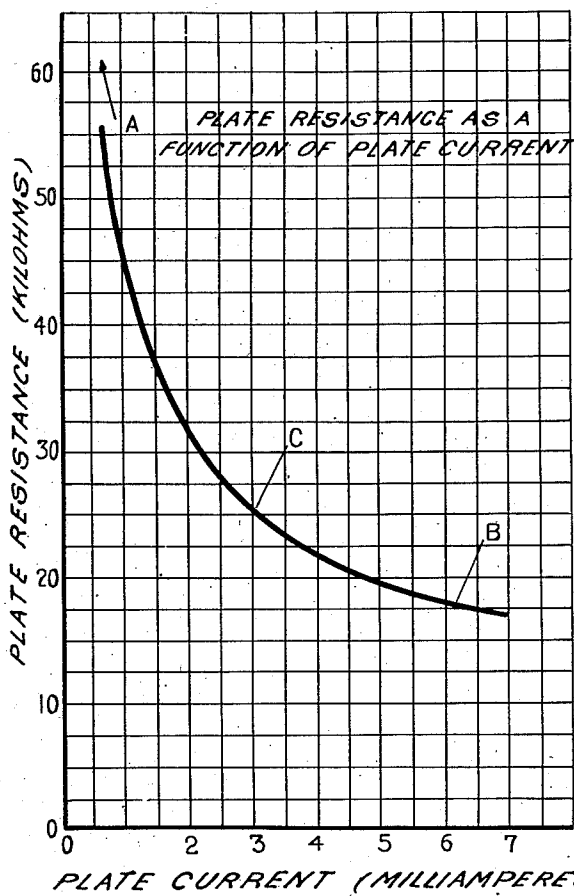
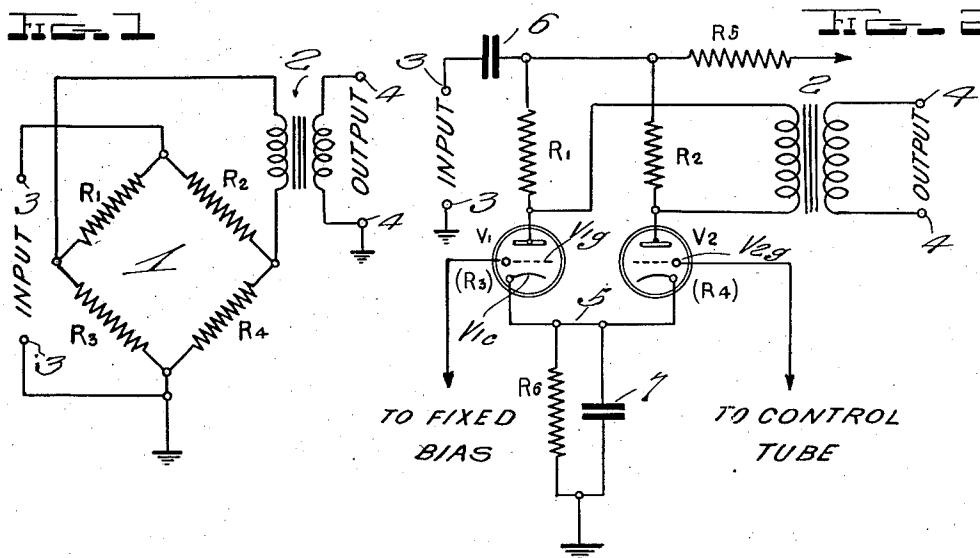
P. G. WULFSBERG

