Feb. 5, 1957 E. H. GAMBLE 2,780,734

VOLTAGE REGULATING SYSTEM

Filed March 6, 1953 3 Sheets-Sheet 1

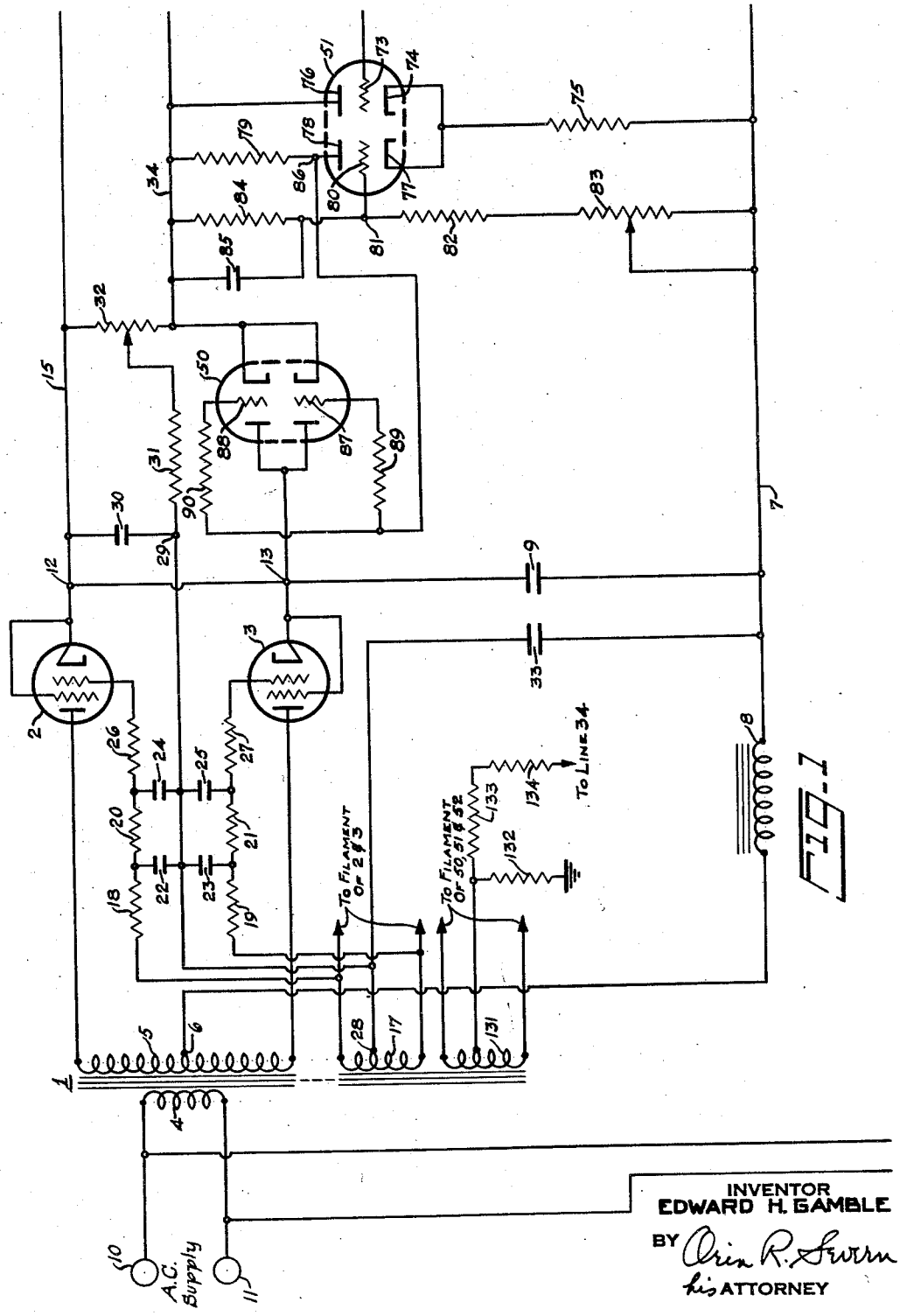
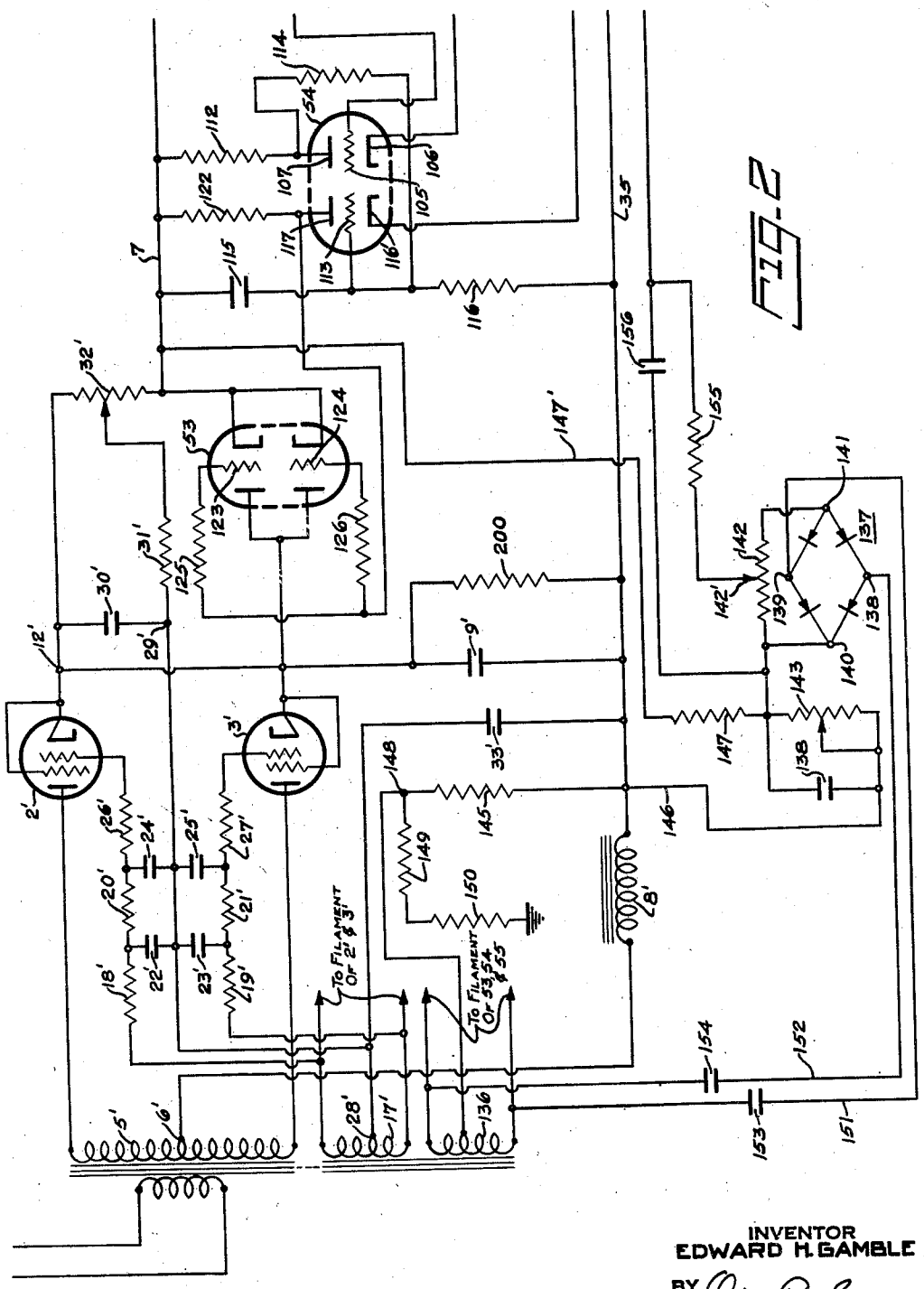


