

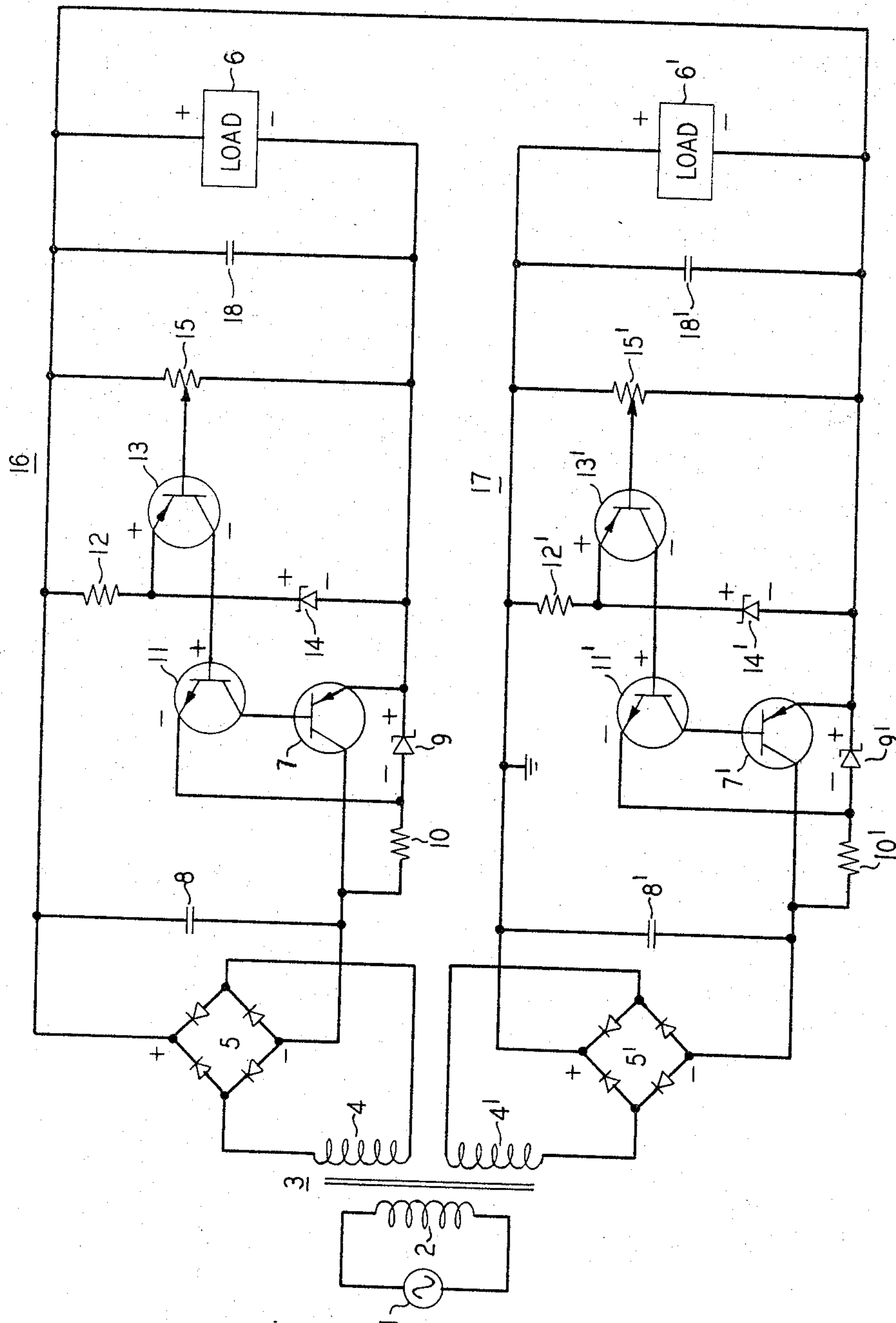
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STABILIZED TRANSISTOR REGULATOR

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STABILIZED TRANSISTOR REGULATOR

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ABSTRACT OF THE DISCLOSURE

A negative line regulator wherein a p-n-p transistor connected with its emitter electrode facing the load is employed as the variable impedance regulating element. Absolute stability against input source variations is provided by serially connecting a zener diode with the base-emitter path of the regulating transistor and the collector-emitter path of the amplifier transistor.