2,372,243

VOLUME LIMITER CIRCUIT

Filed Sept. 4, 1942

4 Sheets-Sheet 1



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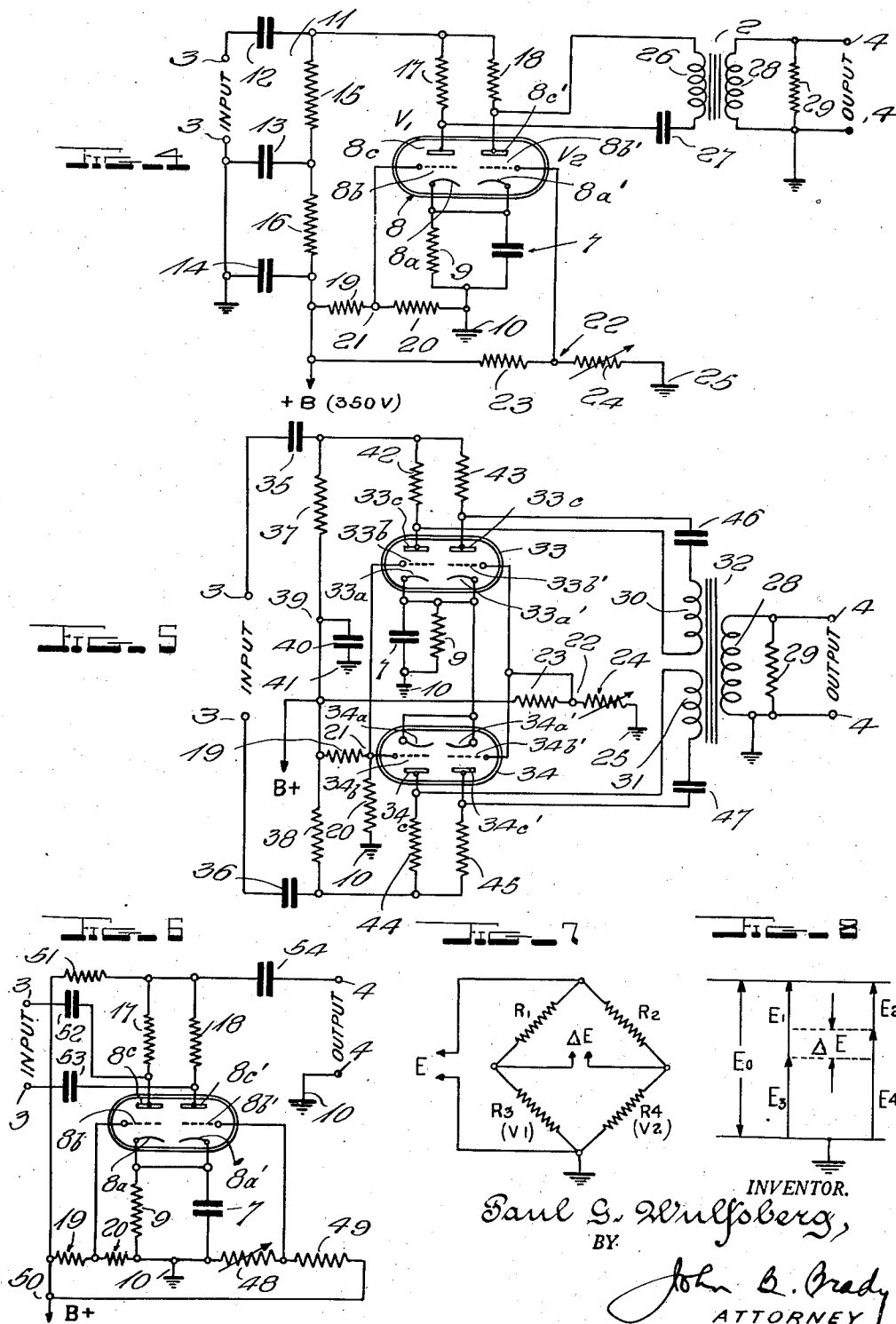
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4 Sheets-Sheet 2