FIG. 1

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VOLTAGE REGULATING SYSTEM

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VOLTAGE REGULATING SYSTEM

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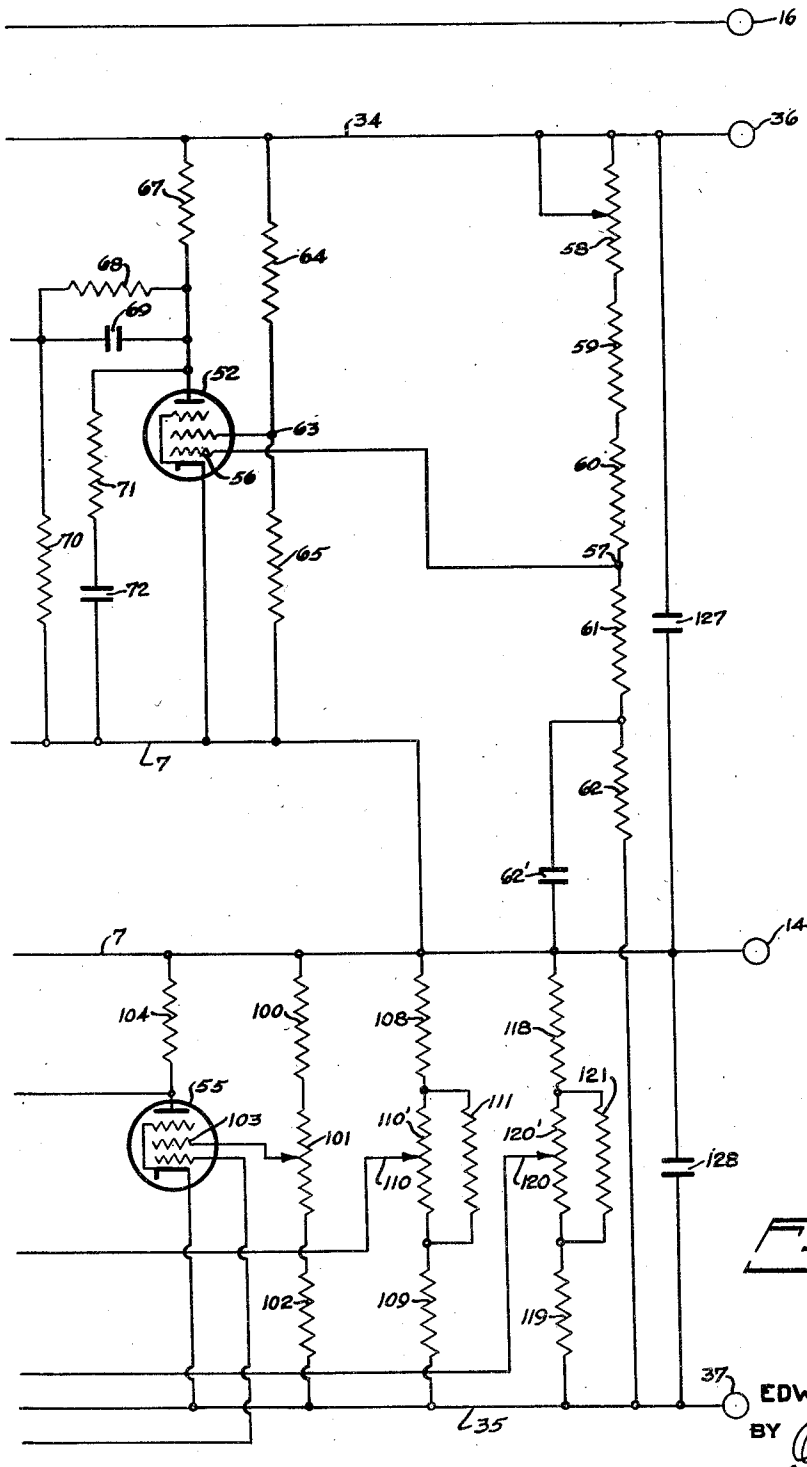


FIG. 3

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2,780,734

VOLTAGE REGULATING SYSTEM

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6 Claims. (Cl. 307—34)

My invention relates to a voltage regulating system having particular applicability but not necessarily limited to supplying substantially constant voltages for direct current amplifiers.