This invention relates to voltage regulator circuits and more particularly to transistor voltage regulator circuits with a high degree of stability.

In the more common regulator circuits, the emitter-collector path of a regulating transistor, which acts as a variable impedance, is connected between the input source of unregulated potential and the load. Load voltage variations are detected and compared with a reference voltage by an error-detector stage, the output of which is connected through a stage of amplification to control the bias of the base emitter path of the regulating transistor. The impedance of the collector-emitter path of the regulating transistor is thus controlled in accordance with load voltage variations.

Because of its high power capabilities and commercial availability, a p-n-p transistor is generally used as the regulating transistor. When the emitter-collector path of the p-n-p transistor is connected between the positive terminal of the source and the positive terminal of the load in positive line regulator fashion, degeneration due to input voltage variations generally presents no problem. When the emitter-collector path of the p-n-p regulating transistor is connected between the negative terminal of the source and the negative terminal of the load to form a negative line regulator, however, input voltage variations interfere with the operation of the amplifier and thereby distort the error or load voltage variation signal and interfere with the regulating property of the circuit. To eliminate this degeneration, the circuits of the prior art have often substituted n-p-n transistors for the p-n-p regulating transistors. Since n-p-n transistors with higher power capabilities are not readily available commercially, however, this method is not entirely satisfactory.

Notwithstanding the degeneration problem, both positive and negative line regulators have suffered transistor damage and failure due to high transient voltages in excess of maximum inverse voltage ratings of the regulator transistors. To protect against such transients, the regulators of the prior art have generally chosen transistors with maximum inverse emitter-base and collector-emitter voltage ratings in excess of the largest transient voltages expected. Such components, however, tend to be expensive and considerably increase the circuit cost.

It is therefore an object of this invention to provide a voltage regulator that is insensitive to input voltage variations and uses a p-n-p transistor as the regulating element.

It is a further object of the invention to provide a voltage regulator wherein transistors with relatively low inverse voltage ratings are inexpensively protected against large transient voltages.

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In accordance with a feature of the invention, a zener diode is connected between the emitter electrode of the transistor of the amplifier stage and the emitter electrode of the p-n-p regulating transistor to stabilize the amplifier and hence the regulating transistor, against variations of the input source. The zener diode also protects the emitter-base and collector-emitter paths of the regulating and amplifying transistors, respectively, against high transient voltages. In addition, the zener diode, in combination with the constant reference zener diode voltage of the error detecting stage, also protects the base-emitter and emitter-collector paths of the amplifying and error detecting transistors, respectively, against high voltage transients.

Other objects and features of the present invention will become apparent upon consideration of the following detailed description when taken in connection with the accompanying drawing in which the single figure is a schematic diagram of an embodiment of the invention.

As can be seen from the drawing, two negative line regulators are provided and, since the regulators are identical, the components of each regulator are represented by the same reference numbers with primes (') added to the reference numbers of the lower regulator. Except where indicated otherwise, an unprimed numerical designation refers to both regulators. In each of the regulators the following connections are made: An input alternating-current source 1 is connected to the primary winding 2 of transformer 3. The secondary winding 4 of transformer 3 is connected to the input terminals of full-wave bridge rectifier 5, while the positive and negative output terminals of the bridge rectifier are serially connected with the load 6 and the emitter-collector path of p-n-p regulating transistor 7. Filter capacitor 8 is also connected across the output terminals of the bridge rectifier. Zener diode 9 is serially connected in the zener direction with loading resistor 10 from the emitter electrode to the collector electrode of transistor 7. The collector-emitter path of n-p-n transistor 11 is serially connected from the base electrode of transistor 7 to the common terminal of zener diode 9 and resistor 10. Resistor 12 is serially connected with the emitter-collector path of p-n-p error detecting transistor 13 from the positive terminal of bridge rectifier 5 to the base electrode of transistor 11. Zener diode 14 is connected in the zener direction from the emitter electrode of transistor 13 to the emitter electrode of regulating transistor 7. The end terminals of potentiometer 15 are connected across the load 6 while the wiper arm of potentiometer 15 is connected to the base electrode of transistor 13. An output filter capacitor 18 is connected across the load 6.

