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VOLTAGE REGULATOR

Filed March 9, 1954

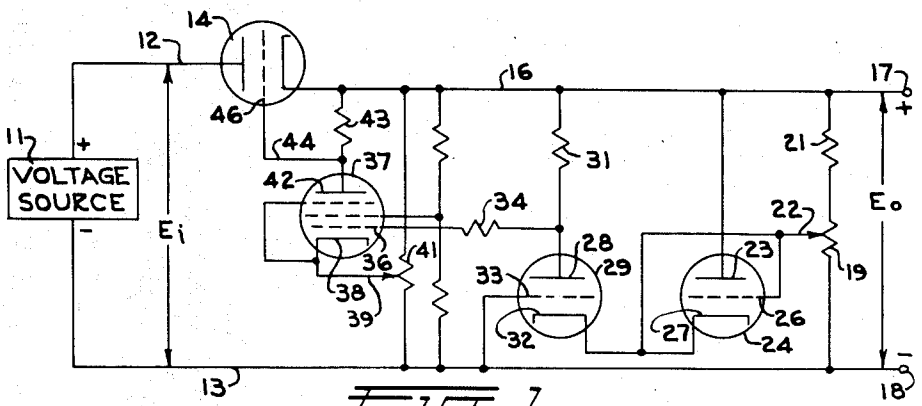



FIG. 1

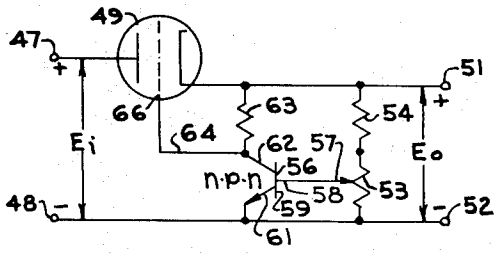



FIG. 2

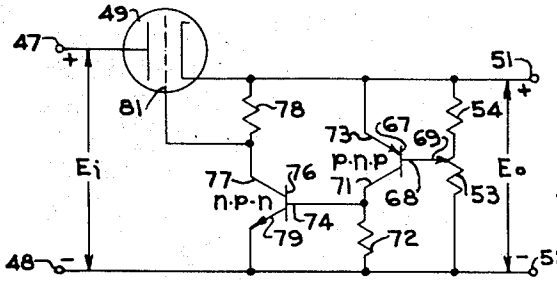



FIG. 3

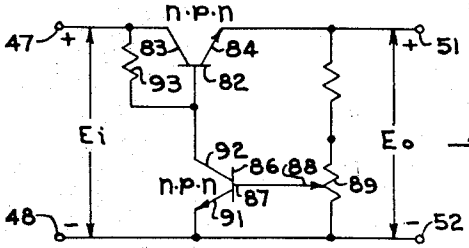



FIG. 4

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# VOLTAGE REGULATOR

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13 Claims. (Cl. 323—22)

This invention relates to direct-current power supplies providing regulated output voltages. Such a supply usually comprises an alternating current source, a rectifier, and filter, with an electronic device for maintaining constant output voltage.

One form of regulating device employed in such a supply includes a sensitive control element such as an electronic tube in series with the output terminals, and an amplifier sensitive to the output potential for controlling the sensitive control element. In addition a reference potential is employed such as the potental drop across a voltage regulator tube, and it may be shown that some sort of reference potential is required in every voltage regulator of this kind.

One purpose of voltage regulation is to keep the power supply output voltage constant. This function of regulation, constancy of output voltage, can be defined as the variation of output voltage divided by the nominal or full-load output voltage. Alternatively the input voltage or its change may be the denominator. That is:

$$\text{Regulation}=\frac{dE_0}{E_0} \quad (1)$$

in which $E_0$ is the nominal output voltage, or

$$\text{Regulation}=\frac{dE_0}{dE_i} \quad (2)$$

in which $E_i$ is the input voltage.

The smaller the value of the fraction the better the voltage regulation is said to be. Either load current change or input voltage change may tend to change the output voltage. The present invention reduces or substantially eliminates changes in output voltage due to either cause.