It is an object of my invention to provide a novel and improved voltage regulating system of high accuracy and reliability.

It is another object of my invention to provide such a system wherein a pentode having a very low plate resistance relative to the magnitude of the impedance connected in its plate-cathode voltage supply circuit is utilized as a voltage reference tube in place of the conventionally used relatively unstable gas filled diode.

It is a further object of my invention to provide a power supply system of the described type wherein plus (+) and minus (—) output voltages are so regulated that one of these voltages serves as a reference for the other and a variation in the reference voltage produces a corresponding change in the other output voltage.

Other objects and advantages of my invention will become apparent as the course of the specification develops.

The invention will be more fully set forth in the following description referring to the accompanying drawings, and the features of novelty will be pointed out with particularity in the claims annexed to and forming a part of this specification.

Referring to the drawings, Figures 1, 2 and 3 are diagrammatic illustrations which together constitute one form of voltage regulating system embodying the features of my invention.

The system includes a transformer-rectifier unit for supplying a positive D. C. regulated output voltage and another transformer-rectifier unit for providing a negative D. C. regulated output voltage, and includes two regulator units for further regulating these output voltages in such a manner that very carefully regulated output voltages both positive and negative with respect to ground are obtained wherein one of such carefully regulated voltages (the negative voltage as shown) serves as a reference for the other carefully regulated voltage (the positive voltage). The transformer-rectifier units for the positive and negative voltages are substantially identical and only one such unit is therefore described. The transformer regulator unit for the positive supply is arbitrarily chosen for purposes of description and similar reference characters are assigned to similar elements in each of the units except that a prime mark (′) is affixed to the reference characters for transformer-rectifier unit supplying the negative voltage.

As shown, the transformer-rectifier unit for the positive supply comprises certain of the windings of a transformer 1, and thyratrons 2 and 3 with associated circuitry. Transformer 1 includes a primary winding 4 which may be connected with any available source of alternating current, and secondary winding 5 for stepping up the supply voltage which winding is connected at opposite ends to the plates of thyratrons 2 and 3, respectively. Winding 5 has its center tap 6 connected

to ground line 7 through coil 8 and to the cathodes of tubes 2 and 3 through both coil 8 and condenser 9.

Thyratrons 2 and 3 conduct only when the plate voltage is positive, and when primary winding 4 is connected at its input terminals 10 and 11 to the available A. C. supply. A rectified positive voltage as smoothed out by the filtering action of coil 8 and condenser 9 is produced between ground, and junctions 12 and 13. This voltage appears across ground line 7 including terminal 14, and line 15 including terminal 16 and has a magnitude which is determined by the grid bias of the thyratron tubes. Such grid biasing voltage has both A. C. and D. C. components. The A. C. voltage component is obtained from the A. C. supply appearing across primary winding 4 of transformer 1 which supply voltage is stepped down by secondary winding 17 of transformer 1 and phased with respect to the plate voltages of the tubes by a resistance-capacitance network connected with the grid and including resistances 18, 19, 20 and 21 and condensers 22, 23, 24 and 25. Grid resistances 26 and 27 also connected to the grid limit grid current in the event of an improper adjustment in the system. The phased A. C. voltage is superimposed upon a D. C. feed-back voltage appearing in the line extending from the center tap 28 of winding 17 to junction 29 which D. C. voltage is equal to the output voltage of tubes 2 and 3 less the voltage drop across condenser filter 30, i. e. across resistance 31 and some portion of adjustable resistance 32. As shown the line between center tap 28 and junction 29 is grounded through condenser filter 33.

The firing time of the thyratron tubes during each cycle of the supply voltage and hence the magnitude of the thyratron output voltage is dependent upon the phase relation of the A. C. grid voltage with respect to the plate voltage of each tube as determined by the aforesaid resistance-capacitance network and the magnitude of the D. C. feed-back voltage, which magnitude is determined by condenser 30 and resistance 31 and upon the adjustment of resistance 32. The values of the resistances and condensers of the phase shifting resistance-capacitor network and of condenser 30 and resistance 31 are chosen so that the thyratron output voltage can be adjusted by means of adjustable resistance 32 to a desired level.

