Nov. 30, 1948. E. M. SORENSEN 2,455,143

CATHODE CONTROLLED ELECTRONIC VOLTAGE REGULATOR CIRCUIT

Filed April 17, 1946 4 Sheets-Sheet 1

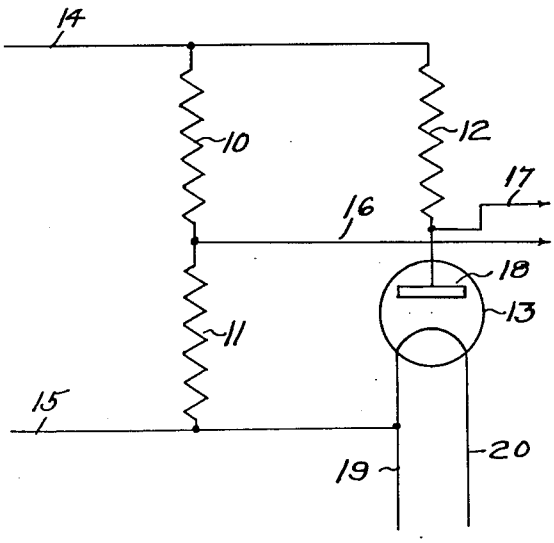

Fig. 1

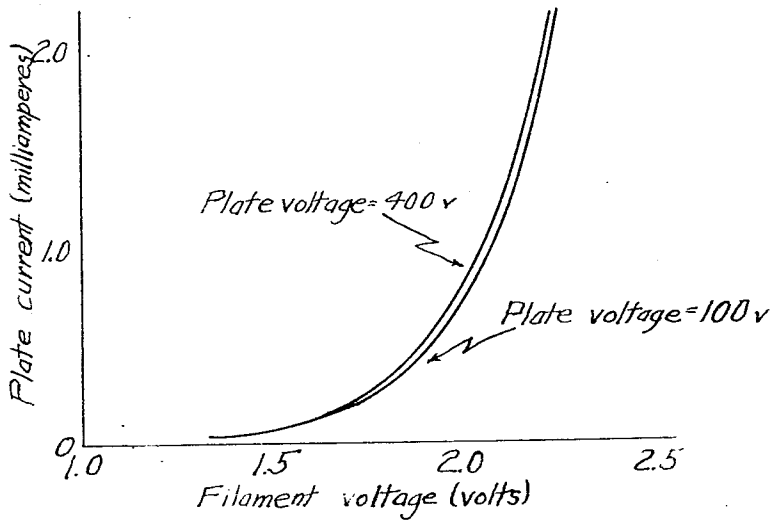

Fig. 2

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Filed April 17, 1946 4 Sheets-Sheet 2