The positive terminal of the load 6 of the upper regulator 16 is connected to the negative terminal of the load 6' of the lower regulator 17. The common positive bridge input terminal, and the positive terminal of the load 6', of lower regulator 17 are grounded. Two negative line regulators, each of which supply a separate load, are shown in the drawing to illustrate an application wherein high transient voltages might be expected. As discussed hereinafter, one such application might be found in traveling wave tube circuits where the grid of the tube or the load 6 of regulator 16 is at one voltage while the second grid of the tube or the load 6' of regulator 17 is at a second, lower voltage with respect to the cathode of the tube or a common point, which may be grounded.

The present invention can best be understood by briefly discussing the regulator circuits of the prior art. Because p-n-p transistors with high power capabilities are readily available commercially, they are usually used as the variable impedance elements in series regulators, i.e., regulators where the regulating element is serially connected between the source and the load. Series regulators are

in turn broken down into two classes, namely, positive and negative line regulators, i.e., regulators wherein the regulating transistor is connected either between the positive input source terminal and the positive terminal of the load or between the negative load terminal and the negative input source terminal.

For most practical applications, each of the positive and negative line regulators usually employ a minimum of three stages, namely, an error detecting stage which detects variations of the load voltage from a reference voltage, an amplifying stage which amplifies the error signal received from the error detecting stage, and the series regulating stage, the impedance of which is varied under control of the error detecting stage. The amplifying stage usually has a large loading resistor connected to it which, in the usual case of the positive line regulator, is also connected to the positive input terminal to obtain the proper biasing polarity to the amplifier stage. Since the base electrode of the regulating p-n-p transistor is also connected to the amplifier and the emitter electrode is also connected to the positive input terminal, the amplifier loading resistor is thus normally shunted across the base-emitter path of the regulating transistor. Recalling that the emitter-base path of the regulating p-n-p transistor is essentially a diode with a relatively low forward conductivity impedance, it is readily seen that this low impedance will effectively bypass any input voltage variations that appear across the loading resistor. Since the input variations are thus bypassed, the effect of the input variations on the amplifier is negligible, and the circuit remains stable in the event of such variations. It should perhaps be noted at this point that any instability due to input variations would have the effect of distorting the amplified error signal and thus impair the regulating properties of the circuit.

In a negative line regulator, however, the base-collector path of a p-n-p regulating transistor faces the input source and, since this path exhibits a relatively high impedance, input variations will appear across both the base-collector path of the regulating transistor and the amplifier load resistor which is connected across the base-collector path. The input variations on the amplifier loading resistor introduce instability in the amplifier and generally distort the error signal to the point where only poor regulation can be obtained.

To eliminate this problem, many prior art circuits use n-p-n transistors as the negative line regulating element, in which event the base-emitter path of the regulating transistor faces the input source and, in the manner discussed in connection with the positive line regulators using p-n-p transistors, the problem is alleviated. Since n-p-n transistors with sufficient power capabilities have only limited commercial availability, however, this variation is usually not satisfactory for most regulator applications, i.e., applications where other than a relatively low power is required.

With this background then, the present circuit is a negative line regulator employing a p-n-p transistor 7, the base-collector path of which "faces" the input source, as the regulating element. Error detecting transistor 13 compares a portion of the load voltage with the constant reference voltage appearing across zener diode 14, which is continuously conducting in the inverse or zener direction, and delivers an error signal to the amplifier stage n-p-n transistor 11. The amplified signal is, in turn, fed to the base-emitter path of p-n-p regulating transistor 7, the impedance of which is thus varied in accordance with load voltage variations. Resistor 10, which connects the emitter electrode of transistor 11 to the negative input terminal, serves as the loading resistor for the amplifier stage.