The output voltage of the thyratron tubes which appears between terminals 14 and 16 is regulated by the D. C. feed-back voltage for the grids of the thyratron tubes since any change in the output voltage of the thyratrons results in a compensating change in the feed-back voltage to alter the firing time of the thyratron tubes and thereby cause the output voltage to approximate the desired value.

As noted, the transformer-rectifier unit producing the negative output voltage is similar to the unit for producing the positive output voltage. The cathodes of the unit for the negative supply are, however, connected through resistance 32′ to ground line 7 for the purpose of obtaining an output voltage which is negative with respect to ground. As shown, the cathodes of tubes 2′ and 3′ connect with winding 5′ at its center tap 6′ through paralleled condenser 9′ and resistance 200, and through coil 8′. The thyratron output voltage of the transformer-rectifier units are carefully regulated in a manner now to be described and the resulting carefully regulated voltages both positive and negative as measured with respect to ground appear in lines 34 and 35, respectively. As shown, line 34 which includes terminal 36 is connected to the cathodes of tubes 2 and 3 through adjustable resistance 32, and line 7 which includes terminal 14 is connected to the cathodes of tubes 2′ and 3′ through adjustable resistance 32′.

Two regulating units are provided, one for maintaining a carefully regulated positive voltage at terminal 36 and

one for maintaining a carefully regulated negative voltage at terminal 37. The regulating unit for the positive voltage includes twin triode series regulating tube 50, twin triode amplifying tube 51 and pentode amplifying tube 52. Similarly the regulating unit for the negative supply includes twin triode series regulating tube 53, twin triode amplifying tube 54 and pentode voltage regulating tube 55. As shown, series regulating tube 50 is connected between the cathodes of thyratrons 2 and 3, and line 34 whereas series regulating tube 53 is connected between the cathodes of thyratrons 2' and 3', and line 7. The system responds to variations in the output voltages at terminals 36 and 37 to change the impedance of these series regulating tubes in such a manner that the output voltages are regulated to a desired value. Furthermore, the carefully regulated negative output voltage at terminal 37 as will be explained serves as a reference for the positive output voltage at terminal 36 so that variations in the negative voltage are followed by corresponding variations in the positive voltage. These following fluctuations in the positive supply compensate for the variations in the negative output voltage when the system is used, for example, as a regulated supply for D. C. amplifiers.

In my system, pentode 55 is used as a reference element in place of the conventionally used gaseous diodes which are relatively unstable. The use of the pentode as voltage regulating tube is accomplished by selecting a tube having a very low plate resistance relative to the magnitude of the impedance connected in its plate-cathode voltage supply circuit so that a substantially constant voltage is maintained across the terminals despite variations in current flowing through the tube.

