Nov. 25, 1952

F. W. ANDERSON

2,619,626

CURRENT SUPPLY APPARATUS

Filed Aug. 19, 1949

Fig. 1.

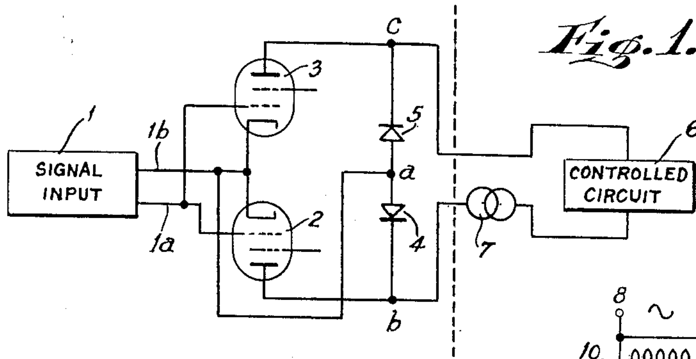


Fig. 2.

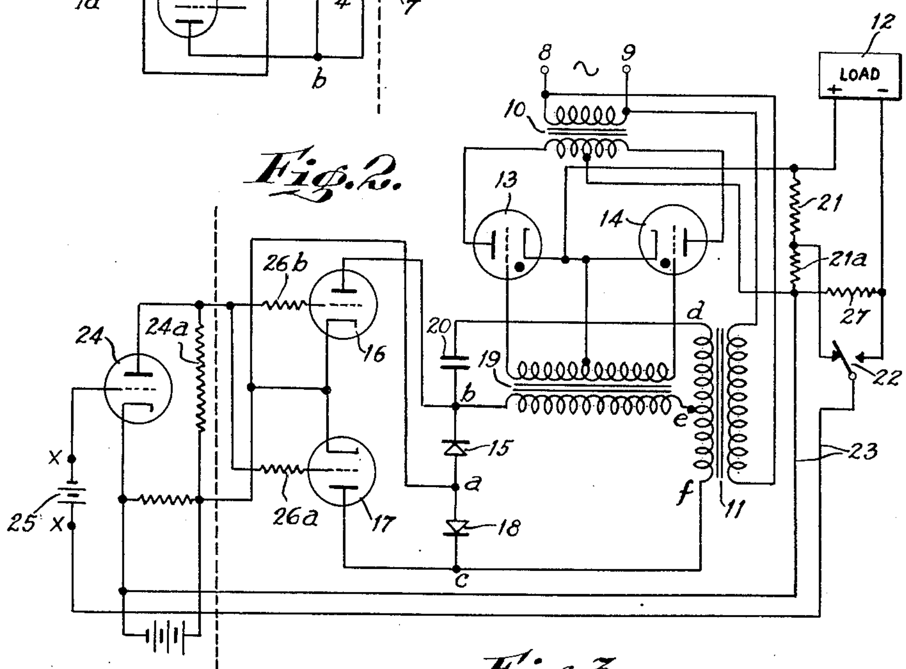
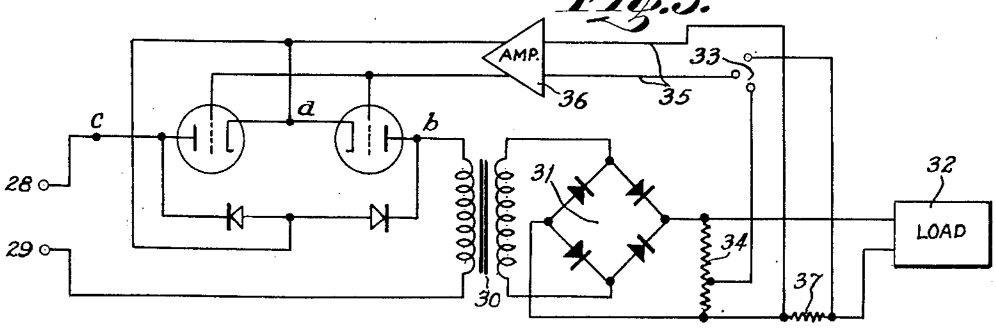


Fig. 3.