The manner in which stabilization against input voltage variations is achieved in the present invention is easily seen by examining the effect of input voltage variations on the base-emitter path of regulating transistor 7. The

emitter electrode of transistor 7 is connected to the negative terminal of the load 6. Since the voltage appearing across the load 6 is regulated by transistor 7 under control of the feedback loop comprising error-detector 13 and amplifier 11, the load voltage, and hence the voltage appearing at the emitter electrode of transistor 7, is regulated and hence constant with respect to input voltage variations. The voltage applied to the base electrode of transistor 7 is the sum of the amplified error voltage appearing across the collector-emitter electrodes of amplifier transistor 11 and the constant voltage appearing across zener diode 9. The voltage across the collector-emitter path of transistor 11 is in turn proportional to the base-emitter voltage of transistor 11, the latter of which may be easily determined by summing the voltages in the base-emitter loop. The following loop equation is thus obtained:

$$V_{be11} = V_{z9} + V_{z14} - V_{ce13}$$

where the subscripts *b*, *c*, and *e* refer to the base, collector and emitter electrodes, respectively, the subscript *z* refers to zener voltage, and the numerals correspond to the numerical designations of the components indicated on the drawing. Since V_{z9} and V_{z14} , or the voltage across zener diodes 9 and 14, respectively, are constant, the variable component of the voltage appearing across the base-emitter path of transistor 11 is equal only to the variable voltage component appearing across the collector-emitter path of error detecting transistor 13. Moreover, as discussed heretofore, the voltage across the load 6 is regulated against input voltage variations, hence only load or error voltage variations, due to changes in load, will be reflected by the collector-emitter voltage of transistor 13. The base-emitter path, and hence the collector-emitter path, of amplifying transistor 11 is thus responsive only to error voltage variations and is nonresponsive to input voltage variations. It follows from the previous discussion, therefore, that the base-emitter path of regulating transistor 7 is responsive only to amplified error voltage variations due to changes in load and is nonresponsive to input variations. The voltage across the load 6 is, therefore, not affected by input voltage variations. Input voltage variations are absorbed by resistor 10 without interfering with the regulating properties of the circuit.

In addition to the stability advantage obtained by the present invention, transistor protection advantages are also obtained in situations where it is desired to supply two or more loads, with the loads being referenced to a common point. Such a situation would arise, for example, where it was desired to supply a first voltage of one magnitude to a grid of a traveling wave tube and a second voltage, of a higher or lower magnitude with respect to the first voltage, to a second grid of the traveling wave tube, with both voltages being referenced to a common point, such as the cathode of the tube. As illustrated by the drawing in such an application, the negative terminal of the load 6 of regulator 16 would be connected to the first grid, the common positive terminal of regulator 16 and the negative terminal of load 6' of regulator 17 would be connected to the second grid, and the cathode of the tube would be grounded as is the positive terminal of regulator 17. Such a configuration could also be used, of course, when it is desired to supply any two loads, particularly where one is "off" ground.

With such configurations care must be taken to prevent transistor damage due to large transients, the magnitudes of which are frequently equal to, or greater than, the potential from the most negative point in the circuit to ground. Transient voltages of these magnitudes, which are generally in excess of the more usual maximum emitter-collector and emitter-base inverse voltage ratings of transistors, may destroy one or more of the regulator transistors. This is especially true in the case of high voltage supplies employing the aforementioned combination of regulators wherein the starting transient voltages are quite large. The prior art has long recognized this transient