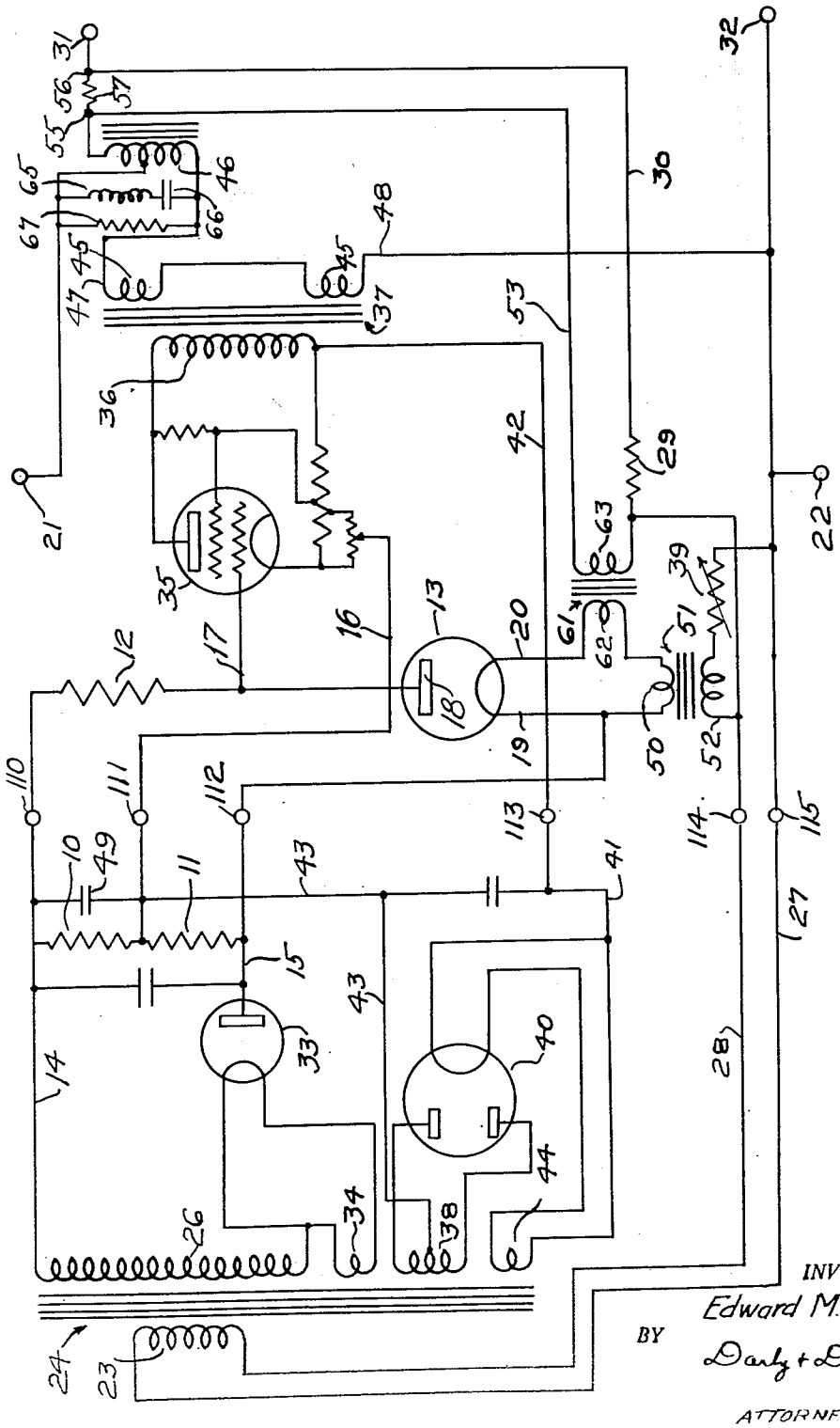

Fig. 3

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CATHODE CONTROLLED ELECTRONIC VOLTAGE REGULATOR CIRCUIT

Filed April 17, 1946 4 Sheets-Sheet 3

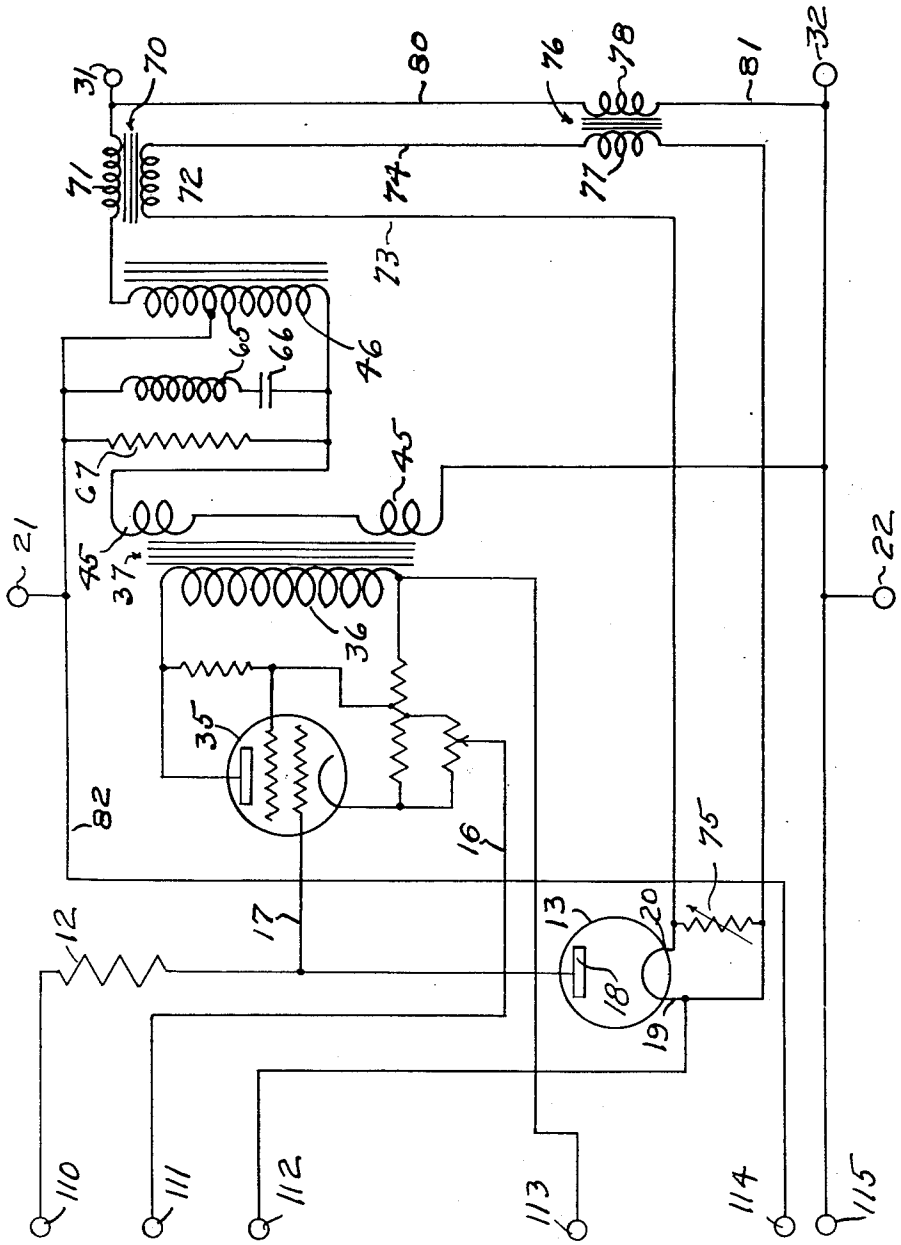

Fig. 4

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Filed April 17, 1946 4 Sheets-Sheet 4