It is conventional in a power supply of the type under consideration to employ a high vacuum electronic tube in series with the load, and to apply the regulatory effort to the control grid of this tube. However, obviously any device which controls electrical power by the application of smaller power may be employed, among such devices being transistors, saturable reactors, and amplidynes. It is also conventional in such power supplies to employ an electronic tube negative feed back amplifier. However it is obvious that in place of the electronic tube amplifier a transistor amplifier may be employed with appropriate changes in connections.

The instant invention is concerned with the reference voltage required in the voltage regulator. In place of any of the conventional forms of reference voltage the instant invention employs a reference voltage depending on a voltage or current inherently generated within the feedback amplifier. The magnitude of this inherent voltage or current is completely or substantially independent of the magnitudes of all externally applied voltages excepting, in the case of electronic tube amplifiers, of the filament voltage. In general, the magnitude of the inherent voltage or current is dependent only upon the materials employed in the construction of the electronic tube or of the transistor.

The inherent voltage in the case of an electronic tube amplifier may be designated as the initial cathode potential and termed $e$. This potential is the sum of the initial velocity potential, $v_i$, due to thermal escape of electrons from the cathode, and of the contact potential, $v_{cp}$, which is in turn dependent upon the work function of the material of which the cathode is made. That is,

$$e=v_i+v_{cp} \quad (3)$$



The inherent voltage $e$ is made to produce a current through a fixed resistor, and it is the resulting voltage drop across this resistor which is employed as the reference voltage V.

In the case of transistors it is simpler to consider currents rather than voltages, and the inherent current employed to generate the reference voltage is described as the collector cutoff current, $I_{co}$. This current is that which flows in the collector circuit when the emitter current is zero, and is the result of an inherent property of the particular transistor. The inherent current $I_{co}$ is made to flow through a fixed resistor, and it is the resulting voltage drop across this resistor which is employed as the reference voltage $V_c$ in the transistor embodiment of this invention.

The general purpose of this invention is to provide a regulated power supply including a feedback amplifier containing an inherent electrical magnitude which serves to generate a reference magnitude.

Another purpose of this invention is to provide a regulated power supply including an electronic tube feedback amplifier having an inherent initial cathode potential, of which the reference potential is a function.

Another purpose of this invention is to provide a regulated power supply including a transistor feedback amplifier having an inherent collector cutoff current, of which the reference potential is a function.

A further understanding of this invention may be secured from the detailed description and drawings, in which:

Figure 1 depicts a regulated voltage supply employing electronic tubes and embodying this invention.

Figures 2 and 3 depict a voltage regulator employing a transistor feedback amplifier.

Figure 4 depicts a transistor voltage regulator employing a series transistor as the sensitive control element.

Referring now to Fig. 1, a source of voltage **11** includes a rectifier energized by alternating current, and emits filtered direct current having a potential $E_i$. This potential is applied to the voltage regulator input conductors **12** and **13**, conductor **12** being positive. Conductor **12** is connected through a series triode **14** to conductor **16** and thence to the regulated power supply output terminal **17**, while conductor **13** is connected directly to the other output terminal **18**. A voltage divider **19** and resistor **21** are placed in series across output terminals **17** and **18**, so that a desired fraction of the output voltage $E_0$ appears at the voltage divider slider **22** in accordance with its manual adjustment. This voltage divider **19** provides means for manually adjusting the output voltage $E_0$ and also acts to correct for changes in output voltage when replacing tubes, caused by differences in individual tube characteristics.

The plate **23** of a triode **24** is connected to the positive regulated conductor **16**, while its grid **26** and cathode **27** are connected to slider **22**. The plate **28** of a triode amplifier **29** is connected to the positive conductor **16** through a resistor **31**, and the cathode **32** is connected to slider 22. Grid **33** is "grounded" to conductor **13**. The output from plate **28** is coupled through resistor **34** to the control grid **36** of an amplifier-inverter pentode **37**. The cathode **38** of pentode **37** is connected to the slider **39** of a voltage divider **41** for adjustment of bias voltage and plate current. The plate **42** is connected through resistor **43** to the positive conductor **16**. The output derived from the plate **42** is applied to the control grid **46** of triode **14** through conductor **44**.