problem but, since no apparent alternatives were available, merely chose relatively expensive transistors with inverse voltage ratings sufficient to withstand the largest transient voltages anticipated. The present circuit, in addition to the stability and degeneration prevention features noted heretofore, protects the regulator circuit from large transient voltages. Additionally, the network comprising zener diode 9 and resistor 10 will bypass transient current surges around the emitter-collector path of transistor 7. As noted, zener diode 9 limits the inverse emitter-base voltage of transistor 7 and the emitter-collector voltage of transistor 11. This limiting and protection action can be easily seen by tracing the protection path from the positive terminal of diode 9, through the emitter-base path of transistor 7, through the collector-emitter path of transistor 11, and back to the negative terminal of zener diode 9. The voltage across the emitter-base path of transistor 7 and the collector-emitter path of transistor 11 is thus limited to the zener voltage of diode 9. Transistor 11, therefore, may be a relatively inexpensive n-p-n transistor instead of an expensive transistor capable of withstanding high inverse voltages as heretofore thought to be necessary. This is especially important in, although clearly not restricted to, a situation where two regulators are employed and large transients might be expected, as in the configurations illustrated in the drawing. Moreover, the base-emitter path of transistor 11 and the emitter-collector path of transistor 13 are also protected by the composite limiting action of zener diodes 9 and 14. This is easily seen by tracing the path from the emitter-collector path of transistor 13, through the base-emitter path of transistor 11, through zener diodes 9 and 14, and back to the emitter electrode of transistor 13. The sum of the voltages appearing across the base-emitter path of transistor 11 and the emitter-collector path of transistor 13 is thus limited to the sum of the zener voltages of diodes 9 and 14. If desired, a zener diode, poled in the direction of zener diode 9, may be connected across the emitter-collector path of regulating transistor 7 to protect this transistor. As discussed heretofore, transistors 11 and 13 may therefore be inexpensive transistors with relatively low maximum inverse voltage ratings rather than the expensive high inverse voltage rated transistors heretofore thought to be necessary.

In summary, therefore, a zener diode 9 connects the emitter electrode of amplifying transistor 11 to the emitter electrode of the regulating transistor 7 to prevent instability or degeneration due to input voltage variations. The stability against input voltage variations is readily seen once it is noted that since the load voltage is regulated, it will vary only with changes in load, and the voltage at the emitter electrode of regulating transistor 7 is therefore nonresponsive to input voltage variations. The voltage at the base electrode of transistor 7 is equal to the sum of the collector-emitter voltage of transistor 11 and the voltage across zener diode 9, the latter which is continuously conducting in the inverse or zener direction. The collector-emitter voltage of transistor 11 is in turn proportional to its base-emitter voltage, the latter of which may be easily determined by summing the voltages in the base-emitter loop. The voltages in this loop comprise only the voltages across diodes 9 and 14, which are continuously conducting in the inverse direction and hence have a constant voltage drop across them, and the voltage across the emitter-collector path of error detecting transistor 13. Since transistor 13 is connected to the load or regulated side of the regulating transistor 7, it is responsive only to load voltage variations and is nonresponsive to input variations. The collector-emitter voltage drop of transistor 13 is therefore nonresponsive to input variations and, since it is the only variable voltage in the loop in which the base-emitter path of amplifying transistor 11 is connected, transistor 11 must therefore also be nonresponsive to input voltage variations. As noted here-

tofore, transistor 11 in turn directly drives the base-emitter path of regulating transistor 7 which must therefore also be nonresponsive to input voltage variations.

In addition to the stability and degeneration prevention features, zener diode 9 also limits the maximum inverse transient voltages appearing across the emitter-base path of transistor 7 and the collector-emitter path of transistor 11. The composite effect of zener diodes 9 and 14 is to limit the maximum inverse transient voltages appearing across the base-emitter path of transistor 11 and the collector-emitter path of transistor 14. The regulator circuits are thus readily applicable to situations wherein it is desired to provide output voltages at different magnitudes with respect to a common point.