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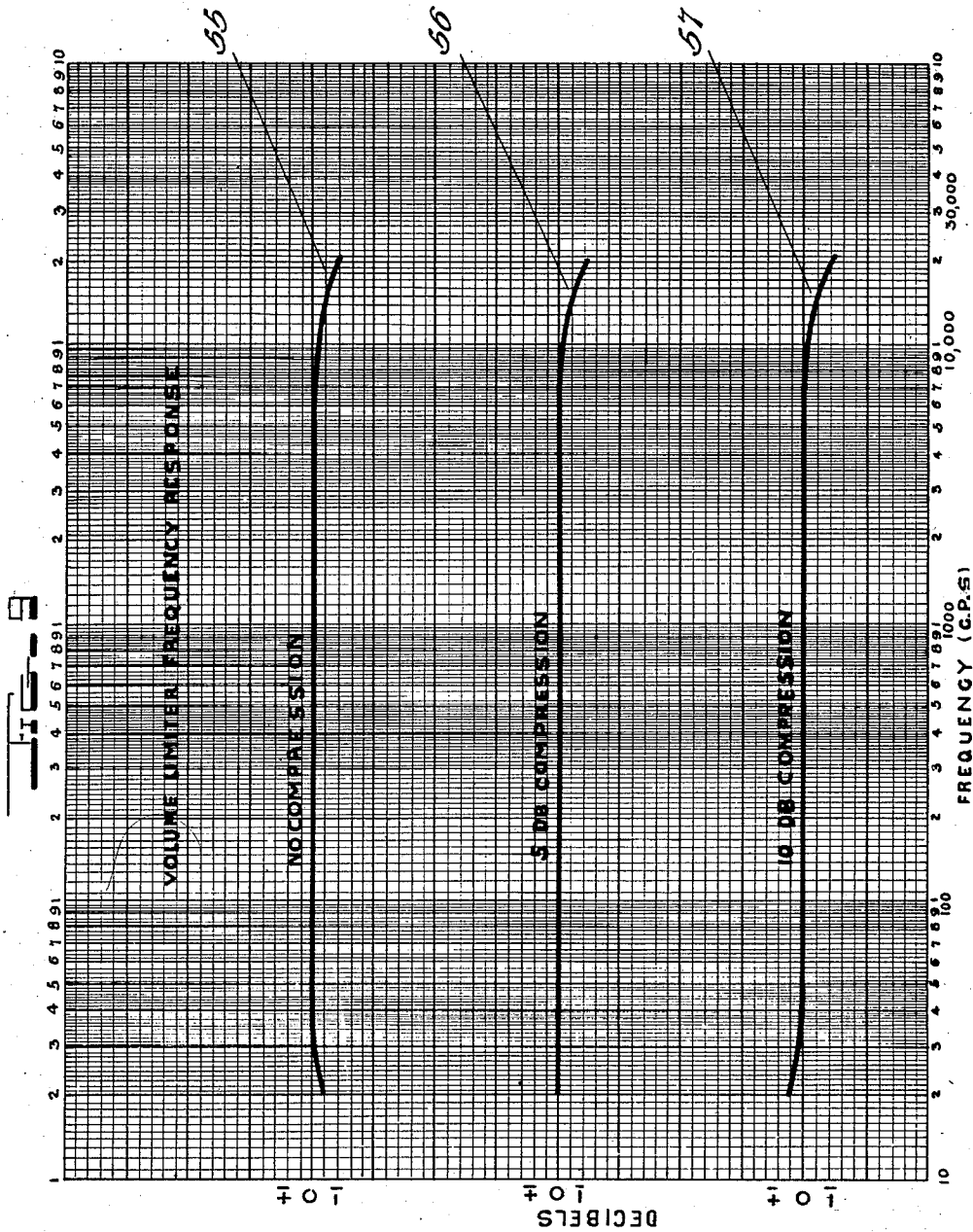
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VOLUME LIMITER CIRCUIT

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4 Sheets-Sheet 3



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UNITED STATES PATENT OFFICE

2,372,243

VOLUME LIMITER CIRCUIT

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9 Claims. (Cl. 178-44)

My invention relates broadly to volume limiting electron tube amplifier circuits and more particularly to an improved limiting amplifier circuit arrangement which is adaptable to resistance coupled amplifiers.

One of the objects of my invention is to provide a balanced bridge type of volume limiting amplifier circuit that is adaptable to a resistance coupled amplifier with the elimination of audio frequency transformers.

Another object of my invention is to provide an improved arrangement for a volume limiting circuit in which transient currents, incident to a change in attenuation in the circuit, are balanced out by the establishment of counter E. M. F.'s which do not affect the passage of the desired current.

Still another object of my invention is to provide a current limiting amplifier including a tube constituted by double triodes each having independent control grids arranged in separate circuits with a fixed bias applied to the control grid of one triode and a variable bias applied to the control grid of the associated triode and with the coating anodes connected in balanced relation for delivering to an output system controlled current.

A further object of my invention is to provide a volume limiting amplifier circuit arrangement in which a pair of electron tube discharge systems are arranged to form the arms of a Wheatstone bridge circuit in association with balancing resistors constituting the complementary arms of the bridge circuit with an input circuit connected across one portion of the Wheatstone bridge circuit and an output circuit connected across another portion of the Wheatstone bridge circuit and with the tubes in the arms thereof operating to balance the Wheatstone bridge circuit for effectively controlling the attenuation of energy impressed upon the input circuit and delivered to the output circuit while substantially eliminating transient currents in the amplification system which are incident to a sudden change in the plate current (and therefore the plate resistance) of the tube.