In the operation of this circuit, changes of the potential of output terminal **17** relative to terminal **18**, whether due to changes in load current or to changes in input voltage, change the potential at the slider **22**. This potential change is amplified in triode **29**, amplified and inverted in pentode **37**, and applied to the control grid **46** of triode **14** in such sense that the voltage drop through this triode is changed in such amount and sense as to correct the original change in the output potential.

It may be shown, as before stated, that in such a circuit a fixed reference potential is essential in order that regulating action be secured. Such a fixed reference potential V is found to be developed as a result of the initial cathode potential $e$ of triode **29**. The potential V is that part

of the voltage drop $E_d$ across the resistor **31** having resistance R which is due to $e$. That is:

$$E_d = I_b R \quad (4)$$

in which $I_b$ is the plate current of tube **29** and is a function of $e$. This is conventionally expressed as

$$I_b = f(E_b + \mu E_c + e) \quad (5)$$

in which $E_b$ is the plate potential, $\mu$ is the amplification constant and $E_c$ is the grid-cathode potential. The plate current $I_b$ thus is due to three causes, and that part due to the initial cathode potential $e$ may be termed $I_e$. It is the potential drop V in the plate resistor **31** due to $I_e$, which is employed as the reference potential in this circuit. That is:

$$V = I_e R \quad (6)$$

The quantity $e$ has the magnitude of a volt or so. Although this is small compared to usual values of plate voltage, it is found that this fixed primary reference potential is large enough to serve as the source of a reference voltage V in highly practical voltage regulators.

The cathode of pentode **37** of course generates an initial cathode potential, but since it is in the second stage of amplification its effect is negligible. The function of this tube is principally to invert the signal, an even number of stages being necessary to apply the signal to the sensitive control tube **14** in the right sense for regulation of the output voltage.

The contact potential, $V_{cp}$, being dependent on the work function of the material of the cathode **32**, is highly dependent on the cathode temperature. It is therefore desirable, in order to stabilize V, to secure constancy of $V_{cp}$ and therefore of $e$. In order to secure constancy of the contact potential $V_{cp}$ in spite of fluctuations of filament voltage and other causes of temperature variation the triode **24** is employed.

In the operation the filament correction triode **24**, is adjusted so that its plate current is considerably higher than the plate current of triode **29**, and causes a selected potential drop in voltage divider **19** between slider **22** and conductor **13**. If for any reason, such as by increase of filament current, the cathode **32** should increase in temperature, its potential will become more negative. But since cathode **27** is heated by the same filament circuit its potential will also decrease and triode **24** will draw more current. The resulting increased potential drop through the lower part of voltage divider **19** will then raise the potential of cathode **32** to neutralize the change made by the temperature change. If the temperature of cathode **32** should decrease, the reverse effects will neutralize its tendency to increase in potential.

Instead of returning the control grid **26** to the slider **22**, it may be found desirable to return it to some other point on the voltage divider **19**, depending on the relations between the characteristics of the particular tubes employed as triodes **24** and **29**.

The principles of this invention are embodied in the circuit of Fig. 2, in which unregulated filtered direct-current potential $E_i$ is applied to input terminals **47** and **48**. A triode **49** in series with input terminal **47** and output terminal **51** is employed as the sensitive control element, and input terminal **48** is connected to output terminal **52**. A voltage divider **53** and resistor **54** in series across tthe output terminals **51** and **52** reduce the output potential $E_o$ to a fraction suitable for feeding back to the sensitive control element **49**, and provide means of adjustment. The negative feedback voltage amplifier is an n-p-n junction transistor **56** connected as a grounded or common emitter amplifier. One input is connected from slider **57** of voltage divider **53** to the base terminal **58** and the other input is through conductor **59** to the emitter terminal **61**. Positive potential is applied to the collector terminal **62** through the collector resistor **63**, and output potential is taken from the collector terminal and applied through conductor **64** to the control grid **66** of triode **49**.