Referring more specifically now to the regulator units including the aforementioned tubes with associated circuitry and the manner of operation of these units, pentode amplifier 52 has its control grid 56 connected at junction 57 to a voltage divider extending across lines 34 and 35 and including adjustable resistance 58 and resistances 59, 60, 61 and 62. A condenser 62' is connected to the voltage divider at one end between resistances 61 and 62, and is connected at its other end to the ground line 7. The screen grid of pentode 52 is connected at junction 63 between resistances 64 and 65 which are series connected between line 34 and ground line 7. The voltage level at junction 57 of the divider determines the bias on the control grid of pentode 52 and any change in such voltage level is applied to the control grid as a principal error voltage and amplified by way of an increase or decrease in current flowing through the pentode which as shown is connected across lines 7 and 34 through resistance 67. A voltage change in line 34 relative to line 7 is reflected as a secondary error voltage applied by way of junction 63 to the screen grid. Such secondary error voltage has very little effect on the overall operation of the regulator unit in view of the low amplification from screen to plate, which may be of the order of unity or less. Assuming a voltage change in line 34 relative to the voltage in line 35 which is maintained substantially constant as will be explained hereinafter, the voltage level at junction 57 changes to alter the grid voltage on tube 52 and the current flowing through that tube. The flow of current is also altered in resistance 67 and various elements in parallel with tube 52 which include resistance 68, condenser filter 69 and resistance 70, and also resistance 71 and condenser filter 72. A change occurs in the voltage level of the plate of tube 52 with respect to its cathode and therefore its lower potential plate-cathode circuit supply line (herein ground line 7), and also with respect to its higher potential plate-cathode circuit supply line (herein line 34). Consequently a similar change occurs at grid 73 of twin triode amplifying tube 51 to alter the flow of current between cathode 74 which is connected to ground line 7 through resistance 75, and plate 76 which is connected to line 34. This altered current flow between cathode 74 and plate 76 of tube 51 results in a change in the voltage level of the other cathode 77 of the tube and there follows a change in current flow between cathode 77 and plate 78, and through the resistance 79 which is connected to plate 78 and line 34. The current flow between cathode 77 and plate 78 is also controlled in part by the bias on grid 80 which is connected at junction 81 to a lead line extending between lines 7 and 34 and including series connected resistances 82 and 83 on one side of junction 81 and parallel connected resistance 84 and condenser filter 85 on the other side of junction 81. Because of the change in current flow through resistance 75, cathode 77, plate 78 and resistance 79, a change in voltage level occurs at junction 86 which is connected to the grids 87 and 88 of series regulating tube 50 through grid resistances 89 and 90. The grid bias of tube 50 is altered and its impedance changed so as to readjust the voltage in line 34, the various elements in the regulating unit having been so chosen that the voltage in line 34 and at terminal 36 is adjusted in the proper amount to bring it back to a predetermined desired value.

Referring now to the regulating unit for maintaining a substantially constant negative output voltage in line 35 and at terminal 37, there is shown connected between line 7 and line 35 a voltage divider including series connected resistances 100, 101 and 102. Pentode 55 has its screen grid 103 connected to resistance 101 and a voltage change in line 35 is reflected as a principal error voltage on the screen grid to increase or decrease the current flowing through tube 55 and resistance 104 which is connected between ground line 7 and the tube plate. As already noted pentode 55 serves as a voltage reference tube, and has a very low plate resistance relative to resistance 104 with which it is connected in series across lines 7 and 35, so that in contrast to the operation of amplifier tube 52 a substantially constant voltage is maintained at the plate of tube 55 with respect to its cathode and therefore with respect to its lower potential plate-cathode circuit supply line (herein line 35), substantially independent of the applied principal error voltage and the consequent variations in current flowing through the tube. Due to the change in current flowing through resistance 104 there is however a change in the voltage level of the plate of tube 55 with respect to its higher potential plate-cathode circuit supply line (herein ground line 7). Tube 55 in view of the associated circuitry thus functions primarily as a voltage reference tube. Its amplification from screen to plate is low, of the order of unity or less.

As a consequence of the last-mentioned voltage level change there is a similar change in the level of grid 105 of amplifying twin triode 54 and a change in the current flowing between its cathode 106 and plate 107. Cathode 106 as shown is connected to a slider contact 110 which is adjustable on resistance 110' in a voltage divider extending across lines 7 and 35 and including series connected resistances 108 and 109 and paralleled resistances 110' and 111. Plate 107 is connected to line 7 through resistance 112. The change in current flowing between cathode 106 and plate 107 readjusts the voltage level of the other grid 113 which is connected to plate 107 through resistance 114 and to lines 7 and 35 through condenser filter 115 and resistance 116, respectively. The change in the voltage level of grid 113 alters the flow of current in tube 54 between cathode 116' and plate 117. Cathode 116' as shown is connected to a slider contact 120 which is adjustable on a resistance 120' in a voltage divider extending across lines 7 and 35 and including series connected resistances 118 and 119 and paralleled resistances 120' and 121, and plate 117 is connected to line 7 through resistance 122. The altered current flow between cathode 116' and plate 117 results in a change in the voltage level of grids 123 and 124 of tube 53 which are connected through grid resistances 125 and 126 to plate 117 thereby varying the impedance of tube 53 to readjust the out-

put voltage in line 35 and at terminal 37 to a desired value.