Other and further objects of my invention reside in the balanced Wheatstone bridge circuit arrangement as set forth more fully in the specification hereinafter following by reference to the accompanying drawings, in which:

Figure 1 is a theoretical diagram showing the fundamental circuit of the volume limiting circuit of my invention; Fig. 2 is a diagrammatic view showing one form of electron tube circuit arrangement embodying the principles of my in-

vention; Fig. 3 is a chart showing the characteristics of the particular tube which has been used in the volume limiting circuit of my invention; Fig. 4 is a diagrammatic circuit arrangement of one of the forms of the volume limiting circuit of my invention; Fig. 5 shows a double Wheatstone bridge circuit and balancing amplifier system constructed in accordance with my invention and showing the means employed for balancing out transient currents; Fig. 6 shows a modified form of limiting amplifier circuit arranged in accordance with my invention; Fig. 7 is a theoretical diagram explaining the operation of the circuit of Fig. 4; Fig. 8 is a vector diagram of the voltage components existent in the volume limiting circuit of Fig. 4; Fig. 9 is a chart showing the frequency response characteristics of the volume limiting circuit of my invention; and Fig. 10 shows a modified circuit arrangement embodying the principles of my invention in a push-pull or double-bridge volume limiting circuit.

Figure 1 shows the fundamental Wheatstone circuit employed in the system of my invention in which the four resistances R_1 , R_2 , R_3 and R_4 comprise the four arms of the bridge. Assuming that the audio frequency transformer 2 is without transmission loss, the power loss from the input circuit 3 to the output circuit 4 is a function of the ohmic values of the resistances R_1 , R_2 , R_3 and R_4 in the bridge. If $R_1 \times R_4 = R_2 \times R_3$, the loss in the circuit is infinite, whereas if one of the resistance values in the bridge is very large compared to the other three, the loss in the circuit may be small.

In the circuit illustrated in Fig. 2, the resistance arms R_3 and R_4 have been supplanted by electron tubes V_1 and V_2 whose plate resistances serve as the third and fourth arms of the bridge. The input terminals are represented at 3 connected to the bridge circuit through condenser 6 while the output terminals are shown at 4 connected through audio frequency transformer 2 in the output circuits of tubes V_1 and V_2 . In order to provide the tubes V_1 and V_2 with plate voltage, modifications of the circuit in Fig. 1 are necessary. The tubes V_1 and V_2 in Fig. 2 are shunted from a source of plate potential through resistance R_5 . Resistance R_5 , if made sufficiently large, will not cause much additional loss in the circuit. The tubes V_1 and V_2 are biased such that when there is no compression in the circuit, V_1 has a low plate resistance and V_2 has a very high plate resistance. The grid electrode V_{2g} of tube V_2 is connected to a control tube while the

grid electrode V_{1g} of tube V_1 is connected to a source of fixed bias. The term "no compression" refers to the point at which the circuit is intended to operate normally. At this point the rectified voltage from the control tube would have no effect on the plate current of the tube V_1 . When there is no compression in the circuit, the grid V_{2g} of tube V_2 is at a potential more negative than the grid V_{1g} of tube V_1 and the plate current of tube V_2 is therefore very small since the voltage across bias resistor R_2 also biases the tube V_2 . Bias resistor R_2 is shunted by condenser 7. The value of resistor R_2 is such that the bias on the grid V_{1g} of tube V_1 is sufficient to limit the plate current to a normal value. From Fig. 2 it may be seen that changes in grid or plate voltages in one tube will affect the other because of the common cathode circuit 5. Compression in the circuit begins to take place as the grid of V_{2g} of tube V_2 becomes less negative in potential. This increases the plate current in tube V_2 , causing its plate resistance to drop. An increase in the plate current of tube V_2 causes the bias on the cathode V_{1c} of tube V_1 to increase, thereby decreasing the plate current of tube V_1 , but increasing its plate resistance. As the plate resistance of tube V_2 decreases toward the value of the plate resistance of tube V_1 , or the plate resistance of tube V_1 increases toward that of tube V_2 , the bridge will approach a balanced condition, assuming that $R_1=R_2$, and the power loss through the circuit will increase rapidly.