It is a property of transistors that a small current called the collector cutoff current, $I_{co}$, flows when the emitter current is zero. This collector cutoff current can be thought of as flowing at all times in addition to other collector currents which flow in accordance with input and output circuit potentials. The collector cutoff current magnitude is nearly independent of all applied potentials, and is employed in this circuit as the source of the reference potential. The collector cutoff current, flowing through the resistor **63**, causes a potential drop $V_c$ therein. It is this potential drop which is employed in this circuit as the reference potential, existing at all times as a part of the potential applied to control grid **66**.

In operation, if the output potential $E_o$ should decrease, the emitter-to-base potential of transistor **56** is decreased. This causes the collector current to decrease, reducing the potential drop in resistor **63** and making control grid **66** less negative. The voltage drop across triode **49** is thereby decreased, neutralizing the drop in output potential. If the output potential $E_o$ should tend to increase the reverse action ensues, against neutralizing the change in output voltage.

The reference potential dependent upon the collector cutoff current is small, so that in some cases one feedback transistor amplifier is not sufficient to provide good regulation. In such cases more than one stage of feedback amplification may be used, an odd number of stages being required if all transistors are of the same type or an even number if they are alternately of the n-p-n and p-n-p types. Fig. 3 illustrates the latter situation.

In Fig. 3 the input terminals **47** and **48** are connected to the output terminals **51** and **52** through series triode **49** as in Fig. 2, and the voltage divider **53** and resistor **54** reduce the feedback signal. A p-n-p junction transistor **67** has its base terminal **68** connected to the slider **69** of voltage divider **53**. The collector **71** is connected through a collector resistor **72** to output terminal **52** and the emitter **73** is connected to output terminal **51**. The output potential taken from the collector **71** contains not only the amplified signal applied to the base but also the reference potential consisting of the potential drop in resistor **72** due to the collector cutoff current. This output potential is applied to the base terminal **74** of an n-p-n junction transistor **76** having its collector **77** connected to output terminal **51** through resistor **78** and its emitter **79** connected directly to output terminal **52**. Connection is made between collector **77** and the control grid **81** of triode **49**.

A transistor may be substituted for the series triode employed in Figs. 1, 2 and 3 as the sensitive control element, and when the series transistor is combined with a transistor feedback amplifier a voltage regulator employing only transistors results. Such a regulator is depicted in Fig. 4. The input terminals **47** and **48** are connected to the output terminals **51** and **52** in series with an n-p-n junction transistor **82**, the collector **83** being connected to terminal **47** and the emitter **84** being connected to output terminal **51**. An n-p-n transistor **86** serves as the negative feedback amplifier, its base **87** being connected to the slider **88** of voltage divider **89**. Its emitter **91** is connected to output terminal **52** and its collector **92** is connected through collector resistor **93** to the positive input terminal **47**. Connection of this resistor to the input terminal instead of to the output terminal **51** is preferable because the potential between base and emitter of transistor **82** is very low, which would necessitate a small value of collector resistor. By connecting the collector resistor to the collector **83** a large value of resistance can be employed resulting in greater amplification and better regulation.

What is claimed is:

1. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a control device having a control electrode for controlling an electrical quantity existing between a pair of other electrodes, one of said pair of electrodes being connected to said source and the other of said pair of electrodes being connected to said load circuit, an amplifying device, a source of fixed primary reference potential, said source being an inherent part of said amplifying device, an impedance connected in series with said amplifier and a source of potential for developing a potential drop in said impedance a portion of which results from the application of said fixed primary reference potential, said portion of potential drop constituting the reference potential utilized by the said power supply, means for applying a potential to said amplifying device proportional to the potential applied to said load circuit, and means for applying the potential of said impedance to the control electrode of said control device.

2. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a control transducer having several electrodes including a control electrode for controlling an

electrical quantity existing between a pair of other electrodes, said pair of electrodes being interposed in series between said source and said load, an electrical amplifying device having at least one stage generating a fixed inherent electrical quantity, an impedance connected in series with said stage and a source of direct current whereby a potential drop is developed in said impedance which is dependent on said fixed inherent electrical quantity, the portion of said potential drop due to said fixed inherent electrical quantity constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for applying the potential existing across said impedance to the control electrode of said control transducer.

3. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, an electronic discharge tube having at least a grid, cathode and anode, said cathode and anode being interposed in series between said source and said load, an electrical amplifying device having at least one stage generating a fixed inherent electrical quantity, an impedance connected in series with said stage and a source of direct current whereby a potential drop is developed in said impedance which is dependent on said fixed inherent electrical quantity, the portion of said potential drop due to said fixed inherent electrical quantity constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for controlling said grid by the potential existing across said impedance, the sense of control being such as to tend to maintain constant potential across said load circuit.

4. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, an electronic discharge tube having at least a grid, cathode and anode, said cathode and anode being interposed in series between said source and said load, the anode being more positive than the cathode, an electronic amplifier stage including discharge tube means having at least a grid, cathode and anode, a source of fixed primary reference potential, said source of fixed primary reference potential being an inherent part of the electronic discharge tube means of said amplifier stage, an impedance connected in series with said electronic discharge tube means and a source of direct current for developing a potential drop in said impedance which is dependent in part on said fixed primary reference potential, that potential drop due to said fixed primary reference potential constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said amplifier stage proportional to the potential existing across said load circuit, and means for applying the potential of said impedance to the grid of said electronic discharge tube in such sense as to tend to maintain constant potential across said load circuit.

5. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a control transducer having several electrodes including a control electrode for controlling an electrical quantity existing between a pair of other electrodes, said pair of electrodes being interposed in series between said source and said load, an electronic amplifier stage including discharge tube means having at least a grid, cathode and anode, said discharge tube means generating a fixed inherent potential, an impedance connected in series with said stage and a source of direct current for developing a potential drop in said impedance which is dependent in part on said fixed inherent potential, that portion of said potential drop due to said fixed inherent potential constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for applying the potential across said impedance to the control electrode of said control transducer is such sense as to tend to maintain constant potential across said load circuit.

6. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, an electronic discharge tube having at least a grid, cathode and anode, said cathode and anode being interposed in series between said source and said load, the anode being more positive than the cathode, an electronic



amplifier stage including discharge tube means having at least a grid, cathode and anode, a source of fixed primary reference potential, said source of fixed primary reference potential being an inherent part of the electronic discharge tube means of said amplifier stage, an impedance connected in series with said discharge tube means and a source of direct current for developing a potential drop in said impedance which is dependent in part on said fixed primary reference potential, that portion of said potential drop due to said fixed primary reference potential constituting the reference potential of said power supply, a triode discharge tube having anode, cathode and control grid, a circuit interconnecting the anode of said triode and said last-named source of direct current, the cathode of said triode and said discharge tube means being connected together and the control grid of said triode being connected to said cathodes whereby changes in the temperature of the cathode of said discharge tube means which tend to vary said fixed primary reference potential are compensated by equal but opposite variations due to similar temperature changes in said triode, voltage-dividing resistor means for applying a potential to said amplifier stage proportional to the potential existing across said load circuit, and means for applying the potential of said impedance to the grid of said electronic discharge tube in such sense as to tend to maintain constant potential across said load circuit.

7. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a control transducer having several electrodes including a control electrode for controlling an electrical quantity existing between a pair of other electrodes, said pair of other electrodes being interposed in series between said source and said load circuit, a transistor amplifier stage including a transistor having at least three electrodes, said transistor generating a fixed inherent collector cutoff current, an impedance connected in series with said stage and a source of direct current for developing a potential drop in said impedance which is dependent in part on said collector cutoff current, that portion of said potential drop due to said fixed inherent collector cutoff current constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for applying a potential in accordance with the potential across said impedance to the control electrode of said control transducer in such sense as to tend to maintain constant potential across said load circuit.

8. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, an electronic discharge tube having at least a grid, cathode and anode, said cathode and anode being interposed in series between said source and said load, the anode being more positive than the cathode, a transistor amplifier stage including a transistor having at least three electrodes, said transistor generating a fixed inherent collector cutoff current, an impedance connected in series with said stage and a source of direct current for developing a potential drop in said impedance which is dependent in part on said collector cutoff current, that portion of said potential drop due to said fixed inherent collector cutoff current constituting the reference potential of said power supply, voltage-dividing resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for applying a potential in accordance with the potential across said impedance to the grid of said electronic discharge tube in such sense as to tend to maintain constant potential across said load circuit.

9. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a triode discharge tube having grid, cathode and anode electrodes, said anode being connected to the positive terminal of said source and said cathode being connected to said load circuit to interpose the anode-cathode circuit of said triode in series with said source and said load circuit, a transistor amplifier stage including a transistor having emitter, collector and base electrodes, said transistor generating a fixed inherent collector cutoff current having a specific value for a selected collector bias potential when the emitter current is zero, a resistor connected between the collector of said transistor and a source of direct current for developing a potential drop therein which is dependent

in part on said collector cutoff current, that portion of said potential drop due to said collector cutoff current constituting the reference potential of said power supply, a resistive voltage divider having terminals connected across the input terminals of said load circuit, a connection from the slider of said voltage divider to the base electrode of said transistor for applying a potential thereto proportional to the potential applied to said load circuit, and means for applying a potential representing the potential drop across said resistor to the grid of said triode discharge tube in such sense as to modify its anode-cathode current in such direction and amount as to tend to neutralize changes in load circuit potential due either to changes in load or to changes in the potential of said source of direct-current potential.

10. A voltage-regulated power supply in accordance with claim 9 in which said transistor is of the n-p-n type having a common emitter circuit, in which said source of direct current is the positive input terminal of said load circuit and in which said last-named means is a conductive connection from said collector electrode to the grid of said triode.

11. A voltage-regulated power supply in accordance with claim 9 in which said transistor is of the p-n-p type having in a common emitter circuit, in which said source of direct current is the negative input terminal of said load circuit and in which said last-named means is a transistor amplifier containing an odd number of stages.

12. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, a transistor having collector emitter and base electrodes, two of said electrodes being interposed in series between said source and said load and the third of said electrodes serving as a control electrode to control the passage of currrent between the first two electrodes, an electrical amplifying device having at least one stage generating a fixed inherent electrical quantity, an impedance connected in series with said stage and a source of direct current for developing a potential drop in said impedance which is dependent in part on inherent electrical quantity, the portion of said potential drop due to said fixed inherent electrical quantity constituting the reference potential of said power supply, voltage-dividing



resistor means for applying a potential to said stage proportional to the potential existing across said load circuit, and means for applying a potential representing the potential across said impedance to the control electrode of said transistor in such polarity as to control the transistor current in such sense and magnitude as substantially to neutralize changes in potential across said load whether due to changes of load or change of potential of said source of direct-current potential.

13. A voltage-regulated power supply comprising, a source of direct-current potential, a load circuit connected to said source, an n-p-n series transistor having collector, emitter and base electrodes, said collector electrode being connected to the positive terminal of said source of direct-current potential and said emitter electrode being connected to said load interposing the transistor in series between source and load, an amplifying n-p-n transistor having emitter, collector and base electrodes, said amplifying transistor generating a fixed inherent collector cutoff current having a specific value for a selected collector bias potential, a resistor connected between the collector of said amplifying transistor and the positive terminal of said source of direct-current potential for developing a potential drop therein which is dependent in part on said fixed inherent collector cutoff current, that portion of said potential drop due to said collector cutoff current constituting the reference potential of said power supply, the emitter terminal of said amplifying transistor being connected to the negative terminal of said source of direct-current potential, a resistive voltage divider connected across the input terminals of said load circuit, a connection from a silder adjustably positioned on said voltage divider to the base electrode of said transistor for applying a potential proportional to that applied to said load circuit, and means for applying a potential representing the potential drop across said resistor to the base electrode of said series transistor, the applied potential being in such sense as to control the current of said series transistor to neutralize changes in load circuit potential.

No references cited.