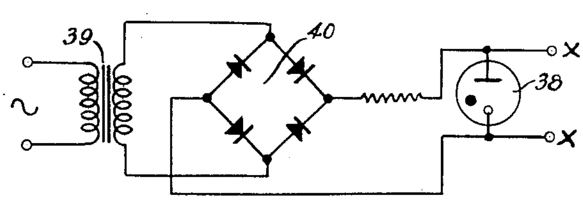


Fig. 2a.

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CURRENT SUPPLY APPARATUS

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Application August 19, 1949, Serial No. 111,203

2 Claims. (Cl. 321—18)

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This invention relates generally to a regulatory system, and more particularly, to a regulatory system for controlling power supply apparatus in accordance with one of the output parameters of the supply.

In certain types of communication systems, means must be provided to obtain a source of direct current power having a characteristic of constant voltage or current. Such direct current power may be required for the charging of batteries, for the operation of repeater stations and for many other purposes incidental to the field of communication.

According to the invention, a full wave, variable resistance network is employed. This network is caused to vary in magnitude by means of a control signal of moderate or low power applied to the control grids of thermionic discharge tubes included as part of the network.

One circuit, according to the invention, includes the variable resistance network as part of a phase shift bridge for grid-controlling a gaseous thermionic discharge rectifier power supply. Such gaseous thermionic discharge rectifiers may be of the type generally known as a "thyratron." By varying the resistance of the network in accordance with a signal derived from one of the output parameters of the thyratron rectifier, the control grid of the thyratron rectifiers may be shifted in phase with respect to its anode voltage to provide an output having a desired constant current or voltage characteristic. The variable resistance network is shown with regard to another circuit, according to the invention, controlling the alternating current input voltage of a conventional rectifier system in accordance with a predetermined output current or voltage. The main object of the invention is to provide a full wave, variable resistance network, arranged to control the output of alternating current regulator and rectifying circuits.

Fig. 1 shows a schematic electric diagram of a variable resistance network in accordance with the invention;

Fig. 2 shows a schematic electric diagram of a preferred embodiment of the invention wherein a variable resistance network as shown in Fig. 1 is employed;

Fig. 2*a* shows an electric schematic variation applicable to the circuit of Fig. 2; and

Fig. 3 shows a further embodiment of the invention.

Referring now to Fig. 1, a variable resistance network according to the invention is shown to the left of the dotted line. A signal, representative of some condition to be controlled, is derived at "signal input" 1. This signal will ordinarily be a unidirectional voltage, varying in magnitude with the control to be effected. The signal is supplied in multiple to the grids of two thermionic discharge tubes 2 and 3. The cathodes of the thermionic discharge tubes 2 and 3 are connected together. Two unidirectional conductors 4 and 5 are connected together in series opposition and the series combination is connected between the anodes of the two thermionic discharge tubes 2 and 3. The common cathode connection of tubes 2 and 3 is connected in turn to the junction of the unidirectional conductors 4 and 5. The anodes of tubes 2 and 3 are individually connected to the circuit 6 under control; in series with the connection from one anode to the control circuit 6 is a source of alternating current 7.

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The general plan will be to modulate the source of alternating current 7 by the variable resistance network as it is supplied to the controlled circuit 6.

In all discussions herein, the flow of current will be assumed as electron flow from negative to positive potential, as compared with conventional battery current flow from positive to negative.

Unidirectional conductors 4 and 5 are sometimes called varistors. They may be metallic or disc rectifiers as shown, utilizing semiconductive materials such as selenium or copper oxide; diodes or other unidirectional conductors may also be employed. Varistor 4 will offer very high resistance to the passage of current flowing from *a* to *b*. The limit of this resistance is dependent upon the practical limitations of the unidirectional conductor employed. Conversely, little or no resistance is offered to current flowing from *b* to *a*, depending also on the practical limitations of the unidirectional conductor employed. Similarly with varistor 5, a high resistance to the flow of current will be experienced by current attempting to flow from *a* to *c*; but a low resistance will be experienced by current passing from *c* to *a*.

Current will flow from the alternating source 7 and in one branch path, passing from the source through the controlled circuit 6, to the point *c*. Assume that the source of alternating current 7 has at a given instant an output polarity making the point *b* negative with respect to *c*, this polarity extending over a half cycle of the output of the alternating supply 7. The current at the now negative point *b* will be unable to pass over the electron path of thermionic discharge tube

2. However, a low resistance current path is offered from *b* to *a* through varistor 4, to the cathode of tube 3, over the space charge path of this tube to the anode, and thence to positive point *c*.