Fig. 3 shows the plate resistance characteristic of the type 6C8G tube I have used in this circuit. The 6C8G tube consists of two low mu triodes in one glass envelope. "A" represents the normal operation point of triode V_2 and "B" represents the normal operating point of triode V_1 . As the compression in the circuit is increased, the plate resistance of each of the triodes moves toward the point indicated by "C." At this point the plate resistances of tubes V_1 and V_2 are equal and, assuming $R_1=R_2$, the circuit has an infinite loss in the ideal case, but practically this value is about 45 to 50 db. with the particular circuit constants which have been employed.

Fig. 4 shows the circuit of my invention for which the data set forth herein is given. The electron tube constituting the equivalent of tubes V_1 and V_2 is indicated at 8 containing within the same envelope the cathodes $8a$ and $8a'$, the coacting control grids $8b$ and $8b'$ and the coacting anodes $8c$ and $8c'$. The cathodes $8a$ and $8a'$ are connected together and to the biasing resistor 9 shunted by condenser 7 and connected to ground at 10. The input terminals 3 connect through the network 11 comprising condensers 12, 13 and 14 and resistors 15 and 16 connected as shown. The network is connected to the arms of the bridge through resistors 17 and 18 (R_1 and R_2) terminating at anodes $8c$ and $8c'$. The circuit to the cathodes from the network 11 is completed through resistors 19 and 20 connected in series with intermediate tap 21 extending to control grid $8b$ for establishing the fixed bias. The control grid $8b'$ is shown connected to tap 22 in the resistance circuit containing resistors 23 and 24, the resistor 24 being variable so that the gain may be varied manually in place of a rectifier circuit from the audio output circuit as would normally be employed. The variable resistor 24 is connected to ground at 25. The output circuit of the Wheatstone bridge which is thus established extends from anodes $8c$ and $8c'$ to the transform-

er 2 having its primary winding 26 connected through condenser 27 with anodes $8c$ and $8c'$ and its secondary winding 28 connected to output terminals 4 with regulating resistance 29 connected in shunt therewith.

It will be observed that the fixed bias is applied to control grid $8b$ while variable bias is applied to control grid $8b'$. The graph for the response data obtained from this circuit is shown in Fig. 9. In this circuit it was found that sudden changes in compression caused slight low frequency transients in the output circuit due to the change in D. C. potential between the anodes $8c$ and $8c'$ of tubes V_1 and V_2 .

Fig. 5 shows a double bridge circuit for a balanced input which has the same characteristics as the circuit in Fig. 4 except that no transients were observed in this circuit. In this circuit the D. C. pulses are balanced out since they set up counter E. M. F.'s in the two primary windings 30 and 31 of the output transformer 32. The arrangement of tubes is similar to the arrangement set forth in Fig. 4 except that two such double triode tubes are provided. I have shown these tubes at 33 and 34, each including cathodes $33a$ and $33a'$; control grids $33b$ and $33b'$; coacting anodes $33c$ and $33c'$ in tube 33; and in tube 34—cathodes $34a$ and $34a'$; control grids $34b$ and $34b'$; and anodes $34c$ and $34c'$. Bias voltage is provided for the grid electrodes by the cathode current through resistor 9 shunted by condenser 7 and connected to ground 10 in a manner similar to a biasing arrangement in the circuit of Figs. 2 and 4. The input circuit terminals 3 are connected through coupling condensers 35 and 36 to the resistance network including resistors 37 and 38 connected through tap 39 to condenser 40 which is connected to ground at 41. A connection is completed from one end of the network through resistors 42 and 43 to anodes $33c$ and $33c'$ respectively. A connection is completed from the other end of the network through resistors 44 and 45 with anodes $34c$ and $34c'$ as shown. The input circuits are completed through resistors 19 and 20 connected to ground 10 in a manner similar to the arrangement illustrated in Fig. 4 and in a similar way a lead from tap 21 is extended to control grids $33b$ and $34b$ as shown. The circuit from control grids $33b'$ and $34b'$ is completed in a manner similar to that illustrated in Fig. 4. Resistor 23 and variable resistor 24 are provided connected to the positive side of the source of B potential and including the intermediate tap 22 and the connection to ground at 25.