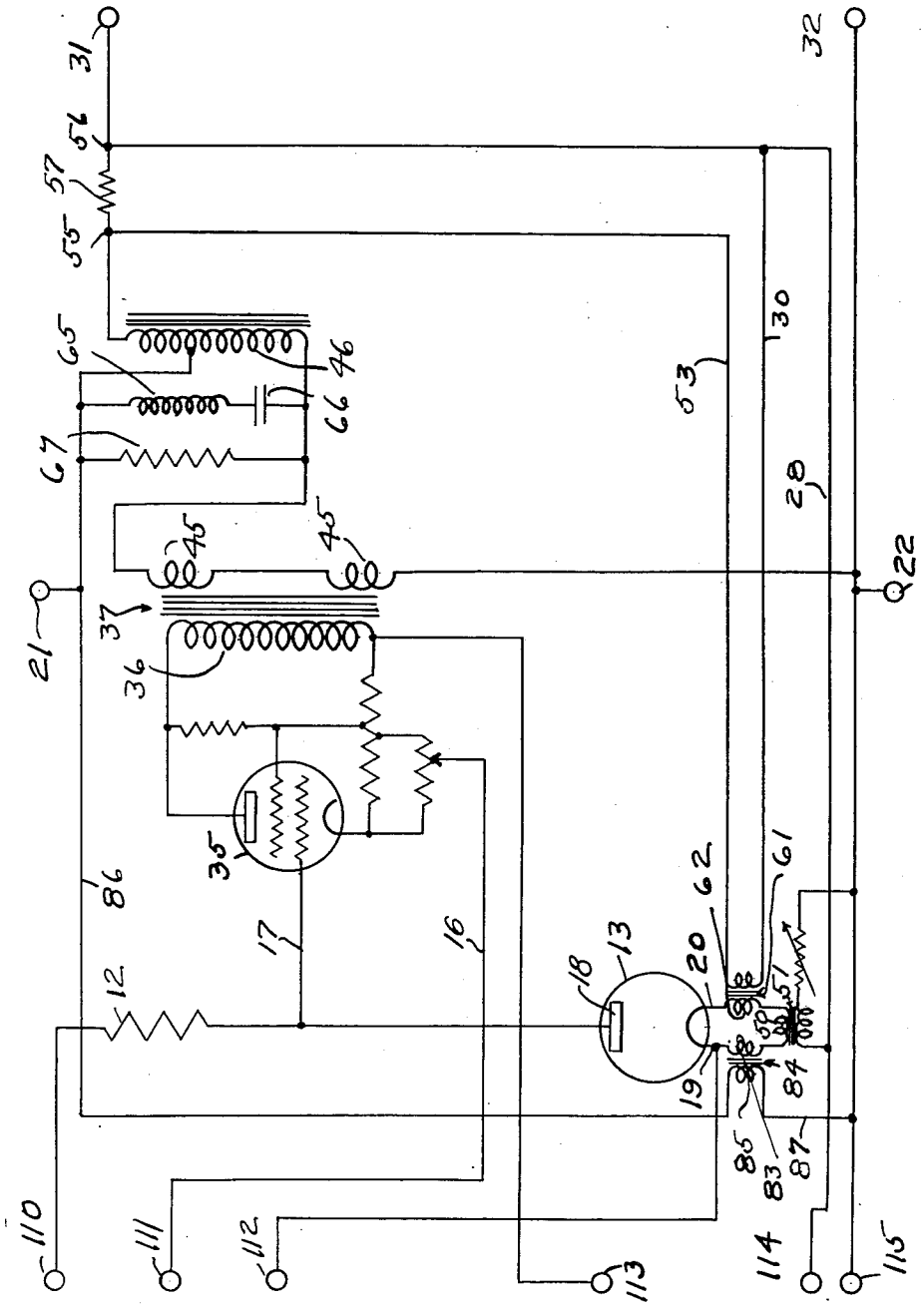

Fig. 5

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UNITED STATES PATENT OFFICE

2,455,143

CATHODE CONTROLLED ELECTRONIC VOLTAGE REGULATOR CIRCUIT

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Application April 17, 1946, Serial No. 662,751

21 Claims. (Cl. 323—42)

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The present invention relates to voltage regulators and particularly to such regulators having the ability to regulate voltage to a very accurate degree.

More particularly still, the invention relates to such voltage regulators which employ electronic means to effect the regulation and still more particularly utilize a diode tube having a tungsten filament.

In the past, various forms of voltage regulators have been constructed both mechanically and electrically operated but even the electrically operated type has possessed the serious disadvantage that the regulation was faulty and could not be maintained accurately. In contrast to these old regulators, my present invention permits the regulation of voltage, particularly A. C., to a fraction of a percent of variation and is therefore usable in situations where no present device suffices.

As has been indicated above, my invention employs a tungsten filament diode, this diode constituting one element of a bridge circuit, the resistance of the diode being effectively varied by varying the filament current and thereby varying the tube emission and impedance. The variation in the balance of the bridge is then utilized to control the output voltage and to maintain it at the set value and this utilization is preferably, though not necessarily, by means of a saturable core reactor.

Furthermore, by a slight modification of the basic circuits of my invention it may be utilized as a current regulator.

It is an object of the invention to provide a voltage regulator which will maintain an output voltage constant within a fraction of one percent during variation of the load or in the input voltage, or both.

It is another object of the invention to provide such a voltage regulator in which the control is electronic in nature.

It is a further object of thei nvention to provide a voltage regulator in which the electronic control includes a tungsten filament diode rectifier arranged in a bridge circuit for detecting variations in the output voltage and applying correction for such variation.

It is a still further object of the invention to provide such a voltage regulator which is operable to regulate A. C. voltages.

It is still another object of the invention to provide a voltage regulator in which the current resulting from the unbalance of a bridge circuit is applied through an amplifying means to a saturable core reactor to thereby control the output voltage.