On the succeeding half cycle of the alternating supply 7, the relative polarities of *b* to *c* will have been interchanged. The voltage existing at point *c*, now negative, will be unable to travel over the electron path of tube 3. However, a low resistance current path is offered from *c* to *a*; the current will travel through the varistor 5 to the cathode of tube 2, over the electron path of this tube from the cathode to anode, thence to positive point *b*.

When the current from the alternating supply 7 reaches that point in the network where passage is made from the cathode to the anode of the thermionic discharge tubes 2 and 3, an apparent resistance will be inserted in the path between the cathode and anode, known generally as anode resistance. The amount of the anode resistance presented will depend upon the potential of the individual control grids with respect to the cathodes. As the control grid of either one of the thermionic discharge tubes becomes charged more negatively with respect to its cathode, the electron flow between the cathode and anode of that discharge tube will decrease in accordance with the negative increase in control grid voltage. Thus, the amount of resistance to the passage of current in either direction from point *b* to point *c* will depend upon the control grid-cathode voltage of the thermionic discharge tube through which the current flows. As the current from alternating supply 7 will flow successively through discharge tubes 2 and 3, the amount of resistance inserted by these discharge tubes can be made to depend upon the control grid-cathode voltage derived from "signal input" 1. If lead 1–*a* becomes more negative with respect to lead 1–*b*, the anode resistance of discharge tubes 2 and 3 and therefore the insertion resistance of the network on the left-hand side of the dotted line will be increased. If lead 1–*a* becomes more positive with respect to lead 1–*b*, the anode resistance of discharge tubes 2 and 3 and therefore the insertion resistance of the network will be decreased. If the signal obtained from "signal input" 1 is representative of a characteristic desired at the input of the "controlled circuit" 6, the amount of resistance inserted by the network including discharge tubes 2 and 3 can be regulated to assist in maintaining the desired characteristic. If thermionic discharge tubes 2 and 3 are pentode vacuum tubes, a higher circuit resistance can be obtained than with triodes.

Referring now to Fig. 2, a thyratron power supply is here shown employing a variable resistance network as previously described. The rectifier circuit compares in some respects with copending United States application of J. R. Stone, Serial No. 111,199, filed August 19, 1949, now Patent No. 2,592,615. The network here comprises two thermionic discharge tubes 16 and 17; varistors 15 and 18 operate in the manner described with reference to Fig. 1.

In general, the circuit shown in Fig. 2 supplies a direct current to a load 12, from a prime source of alternating current, at terminals 8 and 9. The alternating current is applied to the primaries of transformers 10 and 11. The secondary of transformer 10 provides a voltage to the anodes of full wave thyratron rectifiers 13 and 14. The thyratron output is supplied to the load 12 with the negative lead from the center tap of the secondary of transformer 10 and the positive lead from the cathodes of thyratron rectifiers 13 and 14.

Control grid thyratrons or gas triodes such as 13 and 14 provide a variable output in accordance with the phase of their control grid-cathode voltage with respect to the anode-cathode voltage. The grid-electrode of thyratrons is able only to initiate the flow of anode-cathode current; once this current flows, the current magnitude is not controlled by the control grid nor is this grid able to stop the flow of current. Current will cease flowing when the anode voltage applied to the particular thyratron returns from a positive to the zero value and over the succeeding half cycle of anode-cathode voltage presented from the secondary of transformer 10. By delaying the control grid of the thyratron from reaching the point where anode current may flow for an appropriate time, the total current passed by the thyratron anodes can be controlled. The problem of controlling the output of thyratron rectifiers 13 and 14 is therefore reduced to one of shifting the phase of control grid-cathode voltage supplied to the thyratrons with respect to the anode-cathode voltage, to obtain the desired constant current or voltage output.

When the control grid-cathode voltage is in phase with the anode-cathode voltage, the output of the thyratron rectifiers will be at a maximum; when the latter two voltages are 180 degrees out of phase, the output of the thyratrons will be substantially equal to zero.