The circuit includes as heretofore pointed out, two separate output systems including a path from anode $33c$ through primary winding 30 and condenser 46, returning to anode $33c'$. The complementary primary winding 31 is included in a circuit connected at one end to anode $34c$ and extending through condenser 47 returning to anode $34c'$. The counter E. M. F.'s in the primary windings 30 and 31 balance out transient currents transferring only the currents impressed at 3 and desired at the terminals 4 connected to the secondary winding 28 of transformer 32 to which the two primary windings 30 and 31 are coupled.

Fig. 6 shows the volume limiting circuit in which the input and output connections are reversed from those shown in Figs. 4 and 5. This circuit requires a balanced input voltage but requires no output transformer. It has charac-

teristics very similar to those of the circuit shown in Fig. 4. A tube similar to the tube represented in Fig. 4 is employed containing cathodes 8a and 8a', control grids 8b and 8b' and coating anodes 8c and 8c'. The cathodes 8a and 8a' are connected through biasing circuit including resistor 9 and shunt condenser 7 to ground 10 and to the potentiometer circuit including resistor 19, 20, variable resistor 48 and resistor 49 connected to the B supply circuit between terminal 50 and ground 10 as shown. The anodes 8c and 8c' are connected through resistors 17 and 18 to the positive potential supply circuit through regulating resistance 51 as shown. The input circuit at 3 is balanced and is connected through condensers 52 and 53 with anodes 8c and 8c' respectively. The output circuit requires no output transformer but is connected through condenser 54 to output terminals 4, one terminal of which is connected to ground as shown at 10.

Fig. 7 is a theoretical diagram showing the equivalent A. C. circuit for the circuit in Fig. 4. ΔE represents the voltage which appears across the primary winding 26 of transformer 2.

Fig. 8 is a vector diagram showing the relation of the currents in the circuit of Fig. 4 where E_0 designates the input voltage; E_1 the voltage across arm R_1 (17); E_2 the voltage across arm R_2 (18); E_3 the voltage across arm R_3 (V_1) and E_4 the voltage across arm R_4 (V_2). ΔE represents the voltage across the primary winding 26 of the transformer 2.

Measured values of the voltages of the circuit in Fig. 4 (see Figs. 7 and 8) are as follows for several operating conditions. The equivalent plate resistance for each tube is also given:

Amount of compression	E_0	$E_1 = E_0 - E_3$	$E_2 = E_0 - E_4$	E_3	E_4	ΔE
	Volts	Volts	Volts	Volts	Volts	Volts
0 db.....	2.0	0.86	0.17	1.14	1.83	0.67
5 db.....	2.0	0.88	0.50	1.12	1.60	0.37
10 db.....	2.0	0.89	0.67	1.11	1.33	0.22

Amount of compression	Calculated plate resistance of tube V_1	Calculated plate resistance of tube V_2
	Ohms	Ohms
0 db.....	17,800	398,000
5 db.....	18,000	50,600
10 db.....	21,500	31,300

Fig. 9 shows the characteristic frequency response curves for the volume limiting circuit of my invention in which curve 55 shows the frequency response of the volume limiting circuit for a condition of no compression; curve 56 shows the characteristic of the frequency response in the volume limiting circuit for 5 db. compression; and curve 57 shows the frequency response characteristics for the volume limiting circuit of 10 db. compression. It will be seen that the balanced circuit arrangement operates to give substantially flat frequency response over a relatively broad range of frequencies.

In Fig. 10 I have shown a modified form of my invention in which a push-pull or double-bridge volume limiting circuit is provided. A single duotriode 58 is provided including cathode 58a, control grid 58b and anode 58c and also including cathode 58a', control grid 58b' and anode 58c'. The cathode bias illustrated in Fig. 5 is replaced by a fixed grid bias so that there is no longer a