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A still further object of the invention is to provide means whereby the current regulation overcomes variations in either load or input voltage, or both.

It is a still further object of the invention to provide a modification of the basic circuit and voltage regulator whereby an accurate regulation of current may be obtained.

Other objects and features of the invention will be apparent when the following description is considered in connection with the annexed drawings, in which—

Figure 1 is a schematic wiring diagram of a bridge circuit used in connection with a tungsten filament diode to detect and control the voltage output;

Figure 2 illustrates curves of the tungsten filament diode used in my invention, the plate current being plotted against filament voltage for two values of plate voltage;

Figure 3 is a schematic diagram of one form of the complete regulator of my invention;

Figure 4 is a schematic diagram showing the modifications for converting the voltage regulator to a current regulator; and

Figure 5 is a modification of the voltage regulator of Figure 3 showing another mode of compensating for variations in the input voltage.

Referring now to the drawings, and particularly to Figure 1, there is shown therein a bridge circuit comprising the resistances 10, 11 and 12 together with the tungsten filament diode 13. The input to this bridge circuit is over conductors 14 and 15 and the output is taken out in the conventional manner over conductors 16 and 17 which are connected, respectively, between resistances 10 and 11 and resistance 12 and plate 18 of diode 13. For the purpose of obtaining the greatest sensitivity in the detection circuit the input to terminals 14 and 15 should be on the order of 1000 volts or greater. In the following specification, it will be assumed that there is a direct current input to these conductors or terminals.

It will be clear that if the resistors 10 and 11 are of equal value, then the output from terminals 16 and 17 will be reduced to zero when the resistance of the diode 13 is equal to the resistance of resistor 12.

Referring now to Figure 2, it will be seen that when working above the knee of the curve, for a very small change in the potential applied to the diode filament, i. e., the terminals 19 and 20 of Figure 1, there will be a large change in emission

which will be evidenced by a large variation in the plate current. This is, of course, effective to obtain an extremely great sensitivity in the bridge of Figure 1, thus making a large change in output voltage for a relatively small change in filament voltage. As is clear from Figure 2, the effect of a change in plate voltage is very slight and whatever the plate voltage may be the "gain" of the tube is extremely great, i. e., the ratio of a change in plate current to a change in filament voltage is of the order of thousands.

The diode 13 has the characteristic that it will retrace its operating curve; that is, the current which the diode draws, for a given filament potential and a given plate potential will be identical over thousands of filament potential excursions and will be consistent over many hours of operation.

The elementary bridge circuit of Figure 1 is utilized in my system to control the output voltage and to maintain it constant under conditions of variation both of load and of input voltage.

In order to insure extremely accurate regulation to the order of ½ of 1 percent, it is preferable that the diode and its associated bridge network comprising resistors 10, 11 and 12 together with the filament transformers be placed in a temperature-controlled oven so that the ambient temperature of operation is maintained at an exact level.

Referring now to Figure 3, the input terminals are shown at 21 and 22 and the bridge circuit already described is represented by the resistances bearing the same reference numerals as in Figure 1 together with the diode 13. The voltage for the bridge circuit is obtained through the primary winding 23 of a transformer 24, this primary being connected by means of the conductors 27, 28, resistance 29 and conductor 30 across the output terminals 31 and 32. It should be noted at this point that input terminal 22 and output terminal 32 are common.

The secondary winding 26 of transformer 24, as has been indicated, supplies a D. C. potential to the bridge circuit over conductors 14 and 15 the potential being converted to D. C. by the well known action of the diode rectifier 33. The filament of the diode 33 is provided with its potential by means of the secondary winding 34 of transformer 24.

The output of the bridge circuit is connected to terminals 110 and 111 and over conductors 16 and 17 to the grid-cathode or input circuit of the amplifying tube 35 and the output of this tube is applied to the saturating winding 36 of the saturable core reactor 37.

It should be noted that a condenser 49 is provided in shunt relationship to the resistance 10 of the bridge. This condenser is for the purpose of preventing hunting which might otherwise occur. This hunting would result from the fact that sudden surges would appear across the bridge circuit and due to the small time constant of the bridge and power supply combination including the secondary 26 of the transformer 24 the bridge circuit would over correct before the diode had had time to compensate for such surges in the output voltage. The condenser 49 smooths out these surges and lengthens the time constant of the bridge circuit power supply combination. This action may be more clearly understood, if a specific example be considered. Thus, if it be assumed that a certain portion of the load is removed from the regulator, thereby causing the output voltage to rise momentarily it will be seen that the bridge circuit voltage would accordingly rise. Since the filament of the diode 13 would not have had a chance to heat up in accordance with the line voltage change the diode impedance would be higher relatively with the higher voltage impressed across it. This increased impedance would cause the grid of tube 35 to become more positive and ultimately result in an increased line voltage. This condition is a regenerative one and will cause hunting. However, if the condenser 49 be employed the time constant is so lengthened that the current is no longer regenerative and the desired elimination of hunting results.

Plate current for the amplifying tube 35 is supplied from the winding 38 of transformer 24 through the full-wave rectifier 40 and over conductors 41, terminal 113, conductor 42 and winding 36 of reactor 37. The return from the cathode of tube 35 is over conductor 16, terminal 111 and conductors 43 to the winding 38 and thence to the plates of the rectifier 40. Filament voltage for the rectifier 40 is supplied through the winding 44 of transformer 24.