To provide the desired shift in phase, a bridge circuit is employed, having as its four arms: the portion of the secondary of transformer 11 between points *d* and *e*; and between points *e* and *f*; capacitance 20; and the full wave, variable resistance network between points *b* and *c*. A transformer 19 has its primary winding connected between vertices *b* and *e* of this bridge. The secondary of transformer 19 is center-tapped; the extremities of this winding are connected to the control grids of thyratrons 13 and 14, the center tap being connected in multiple to the cathodes of these thyratrons.

That arm of the bridge between points *b* and *c*, the variable resistance network, operates in the manner described with reference to Fig. 1. Thermionic discharge tubes 16 and 17 will provide successive paths of variable resistance upon the consecutive half cycles of the voltage provided across points *e* and *f* of the transformer 11 secondary. The amount of the resistance inserted by the variable resistance network depends upon the control grid-cathode voltage applied to tubes 16 and 17; the resistance in the arm of the bridge extending from *b* to *c* will be varied in accordance with changes of the latter voltage.

The primary winding of transformer 19, between *b* and *e*, will have a voltage adduced therein depending upon the voltage balance of the bridge arms. A voltage is developed across the arms from *d* to *e* and from *e* to *f* of the secondary of transformer 11. The phase of the voltage presented between *b* and *e* of the primary of transformer 19 will depend upon the magnitude of the variable resistance network between points *b* and *c*. The balance obtained by the bridge circuit will depend upon the magnitude of this variable resistance and two extreme cases can be considered: (A) where the variable resistance network presents a resistance so high as to approach an open circuit, and (B) where the magnitude of the variable resistance network becomes so small as to be negligible. In the former case (A), the voltage presented by the secondary of transformer 11 between e and f can be virtually eliminated from consideration, and the voltage presented to the primary of transformer 19 is that developed across the d to e portion of the secondary of transformer 11 in series with the capacitance 20. The phase of the voltage appearing across the primary of transformer 19 will be shifted 180 degrees from the supply voltage presented between terminals 8 and 9. Assuming the second condition (B), the voltage at the primary of transformer 19 between b and e will be substantially the same voltage as exists between points e and f of the secondary of transformer 11; the value of resistance between points b and c will reach such a low value as to become negligible. The voltage then presented to the secondary transformer 19 will be substantially the same voltage as exists between the anodes of thyratrons 13 and 14. In the range between the two conditions stated, for various values of the variable resistance network in the bridge arm between points b and c, the voltage from b to e at the primary of transformer 19 will vary from 180 degrees out of phase to the in-phase condition depending upon the value of the magnitude of the variable resistance network bridge arm. The control of phase of the grid-cathode voltage of thyratrons 13 and 14 can be obtained by manipulating the ratio of the in and out-of-phase voltage components supplied the primary of transformer 19 in the manner described; these components being ultimately applied to the control grid-cathode circuits of thyratrons 13 and 14 through the secondary of transformer 19.

The amount of phase shift in the thyratron grid voltage has been seen to depend upon the magnitude of the variable resistance network between c and b, and thus ultimately upon the control grid-cathode voltage of thermionic discharge tubes 16 and 17.

Assuming that the output of the thyratron rectifier system is to display a constant voltage characteristic, a voltage divider 21 is connected to the rectifier output. A portion of the output voltage is sampled over a segment 21–a, of voltage divider 21; this portion will contain voltage variations proportional to output voltage changes of the rectifier system. Assuming that switch 22 is closed to the left-hand position, the voltage developed across 21–a will be transmitted to leads 23.

To obtain a closely regulated output voltage, relatively small voltage variations appear across conductors 23, representative of output voltage variations. The variations are amplified and presented to the control grids of discharge tubes 16 and 17, which in turn provide control of the thyratrons 13 and 14 in accordance with the prior description. A direct coupled amplifier is employed to increase the sensitivity of the regulatory system, and is shown to the left of the dotted line, in Fig. 2. Voltage variations developed across 21–a are supplied between the cathode and control grid of a thermionic discharge amplifying tube 24, in series with a source of bias 25.