need for tubes in both arms of the bridge circuit as previously required. The control rectifier as illustrated at 59 includes the cathodes 59a and 59a' and associated anodes 59b and 59b' having input transformer 60 with primary winding 61 and magnetically coupled secondary windings 62 and 63 connected to the anodes 59b and 59b' respectively and connected to the source of negative bias voltage through lead 64. The windings 62 and 63 are mutually connected at 65 and connect through resistor 66 with the cathodes 59a and 59a' which connect to ground through condenser 67. The primary winding 61 connects in the output circuit of the audio frequency amplifier system 68, the volume of whose output is to be limited. A connection is made to one side of the primary winding 61 to the source of B potential indicated at 69 through plate supply resistor 70. A connection is made to ground around plate supply resistor 70 through condenser 71. The amplifier system 68 is shown leading to the succeeding stage through coupling condenser 72. Normal grid bias is provided through cathode resistor 73 shunted by condenser 74. The input circuit to the limiter tube 58 is similar to that described in connection with Fig. 5, that is, the input terminals 3 connect through coupling condensers 35 and 36 to the resistance network including resistors 37 and 38 and the associated resistors 75, 76, 77 and 78. The anodes 58c and 58c' are connected with the network through resistors 79 and 80. The cathodes 58a and 58a' connect to ground at 81 and to tap intermediate resistors 76 and 77 at 82 through condenser 83 to tap 84 intermediate resistors 37 and 38 to lead 85, resistor 86, to the positive side of the B potential source indicated at 69. The primary winding 30 of transformer 32 is connected at one end with anode 58c and at the opposite terminal 40 with tap 87 intermediate resistors 75 and 76. The primary winding 31 of transformer 32 connects at one end to anode 58c' and at the other end to tap 88 intermediate resistors 77 and 78.

The circuit including the control rectifier has been found to be entirely satisfactory and efficient in operation. The several forms of the volume limiting circuit of my invention have been successfully used in the control of current in audio frequency transmission systems. While I have described my invention in certain preferred embodiments, I realize that changes may be made by those skilled in the art in the details of the circuit arrangement and it is not my intention that my invention be limited to the precise circuit arrangement or frequency range shown but that my invention shall be construed to cover various modifications of the circuits illustrated and various frequencies including radio frequencies within the scope of the appended claims.

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

1. A volume limiting circuit for operation at audio frequencies comprising a pair of electron discharge devices, each of said devices including a pair of triodes, each comprising a cathode, a control grid and a coating anode and forming the arms of a pair of Wheatstone bridge circuits, balancing resistors connected with said anodes and constituting the complementary arms of each of the Wheatstone bridge circuits, an input circuit common to said pair of Wheatstone bridge circuits, separate output circuits connected with the anodes of each of said devices, and an output circuit connected in common to said separate output circuits.

2. A volume limiting circuit for operation at audio frequencies comprising a pair of electron discharge devices, each of said devices including a pair of triodes, each comprising a cathode, a control grid and a coacting anode and forming the arms of a pair of Wheatstone bridge circuits, balancing resistors constituting the complementary arms of each of the Wheatstone bridge circuits and electrically connected with said anodes, an input circuit common to said pair of Wheatstone bridge circuits, an output circuit including inductive windings connected in shunt with the anodes of the triodes in the respective Wheatstone bridge circuits, said inductive windings being coupled in opposed relation for cancelling transient currents in said circuits, and an output winding coupled with each of said inductive windings.

3. A volume limiting circuit for operation at audio frequencies comprising a pair of electron discharge devices, each of said devices including a pair of triodes, each comprising a cathode, a control grid and a coacting anode and forming the arms of a pair of Wheatstone bridge circuits, balancing resistors constituting the complementary arms of each of the Wheatstone bridge circuits and electrically connected with said anodes, an input circuit common to said pair of Wheatstone bridge circuits, a circuit including inductive windings and condensers disposed in series and terminating at the anodes of the respective triodes in said Wheatstone bridge circuits, said inductive windings being coupled in opposed relation for cancelling transient currents incident upon said Wheatstone bridge circuits, and an output winding coupled with each of said inductive windings for receiving attenuated current substantially free from transients.

4. A volume limiting circuit for operation at audio frequencies comprising a pair of electron discharge devices, each of said devices including a pair of triodes, each comprising a cathode, a control grid and a coacting anode and forming the arms of a pair of Wheatstone bridge circuits, balancing resistors constituting the complementary arms of each of the Wheatstone bridge circuits and electrically connected with said anodes, an input circuit common to said pair of Wheatstone bridge circuits, means for impressing a fixed bias on the control grid of one of the triodes of each of said Wheatstone bridge circuits, means for impressing a variable bias upon the control grids of the other triodes of each of said Wheatstone bridge circuits, an output circuit each including an inductance and condenser disposed in series and connected with each of said Wheatstone bridge circuits, and means coupling said output circuits for cancelling transient currents therein while transferring the current impressed upon the input circuit.