An A. C. winding for the saturable core reactor 37 is shown at 45 being in series with the "primary" of auto transformer 46 and connected across the input 21 and 22. As will be described in greater detail later, the winding 36 of reactor 37 is so connected that when the control grid of tube 35 becomes less negative, the plate current in the winding 36 will increase and thus cause the reactor to have less reactance between the terminals 47 and 48, thus causing the potential applied to the auto transformer 46 to increase and of course increasing the output potential across terminals 31 and 32.

In order that the wave form of the input voltage may be corrected to eliminate unwanted harmonics and also lower the impedance of the output circuit to improve the sensitivity of the regulator a wave form corrector circuit is provided and is connected in parallel with the primary of the auto transformer 46. This wave form corrector comprises the usual inductance condenser combination such as is shown in Figure 3 at 65 and 66. In addition to performing the functions above mentioned the wave form corrector 65, 66 also provides at the fundamental power frequency a capacitative load which acts effectively as a power factor corrector and lowers the output without, at the same time, dissipating an excess of power.

Furthermore, a range stabilizing resistor 67 is likewise connected in parallel to the primary of the auto transformer 46, this resistor lowering the impedance of the auto transformer primary and thereby giving to the alternating current winding 45 of the reactor 37 a greater range of control over the voltage impressed across the primary of the auto transformer 46.

The voltage applied to conductors 19 and 20 and thus to the tungsten filament of the bridge diode 13 is produced in the secondary 50 of transformer 51, the primary 52 of which is connected in essence across the output terminals 31 and 32. A variable resistance 39 is connected in series with the primary 52 of transformer 51 this resistance serving as a means for adjusting the output level. Thus, any variation in output voltage will cause a proportional variation in the filament voltage of tube 13 and will be followed immediately by a change in the balance of the resistance bridge previously described, thereby effecting the output voltage and restoring it to the preset value, the action, however, being so rapid that there is constant maintenance of the voltage within nar-

row limits, the correction of the voltage taking place within one-tenth of a second or less. If there be an increase in load across output terminals 31 and 32, there will be a corresponding drop in voltage across these terminals with a resultant drop in voltage applied to terminals 19 and 20 of diode 13. As a result of this voltage drop and the consequent decrease in emissivity and increase in resistance of the diode 13, the bridge balance will be upset making the control grid of tube 35 less negative and causing an increase in the output voltage to its preset value. Of course, if the output voltage rises, the opposite effect occurs and the tube 13 becomes in effect a lesser resistance in the bridge and a resulting adjustment of the output voltage in a downward direction occurs.

Although the device already described is effective to regulate voltage to a considerable extent and is in fact better than any known voltage regulator it has some slight disadvantage in that the amplifying tube 35 may not have sufficient gain so that complete correction can occur, there being a slight droop in the curve of the regulator output voltage plotted against its load. In order to correct this condition and effect an output which is substantially constant, I provide a compensating transformer 61, the primary 63 of which is connected by means of conductors 53 and 30 to terminals 55 and 56 between which is a known predetermined length of conductor 57 having a known resistance. If the input line voltage remains constant and there is an increase in load applied across terminals 31 and 32, the result will be an increased voltage drop across conductor 57. This drop may be extremely low and may in fact be in the neighborhood of from 25 to 55 millivolts depending on the load and the resistance of the wire. Transformer 61 is so wound that instantaneous voltage applied through its secondary 62 in response to variations in voltage in primary 63 is in opposition to the voltage generated in secondary winding 50 of transformer 51. Consequently, when the voltage decreases in transformer 51 due to an increase in load it is still further reduced by the bucking voltage applied to the filament circuit of tube 13 by virtue of the increased opposing phase voltage resulting from the increased drop in voltage across conductor 57 from terminal 55 to terminal 56.

In a particular case, a ratio for transformer 61 of three to one has been found satisfactory, that is ⅓ the amount of voltage existing between points 55 and 56 is applied to the filament circuit of diode 13. In this particular case, the diode operated on a filament voltage of approximately 2.05 volts and the compensating voltage generated across the secondary 62 of transformer 61 was of the order of 5 to 15 millivolts.

By adjusting the amount of voltage drop which occurs between terminals 55 and 56, it is possible to so compensate that the regulator will actually increase the output voltage upon an increase in load. Naturally, since this is possible, an adjustment may be made whereby there will be a straight line relationship between output and load and therefore there will be substantially no deviation in output voltage no matter how the load may vary.

In addition to the variations in output, which may result from load variations, a possibility of variations in output voltage resulting from variations in input voltage exists. In other words, as the input voltage applied between terminals 21 and 22 increases an increase in the output potential existing between terminals 31 and 32 will

be experienced. This increase in potential at the output is of course a function of the ability of the bridge network consisting of resistors 10, 11 and 12, and diode 13 to respond to the changes that are taking place in the output of the regulator between terminals 31 and 32. Now the current in the saturable core reactor 37 is an inverse function of the input voltage. That is to say, if the input voltage is low the current in the saturable core reactor becomes high. Thus, if a function of this change be induced into the filament of the diode 13 compensation for input voltage variations as well as for load variations in the output can be made, thereby stabilizing the output so that the variation thereof is extremely small and the output approaches a constant value.