As previously stated, the regulated negative supply voltage appearing at terminal 37 serves as a reference for the positive supply voltage which appears at terminal 36 and any departure in the negative output voltage not adjusted by the regulator unit for the negative output is accompanied by a corresponding change in the positive output voltage. Assuming a departure from the desired regulated negative output voltage, the voltage level at junction 57 is altered in magnitude to readjust the bias on the control grid of tube 52 and by means of the circuitry already described including tube 51, the impedance of series regulating tube 50 is varied to adjust the level of the output voltage at terminal 34 to a value corresponding in magnitude to the value of the negative voltage at terminal 37.

As shown condensers 127 and 128 are provided between the ground line 7 and lines 34 and 35 to filter any A. C. voltage that might conceivably occur at the output terminals and provide a low output impedance.

Suitable means are provided for heating the filaments of tubes 50, 51 and 52 and include secondary windings 17 and 131 which are linked with primary winding 4. The A. C. voltage appearing across primary winding 4 is stepped down by means of windings 17 and 131 and utilized in heating the aforesaid tubes. As indicated, the opposite ends of winding 17 are connected with the filaments of thyratrons 2 and 3 and the opposite ends of winding 131 are connected with the filaments of tubes 50, 51 and 52. The center tap of winding 131 is connected to ground through resistance 132 and to the positive output voltage in line 34 through resistances 133 and 134. Similar means are provided for heating thyratrons 2' and 3' and tubes 53, 54 and 55. The filaments of thyratrons 2' and 3' are connected with opposite ends of secondary winding 17' which is linked with primary winding 4', whereas filaments of tubes 53, 54 and 55 are connected with secondary winding 136 also linked with primary winding 4'. Secondary windings 17' and 136 step down the supply voltage appearing across winding 4' to a suitable value for heating the filaments.

Tube 55 is provided with suitable circuitry to compensate for any changes in the filament voltage due for example to changes in the supply voltage. Such circuitry includes a full-wave bridge rectifier designated in the drawings by reference character 137. Bridge rectifier 137 has opposite terminals 138 and 139 connected across secondary winding 136, and its other terminals 140 and 141 connected across an adjustable resistance 142. Terminal 140 is connected to the center tap of winding 136 through paralleled adjustable resistance 143 and condenser 138, and resistance 145 in line 146. Terminal 140 is also connected to the ground line through resistance 147 in line 147'. As shown, line 146 is grounded at junction 148 through resistances 149 and 150. Terminals 138 and 139 as stated are connected across winding 136, and leads 151 and 152 including condensers 153 and 154 respectively make this connection to provide a desired level of D. C. voltage at terminals 140 and 141 of the bridge. A suitable voltage is picked off adjustable resistance 142 by adjustable contact 142' which connects with the control grid of tube 55 through a suitable filter including resistance 155 and condenser 156. By reason of the described circuitry variations in filament voltage are accompanied by variations in the nature of a secondary error voltage on the control grid which compensate for the changes in the filament voltage.

It will now be apparent that I have provided a novel and improved power supply control system which is sensitive to changes in the input voltage and to changing load conditions. The system is effective to maintain voltages at the output terminals at a predetermined desired level in accordance with the design of the system and it is inherent in the system that a change in a voltage level at one output terminal is further compensated as by a corresponding fluctuation in voltage at the other output terminal.

It should be understood that this invention is not limited to specific details of construction and arrangement thereof herein illustrated, and that changes and modifications may occur to one skilled in the art without departing from the spirit of the invention.

What is claimed is:

1. In a voltage regulating system, an output line and a ground line, voltage dividing means connected between said output line and ground, a vacuum tube having characteristics such that a constant voltage is maintained across plate and cathode terminals with varying current through the tube, circuit means including a resistor connecting one of said terminals to one line, the other terminal being connected to the other line, said tube having a grid connected to said voltage dividing means, a twin triode connected at a grid thereof to said circuit means with the plates cathode and other grid connected between the output line and ground, a series regulator operatively connected to said twin triode, and a direct voltage source with said series regulator connected between the voltage source and one of said lines to compensate for said variations and thereby maintain a substantially constant voltage in said output line.