5. A volume limiting circuit for operation at audio frequencies comprising an electron discharge system constituted by a pair of triodes, each of said triodes including a cathode, a control grid and a coacting anode, a pair of Wheatstone bridge circuits, one arm of each of said Wheatstone bridge circuits being constituted by one of said triodes and the other arms of said Wheatstone bridge circuits being constituted by balancing resistors connected with the anodes of said triodes, an input circuit common to each of said Wheatstone bridge circuits, an output circuit connected with the anode of the triode of one Wheatstone bridge circuit and with the balancing resistors of that circuit, a separate output circuit

connected with the anode of the other of said triodes in the other of said Wheatstone bridge circuits and with the balancing resistors in said last mentioned Wheatstone bridge circuit, and a common output circuit coupled with each of said separate output circuits.

6. A volume limiting circuit for operation at audio frequencies comprising an electron discharge system constituted by a pair of triodes, each of said triodes including a cathode, a control grid and a coacting anode, a pair of Wheatstone bridge circuits, one arm of each of said Wheatstone bridge circuits being constituted by one of said triodes and the other arms of said Wheatstone bridge circuits being constituted by balancing resistors, an input circuit common to each of said Wheatstone bridge circuits, an output circuit connected with the anode of the triode of one Wheatstone bridge circuit and with the balancing resistors of that circuit, a separate output circuit connected with the anode of the other of said triodes in the other of said Wheatstone bridge circuits and with the balancing resistors in said last mentioned Wheatstone bridge circuit, and means in said output circuits for substantially cancelling transient currents in said Wheatstone bridge circuits while transferring the current impressed upon the input circuit and desired at the output circuit.

7. A volume limiting circuit for operation at audio frequencies comprising an electron discharge system constituted by a pair of triodes, each of said triodes including a cathode, a control grid and a coacting anode, a pair of Wheatstone bridge circuits, one arm of each of said Wheatstone bridge circuits being constituted by the electron discharge path through one of said triodes and the other arms of said Wheatstone bridge circuits being constituted by balancing resistors, an input circuit common to each of said Wheatstone bridge circuits, an output circuit connected with the anode of the triode of one Wheatstone bridge circuit and with the balancing resistors of that circuit, a separate output circuit connected with the anode of the other of said triodes in the other of said Wheatstone bridge circuits and with the balancing resistors in said last mentioned Wheatstone bridge circuit, means for impressing a predetermined bias potential upon each of said control grid electrodes, and means coupled with both of said output circuits for transferring current from said output circuits substantially free of transient currents.

8. A volume limiting circuit for operation at audio frequencies comprising an electron discharge system constituted by a pair of triodes, each of said triodes including a cathode, a control grid and a coacting anode, a pair of Wheatstone bridge circuits, one arm of each of said Wheatstone bridge circuits being constituted by the electron discharge path through one of said triodes and the other arms of said Wheatstone bridge circuits being constituted by balancing resistors, an input circuit common to each of said Wheatstone bridge circuits, an output circuit connected with the anode of the triode of one Wheatstone bridge circuit and with the balancing resistors of that circuit, a separate output circuit connected with the anode of the other of said triodes in the other of said Wheatstone bridge circuits and with the balancing resistors in said last mentioned Wheatstone bridge circuit, a common source of bias potential, means for impressing said bias potential on each of said control grid electrodes, and means for inductively an-

nuling the effect of transient currents generated in said Wheatstone bridge circuits incident to varying the attenuation of the current impressed upon the input to the circuits.

9. A volume limiter circuit for operation at audio frequencies comprising a duo-triode tube including two sets of cathode control grid and anode electrodes, an input circuit connected in symmetrical arrangement with said anodes and cathodes, a resistance network connected in shunt with the cathode and anode of each of the sets of electrodes, a control rectifier disposed in circuit with said control grid electrodes for impressing bias potential thereon, a pair of output

circuits each connected between an anode and a tap in said resistance network for each of said sets of electrodes, a primary winding in each of said output circuits, a secondary winding coupled to both of said primary windings, an audio frequency amplifier coupled with said secondary winding and a circuit extending from the output of said audio frequency amplifier to said control rectifier for controlling the operation of said control rectifier and governing the bias potential impressed upon the grid electrodes of said duo-triode tube.

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