In order to accomplish the purpose mentioned above, the resistor 29 is connected in the conductor 30 as has been described, this resistor thus being in series with the primary of the transformer 61 and being likewise in series with one side of the winding 23 of power transformer 24. Thus, as the input voltage rises there will be an additional drop across resistor 29, since transformer 24 will effectively have a lesser load, which will cause a change in the potential existing across the primary 63 of transformer 61, thereby causing an increase (or more accurately, causing less decrease) in the filament potential of the diode 13 and thus resulting in a decrease in saturating current in the winding 36 of reactor 37 to thus lower the output potentials across terminals 31 and 32 to the predetermined value.

As has been indicated hereinabove, the voltage regulator above described may be modified so that it will function as a current regulator to provide a constant current in a load circuit. Figure 4 illustrates the modifications for converting the voltage regulator to a current regulator. In this figure the terminals 110 through 115 are identical with those of Figure 3, and it is understood that the equipment appearing to the left of these terminals in Figure 3 will be utilized with the circuit of Figure 4.

In general the circuit is extremely similar to that of Figure 3. However, the diode 13, although connected in the bridge circuit consisting of the resistors 10, 11 and 12, has its filament current supplied in a different manner than is the case in the circuit of Figure 3. As will be seen in Figure 4 there is supplied a current transformer 70, the primary 71 of which is connected in series with the output of the regulator near the output terminal 31. The secondary 72 of the transformer 70 is connected by means of the conductors 73 and 74 to the terminals 19 and 20 of the diode 13. Across the leads 73 and 74 is placed a variable resistor 75 while in series in lead 74 is the winding 77 of a transformer 76. This winding 77 is the secondary of the transformer and the primary 78 thereof is connected by means of the conductors 80 and 81 across the output terminals 31 and 32.

It should be noted that in this case the primary 23 of the power transformer 24 is connected by means of the conductor 82, terminal 114, conductor 28, conductor 27, and terminal 115 across the input of the regulator so that variations in the output voltage are ineffective to alter the voltage supply to the bridge circuit.

In operation this circuit functions as follows: upon a decrease in load the current in the winding 71 of transformer 70 decreases. As a result of this decrease the current supplied to the filament

of the diode 13 decreases and the diode thus has an increased impedance. As a result of such increase in impedance the control grid of tube 35 becomes less negative, thereby causing an increase in the current flowing in the D. C. winding 36 of reactor 37, thus causing the potential of auto transformer 46 to increase and thereby increasing the output potential across terminals 31 and 32. Due to this increase in output potential the current is brought up to its preset value and thus a constant current is produced in the output. However, if the diode filament were fed by the transformer 70 without correction there would be an over correction or hunting produced and the current output would not remain truly constant. In order to prevent such over correction the transformer 76 is utilized, its primary being connected as has been stated, across the output terminals 31 and 32 and its secondary 77 being connected in series with the secondary 72 of transformer 70 in such a manner that the currents produced by secondary 77 buck those produced by secondary 72. As a result of this connection any increase in load causing a corresponding instantaneous increase in the output current tends to decrease the resistance of diode 13 but the decrease is less than it would otherwise be because of the action of transformer 76. Further, when the voltage has been readjusted to maintain the output current at its present value that adjustment is effective to alter the bucking current produced in the winding 77 of transformer 76 and thus serves to cause operation of the diode filament at a temperature which maintains the new output voltage at a value such that the output current remains constant.

The circuit of Figure 3 provides correction both for variations in input voltage and for variations in load. At times, however, it is unnecessary to correct for load variations and desirable to correct only for variations in the input voltage. Under such circumstances, it is of course desirable to utilize simpler equipment than that shown in connection with Figure 3. For this purpose the circuit of Figure 5 serves well. In this instance the power transformer 24 is connected directly across the output terminals 31 and 32 as may be seen in Figure 5, in which figure terminals 110 through 115 are identical with those in Figure 3 and the apparatus to the left of these terminals in Figure 3 is to be considered as being present in the circuit of Figure 5. The filament circuit 19–20 of diode 13 is provided as before with the secondary windings 62 and 50 of the transformers 61 and 51, respectively, and in addition a third transformer secondary 83 is connected in the filament circuit 19–20, this secondary being part of transformer 84, the primary 85 of which is connected by means of conductors 86 and 87 directly across input 21–22. It will be seen that by the use of transformer 85 in a circuit as described the voltage applied to the filament of diode 13 is modified by changes in the voltage input across terminals 21 and 22 and that this is done without regard to the load applied across terminals 31 and 32. In utilizing this arrangement the secondary 83 is connected in series with secondaries 62 and 50 in such a manner as to aid transformer secondary 50. Also, the turns ratio of transformer 51 is modified in order that the total voltage appearing across the diode filament be kept at substantially the value which it had when the arrangement of Figure 3 was utilized. The

amount of voltage which is inserted in series with transformer secondary 50 from the secondary 83 is conveniently 1% to 5% of the total voltage impressed upon the diode filament by the three transformer secondaries 62, 50 and 85.

While I have described a preferred embodiment of my invention, it will be understood by those skilled in the art that my invention is capable of various modifications and I do not desire therefore to be restricted to the particular details shown and described, but to be limited only by the appended claims.

What is claimed is:

1. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, means connected across said output circuit for applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, means for supplying a rectified voltage derived from said output circuit to said bridge network, a capacitance across one of the arms of the bridge to prevent fluctuations in the rectified supply thereto effecting the output of said bridge, an amplifier connected across said bridge and responsive to the degree of unbalance thereof and means operable under control of said amplifier to maintain the output voltage at the predetermined value.

2. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, means connected across said output circuit for applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, an amplifier connected across said bridge and responsive to the degree of unbalance of said bridge, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series and said series being connected across the input, and said winding of said saturable core reactor being connected in the output circuit of said amplifier whereby variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to bring it immediately to a predetermined level.

3. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit comprising a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said electron tube to thereby vary the tube impedance and the balance of said bridge circuit, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input and the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and

cause readjustment of said output voltage to a predetermined value.

4. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, means comprising a condenser inductance combination to correct the wave form of the output of said regulator, said means being connected across the primary of said auto transformer, the saturating winding of said saturable core reactor being connected in the output of said amplifier whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined level.

5. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, and means comprising a resistance in shunt to the primary winding of said auto transformer to stabilize the action of the regulator, the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier, whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

6. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, means comprising a condenser inductance combination to correct the wave form of the output of said regulator, and means comprising a resistance in shunt to the primary winding of said auto transformer to stabilize the action of the regulator, the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier, whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

7. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit comprising a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said electron tube to thereby vary the tube impedance and the balance of said bridge circuit, resistance means connected in series with said tube filament supply for controlling the level of output of the regulator, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input and the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

8. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, resistance means connected in series with said tube filament supply for controlling the level of output of the regulator, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, means comprising a condenser inductance combination to correct the wave form of the output of said regulator, said means being connected across the primary of said auto transformer, the saturating winding of said saturable core reactor being connected in the output of said amplifier whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined level.

9. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, resistance means connected in series with said tube filament supply for controlling the level of output of the

regulator, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, and means comprising a resistance in shunt to the primary winding of said auto transformer to stabilize the action of the regulator, the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier, whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

10. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge circuit containing a plurality of resistors and a two element electron tube, means for supplying said bridge circuit with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said two element electron tube to thereby vary the tube impedance and the balance of said bridge circuit, resistance means connected in series with said tube filament supply for controlling the level of output of the regulator, an amplifier connected across the diagonal of said bridge circuit, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input, means comprising a condenser inductance combination to correct the wave form of the output of said regulator, and means comprising a resistance in shunt to the primary winding of said auto transformer to stabilize the action of the regulator, the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier, whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

11. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected thereto, a bridge network including a diode electron tube as one of the arms thereof, a transformer having its primary winding across said output circuit and its secondary winding connected to the filament of the said diode to thereby vary the impedance of said diode and determine the balance condition of said bridge, an amplifier connected across the diagonal of said bridge network, said amplifier being responsive to the degree of unbalance of said bridge, means connected across said output circuit and controlled by said amplifier to adjust the output voltage toward a predetermined value upon a change therein, a resistance in series with the load, a transformer having its primary connected across said resistance and its secondary in the filament circuit of said diode whereby the impedance of said diode and the balance of said bridge is additionally affected to effect additional correcton and complete the adjustment of the output voltage to a predetermined value.

12. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, means connected across said output circuit for applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, an amplifier connected across said bridge and responsive to the degree of unbalance of said bridge, means connected across said output circuit and controlled by said amplifier to adjust the output voltage toward its predetermined value upon a change therein, a resistance in series with the load, a circuit connected across said resistance to vary the filament potential of said diode to further adjust the balance of said bridge to thereby effect additional correction and complete the adjustment of the output voltage to its predetermined value.

13. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected thereto, and having one terminal common to the said input circuit, a bridge network including a diode electron tube as one of the arms thereof, a transformer having its primary connected across said output circuit and its secondary connected in series with said diode filament to vary the impedance of said diode in accordance with variations in said output voltage, said impedance variation determining the balance condition of said bridge, an amplifier connected across the diagonal of said bridge network, said amplifier being responsive to the degree of unbalance of said bridge, means operable under control of said amplifier to adjust the output voltage to its predetermined value upon an instantaneous change therein, a resistance in series with the load, a transformer having its primary winding connected across said resistance and its secondary winding in series with said first mentioned transformer secondary and said diode filament to thereby further vary the impedance of said diode and further adjust the balance of said bridge, a resistance in series with said primary of said second transformer, a third transformer having its primary winding connected from the point common to the said input and output circuit to the juncture of the windings of said second transformer primary and said last mentioned resistance, said third transformer serving to supply potentials through its secondary to said bridge network and said third transformer tending to draw more current under increases in the input voltage whereby the potential across the primary winding of said second transformer is caused to increase and the reaction through said bridge network and said amplifier brings about a variation in the output voltage to compensate for variation in the input voltage to thereby maintain the output voltage constant under variations both in load and in input voltage.

14. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected thereto, and having one terminal common with said input circuit, a bridge network including a diode electron tube as one of the arms thereof, a transformer having its primary connected in series with a resistor across said output circuit, said resistor being variable and adapted to adjust the level of output of the regulator, the transformer secondary being connected in series with said diode filament to vary the impedance of said diode in accordance with the variations in said output voltage, said impedance variation determining the balance condition of said bridge network, said amplifier being responsive to the degree of unbalance of said bridge, means operable under control of said amplifier to adjust the output voltage to its predetermined value upon an instantaneous change therein, a resistance in series with the load, a

transformer having its primary winding connected across said resistance and its secondary winding in series with said first mentioned transformer secondary and said diode filament to thereby further vary the impedance of said diode and further adjust the balance of said bridge, a resistance in series with said primary of said second transformer, a third transformer having its primary winding connected from the point common to the said input and output circuit to the juncture of the windings of said second transformer primary and said last mentioned resistance, said third transformer serving to supply potentials through its secondary to said bridge network and said third transformer tending to draw more current under increases in the input voltage whereby the potential across the primary winding of said second transformer is caused to increase and the reaction through said bridge network and said amplifier brings about a variation in the output voltage to compensate for variation in the input voltage to thereby maintain the output voltage constant under variations both in load and in input voltage.

15. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected thereto, and having one terminal common with said input circuit, a bridge network including a diode electron tube as one of the arms thereof, a transformer having its primary connected in series with a resistor across said output circuit, said resistor being variable and adapted to adjust the level of output of the regulator, the transformer secondary being connected in series with said diode filament to vary the impedance of said diode in accordance with the variations in said output voltage, said impedance variation determining the balance condition of said bridge network, said amplifier being responsive to the degree of unbalance of said bridge, means operable under control of said amplifier to adjust the output voltage to its predetermined value upon an instantaneous change therein, a resistance in series with the load, a transformer having its primary winding connected across said resistance and its secondary winding in series with said first mentioned transformer secondary and said diode filament to thereby further vary the impedance of said diode and further adjust the balance of said bridge, a third transformer having its primary connected across said input and its secondary in the filament circuit of said diode, the input to said filament circuit from said third transformer being in aiding relationship to the input from said first transformer, said third transformer serving to correct the regulation in accordance with variations in the input voltage.

16. In an accurate current regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, a transformer connected in series in said output circuit, the secondary of said transformer applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, an amplifier connected across said bridge and responsive to the degree of unbalance thereof, a saturable core reactor connected across said input circuit, said saturable core reactor having a saturating winding, said winding being connected in the output circuit of said amplifier, whereby variations in the output current cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to return the output current to its pre-set level.

17. In an accurate current regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, a transformer connected in series in said output circuit, the secondary of said transformer applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, resistance means connected in shunt to said transformer secondary and diode filament to determine the level of current output of the regulator, an amplifier connected across said bridge and responsive to the degree of unbalance thereof, a saturable core reactor connected across said input circuit, said saturable core reactor having a saturating winding, said winding being connected in the output circuit of said amplifier, whereby variations in the output current cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to return the output current to its pre-set level.

18. In an accurate current regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, a transformer connected in series in said output circuit, the secondary of said transformer applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, a second transformer having its primary connected across the output of said regulator and its secondary in series connection with the secondary of said first mentioned transformer, and arranged to oppose the current supplied to the filament by said first mentioned transformer to thereby prevent overcorrection, an amplifier connected across said bridge and responsive to the degree of unbalance thereof, a saturable core reactor connected across said input circuit, said saturable core reactor having a saturating winding, said winding being connected in the output circuit of said amplifier, whereby variations in the output current cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to return the output current to its pre-set level.

19. In an accurate current regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, a transformer connected in series in said output circuit, the secondary of said transformer applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, resistance means connected in shunt to said transformer secondary and diode filament to determine the level of current output of the regulator, a second transformer having its primary connected across the output of said regulator and its secondary in series connection with the secondary of said first mentioned transformer, and arranged to oppose the current supplied to the filament by said first mentioned transformer to thereby prevent overcorrection, an amplifier connected across said bridge and responsive to the degree of unbalance thereof, a saturable core reactor connected across said input circuit, said saturable core reactor having a saturating winding, said winding being connected in the output circuit of said amplifier,

whereby variations in the output current cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to return the output current to its pre-set level.

20. In an accurate voltage regulator, in combination, an input circuit, an output circuit adapted to have a load connected therein, a bridge network including a diode electron tube as one of the arms thereof, means connected across said output circuit for applying a voltage to the filament of said diode to thereby determine the balance condition of said bridge, an amplifier connected across said bridge and responsive to the degree of unbalance of said bridge, a saturable core reactor connected across said input circuit, an auto transformer connected across said input circuit and in series with said saturable core reactor, means comprising a condenser inductance combination to correct the wave form of the output of said regulator, said means being connected across the primary of said auto transformer, and a saturating winding for said saturable reactor, said winding being connected in the output circuit of said amplifier whereby variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and corresponding variations in the output voltage to bring it immediately to a predetermined level.

21. In an accurate voltage regulator for alternating current, in combination, an input circuit, an output circuit adapted to have a load connected therein, a balancing network comprising a plurality of resistors and a two element electron tube, means for supplying said balancing network

with direct current derived from said output, means connected across said output for varying the potential applied to the filament of said electron tube to thereby vary the tube impedance and the balance of said balancing network, an amplifier connected across the output of said balancing network, a saturable core reactor, an auto transformer, the operating winding of said saturable core reactor and the primary of said auto transformer being connected in series across the input and the saturating winding of said saturable core reactor being connected in the output circuit of said amplifier whereby minute variations in the output voltage cause variations in the degree of saturation of said saturable core reactor and cause readjustment of said output voltage to a predetermined value.

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REFERENCES CITED

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

UNITED STATES PATENTS

Number	Name	Date
1,130,009	Nicolson	Mar. 2, 1915
1,270,465	Toomey	June 25, 1918
1,874,716	Stoller	Aug. 30, 1932
2,008,855	Drobish	July 23, 1935
2,066,943	Philpott	Jan. 5, 1937
2,149,080	Wolff	Feb. 28, 1939
2,294,375	Belar	Sept. 1, 1942
2,305,307	Wellenstein	Dec. 15, 1942
2,422,141	Skehan	June 10, 1947