2. In a voltage regulating system, a source of unregulated direct voltage, voltage control means operatively connected to said source, said voltage control means having a high potential output line and a low potential output line and including a series regulator connected between said source and one of said output lines, voltage dividing means connected across said lines for producing voltage variations responsive to voltage variations of said source, a vacuum tube, plate-cathode circuit supply means for said vacuum tube including a first connection from its anode electrode to said high potential output line and a second connection from its cathode electrode to said low potential output line, means connecting a grid of said tube to said voltage dividing means for effecting variations in its plate current according to variations in the voltage across said lines, one of said first and second connections comprising an impedance of a magnitude relatively large compared to the plate resistance of said tube for effecting variations in the voltage between the electrode and the line spanned by said one of the first and second connections according to said current variations and for maintaining the voltage between the last-referred-to electrode and the other output line substantially independent of said current variations, and means included in said voltage control means and operatively connected to said last-referred-to electrode and to said series regulator for amplifying said effected voltage variations and applying the amplified variations to said series regulator so as to minimize the variations across said lines, whereby a regulated output voltage is obtained.

3. In a voltage regulating system, two unregulated direct voltage sources, voltage control means operatively connected to said sources, said voltage control means having first, second and third output lines of respectively high, intermediate and low potential, first voltage dividing means connected across said second line and one of said first and third lines for producing voltage variations responsive to voltage variations of one of said sources, a first vacuum tube, plate-cathode circuit supply means for said vacuum tube including a first connection from its anode electrode to the higher potential line selected from the pair consisting of said second line and said one of the first and third lines and including a second connection from its cathode electrode to the lower potential line of said pair, means connecting a grid of said tube to said voltage dividing means for effecting variations in its plate current according to variations in the voltage across said voltage dividing means, one of said first and second con-

nections comprising an impedance of a magnitude relatively large compared to the plate resistance of said tube for effecting variations in the potential between the electrode and the line spanned by said one of the first and second connections according to said current variations and for maintaining the potential of the last-referred-to one electrode with respect to the line connected to the other electrode independent of said current variations, means connecting to said voltage control means said one electrode whose potential is independently maintained thereby to cause said voltage control means to minimize the voltage variations across said voltage dividing means and to provide a first regulated output voltage of one polarity at said one of the first and third lines with respect to said second line, second voltage dividing means connected across said first and third lines for producing voltage variations responsive to voltage variations of the other of said sources and of said first regulated output voltage, a second vacuum tube, plate-cathode circuit supply means for said second vacuum tube comprising a third connection from its anode electrode to the higher potential line selected from the pair consisting of said second line and the other of said first and third lines and comprising a fourth connection from its cathode electrode to the lower potential line selected from said last-named pair, means connecting a grid of said second tube to said second voltage dividing means for effecting variations in its plate current according to variations in the voltage across said second voltage dividing means, one of said third and fourth connections comprising a second impedance for amplifying the last-named voltage variations according to the last-named current variations, and means connecting to said voltage control means said second impedance thereby to cause said

voltage control means to produce a second regulated output voltage of opposite polarity at said other of the first and third lines with respect to said second line and to adjust the level of said second regulated output voltage to a value corresponding in magnitude to the value of said first regulated output voltage according to residual variations therein.

4. The combination as defined in claim 3, wherein the first vacuum tube is a pentode having the screen grid connected to the first voltage dividing means, and with the addition of means connected to the control grid of said first vacuum tube to compensate for filament voltage changes.

5. The combination as defined in claim 2, wherein the vacuum tube is a pentode having the screen grid connected to the voltage dividing means.

6. The combination as defined in claim 2, wherein the vacuum tube is a pentode having the screen grid connected to the voltage dividing means, and with the addition of means connected to the control grid to compensate for filament voltage changes.

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