With the polarities as indicated in Fig. 2, a negative grid bias must be introduced at amplifying tube 24, overcoming the residual positive voltage developed at the upper end of 21–a which would render the grid excessively positive; at the same time, the signals representative of voltage variation will be transmitted to the grid circuit of amplifier 24. While bias supply 25 is indicated as a battery, any conventional type of direct current power supply of suitable voltage stability may be employed between terminals x—x. Referring to Fig. 2a, a rectifier type power supply, employing a regulatory gaseous discharge tube 38 may be utilized. Alternating current supplied to transformer 39 is rectified by a bridge rectifier 40 and thence supplied in parallel with the regulatory tube 38 to the terminals x—x.

The signals representative of voltage variation in the output of thyratron rectifiers 13 and 14 will be amplified in the amplifying tube 24. This amplified voltage appears across resistance 24–a, which is in turn coupled to the control grid-cathode circuit of the variable resistance network tubes 16 and 17. Direct coupled amplifying tube 24 may be a triode of the type shown, or of any convenient type. Resistances 26–a and 26–b in the circuit of the variable resistance network discharge tubes 16 and 17 are inserted to limit the flow of grid current in the latter tubes.

To demonstrate the operation of the circuit, it may be assumed that the voltage across divider 21 rises; a proportional rise develops across 21–a of voltage divider 21. This variation will be communicated to the control grid-cathode circuit of amplifier tube 24 over conductors 23; the steady direct current component developed across 21–a is overcome, at least in part, by the bias supply 25. The increase in output voltage renders the control grid of amplifier tube 24 more positive or less negative and will increase the anode-cathode current drawn by the amplifier tube. In turn, the voltage drop across resistance 24–a, common to the grid-cathode circuit of tubes 16 and 17, will be increased, providing a more negative voltage to the grids of 16 and 17. A more negative voltage between the grid and cathode of 16 and 17 will increase the resistance offered between points b and c by the variable resistance network. As has been shown, this change in the bridge arm will shift the phase of voltage presented the primary of transformer 11, in turn producing an increased phase shift between the grid-cathode voltage and anode-cathode voltage applied to thyratron rectifiers 13 and 14. The latter increased phase shift decreases the output of the thyratrons 13 and 14, providing a lower output voltage and thus corrects for the originally assumed increase in output voltage.

Similarly, a decrease in output voltage can be shown to provide an increase in thyratron output through the regulatory system described.

If the output of the thyratron rectifier system is to be regulated in a manner providing a constant current output, independent of the load imposed upon the rectifier, the switch 22 is made to its right-hand contact. Resistance 27 is connected in series with the output of the thyratron rectifier to the load; the voltage drop experienced by resistance 27 will depend substantially upon the load current flowing therein. As a result, the leads 23 connected across resistance 27 will reflect voltage variations representative of variations in the load current of the thyratron rectifier. In turn, these variations representative of load current changes are supplied to the grid-cathode circuit of the direct coupled amplifier tube 24. The variations will be amplified in amplifier tube 24, and are presented to the grid-cathode circuit of the variable resistance network tubes 16 and 17; appropriate changes in the phase of the grid voltage presented to the thyratron rectifiers 13 and 14 will be achieved. The output of the thyratron rectifiers 13 and 14 are in turn altered to control the output voltage and maintain the load current at a predetermined value.

To illustrate the operation of the system in providing constant current regulation, a rise in load current will be reflected by an increase in voltage drop across resistance **27**, making the grid of amplifier tube **24** more positive or less negative. As in the illustration of the constant output voltage condition, the more positive condition of the grid of amplifier tube **24** will ultimately result in a reduction in the output of thyratrons **13** and **14**, lowering the rectifier output voltage and thus reducing the load current, compensating for the originally assumed load current rise.

Similarly, a drop in load current can be shown to provide an increase in thyratron rectifier output, increasing the output voltage and increasing the load current, and compensating for the load current drop.

Thus, depending upon whether switch **22** is operated to left or right-hand contact, the output of the thyratron rectifier supply can be maintained to have either a constant voltage or constant current output operating characteristic.

Referring now to Fig. 3, a regulating system, according to the invention, is shown as applied to other types of rectified arrangements. A source of alternating current is supplied to terminals **28** and **29**; thence in series with a full wave, variable resistance network between points *b* and *c*, to the primary of transformer **30**. The secondary of transformer **30** is connected to a full wave bridge rectifier **31**, the output vertices of the bridge rectifier **31** being coupled to a load circuit **32**.

The operation of the full wave, variable resistance network between points *c* and *b* is as described with reference to Fig. 1. Assuming that switch **33** is connected to the lower contact, voltage divider **34** connected across the output vertices of rectifier **31** will provide a portion of the output voltage to conductors **35**. Variations proportional to change in output voltage are transmitted to an amplifier **36** which can be similar in construction to the one employing tube **24** in Fig. 2. The output of amplifier **36** provides a signal input controlling the operation of the variable resistance network. The network introduces a varying resistance between points *c* and *b*, in turn varying the magnitude of the alternating voltage supplied to the primary transformer **30**, in accordance with variations in the output voltage. The latter output voltage may thus be maintained at a substantially constant value.

Similarly, variations in output load current will produce corresponding voltage drop variations across resistance **37**. Assuming switch **33** is made to its upper contact, this voltage in turn is amplified by the amplifier **36** and thence supplied to the full wave, variable resistance network. Again, the magnitude of the alternating voltage supplied from terminals **28** and **29** to the primary of transformer **30** can be varied by changing the resistance inserted between *c* and *b* by the variable resistance network in accordance with changes in load current. An appropriate compensation in the alternating supply voltage may thus be made to the input of transformer **30** maintaining the output voltage at such values that the load current will remain substantially constant.

It is obvious that the scope of the invention is not limited to the specific embodiments described, and that the invention may be employed in arrangements other than those given by way of example.

What is claimed is:

1. A power supply system comprising a first and a second grid-controlled gaseous discharge device each having a cathode, an anode and a grid, energizing circuits for supplying an alternating voltage of given phase to the anode-cathode circuits of the said gaseous discharge devices in push-pull, means for supplying a direct current from the said gaseous discharge devices to a load circuit to set up a direct output voltage, a constant output control circuit comprising, a transformer having primary and secondary windings, the primary winding of the said transformer being connected to the said alternating supply source having a given phase, a phase shifting bridge having output vertices, first and second arms displaced about the said output vertices, said first and second arms comprising half portions of the secondary of the said transformer, means to couple the output vertices of the said bridge to the grid-cathode circuit of the said first and second gaseous discharge devices in push-pull, the third and fourth arms of the said bridge displaced about the said output vertices, said third arm including a capacitance element and said fourth arm having first and second branch paths each including a thermionic discharge tube having a cathode, grid, and anode and an asymmetrically conducting device connected in series with the anode-cathode circuit of the said thermionic discharge tube and having a concurrent polarity of current flow therewith, means to connect said first and second branch paths in parallel and conducting in opposite directions respectively, means for amplifying said direct output voltage, and means to impress the said amplified direct output voltage in multiple to the grid-cathode circuits of the said thermionic discharge tubes.

2. In combination, rectifying means comprising a first and a second space current device each having an anode, a cathode and a control electrode for supplying current from an alternating-current supply source through the space current path of said devices to a load circuit, a phase shift bridge circuit comprising two parallel current paths connecting the input vertices of said bridge, one of said parallel paths comprising a first and a second impedance arm in series, the other of said parallel paths comprising in series a third arm having a reactive impedance and a fourth arm having a variable resistive impedance, the output terminals of said bridge being the common terminal of said first and second arms and the common terminal of said third and fourth arms, said fourth bridge arm comprising a third and a fourth space current device of the vacuum type each having an anode, a cathode and a control electrode and a first and a second asymetrically conducting device each having a resistance to current flow in one direction therethrough which is much lower than its resistance to current flow in the opposite direction therethrough, the anodes of said third and fourth devices being connected respectively to an output terminal and an input terminal of said bridge, said cathodes of said third and fourth devices being conductively connected, said first asymmetrically conducting device being connected across the anode-cathode path of said third device and having a relatively low resistance when the cathode of said third device is positive with

respect to its anode, said second asymmetrically conducting device being connected across the anode-cathode path of said fourth device and having a relatively low resistance when the cathode of said fourth device is positive with respect to its anode, means for impressing a voltage from said supply source across the input terminals of said phase shift bridge, means for impressing a voltage from the output terminals of said bridge upon circuits connecting the control electrode and cathode of said first and second space current devices respectively, means for deriving a unidirectional voltage which varies in response to changes of current flow in said load circuit, and means for impressing said derived voltage upon a circuit connecting the control electrode and

cathode of each of said third and fourth space current devices.

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