The above-described arrangement is illustrative of the principles of the invention. Other embodiments may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A regulator comprising a source of input voltage, a load, regulating and amplifying transistors, each having base, collector, and emitter electrodes, means serially connecting said source of input voltage, said load, and the emitter-collector path of said regulating transistor, the emitter electrode of said regulating transistor being connected to said load, the collector electrode of said regulating transistor being connected to said source, detecting means responsive to variations of said load voltage from a reference voltage, means connecting the base-emitter path of said amplifying transistor to receive current variations from said detecting means, means connecting the collector-emitter path of said amplifying transistor to supply current to the emitter-base path of said regulating transistor, and biasing stabilization means connected to the emitter electrodes of said regulating and amplifying transistors to maintain a substantially constant voltage independent of input source variations between the emitter electrodes of said regulating and amplifying transistors, whereby the regulating function of the emitter-collector path of said regulating transistor is made insensitive to amplitude variations of said input source.

2. A regulator comprising a source of input voltage, a load, regulating and amplifying transistors, each having base, collector, and emitter electrodes, means serially connecting said source of input voltage, said load, and the emitter-collector path of said regulating transistor, the emitter electrode of said regulating transistor being connected to said load, the collector electrode of said regulating transistor being connected to said source, detecting means responsive to variations of said load voltage from a reference voltage, means connecting the base-emitter path of said amplifying transistor to receive current variations from said detecting means, and normally conductive biasing stabilization means serially connecting the emitter-collector path of said amplifying transistor and the base-emitter path of said regulating transistor to supply current from said amplifying transistor to said regulating transistor and to stabilize the voltage appearing across said emitter-collector and said base-emitter paths of said amplifying and regulating transistors at a predetermined magnitude whereby said regulating and said amplifying transistors are protected from high inverse voltage transients above said predetermined magnitude.

3. A regulator comprising a source of input voltage, a load, regulating and amplifying transistors, each having base, collector, and emitter electrodes, means serially connecting said source of input voltage, said load, and the emitter-collector path of said regulating transistor, the emitter electrode of said regulating transistor being connected to said load, the collector electrode of said regulating transistor being connected to said source, detecting means responsive to variations of said load voltage from a reference voltage, means connecting the base-emitter

path of said amplifying transistor to receive current variations from said detecting means, means connecting the collector-emitter path of said amplifying transistor to supply current to the emitter-base path of said regulating transistor, a zener diode, said zener diode being connected between the emitter electrodes of said regulating and amplifying transistors so as to be continuously conducting in the inverse direction to maintain a substantially constant potential difference between the emitter electrodes of said regulating and amplifying transistors whereby the regulating function of the emitter-collector path of said regulating transistor is insensitive to amplitude variations of said input source.

4. A regulator comprising a source of input voltage, a load, regulating and amplifying transistors, each having base, collector, and emitter electrodes, means serially connecting said source of input voltage, said load, and the emitter-collector path of said regulating transistor, the emitter electrode of said regulating transistor being connected to said load, the collector electrode of said regulating transistor being connected to said source, detecting means responsive to variations of said load voltage from a reference voltage, means connecting the base-emitter path of said amplifying transistor to receive current variations from said detecting means, means connecting the collector-emitter path of said amplifying transistor to supply current to the emitter-base path of said regulating transistor, an amplifier loading resistor connected between the emitter electrode of said amplifying transistor and the terminal of said input source to which the collector electrode of said regulating transistor is connected, and a zener diode connected in the zener direction from the emitter electrode of said regulating transistor to the emitter electrode of said amplifying transistor to maintain a substantially constant potential insensitive to input voltage variations across said loading resistor between the emitter electrodes of said regulating and amplifying transistors, whereby input source variations all appear across said loading resistor without interfering with the regulating properties of the regulator.

5. A negative line regulator comprising a source of input potential, a load, a regulating transistor, an amplifying transistor, and an error detecting transistor, each of said transistors having base, collector, and emitter electrodes, means serially connecting said source of input potential, said load, and the emitter-collector path of said regulating transistor, means connecting the base-emitter path of said error detecting transistor to a constant reference voltage and at least a portion of the voltage appearing across said load to detect variations of the load voltage from the constant reference voltage, means connecting the emitter-collector path of said error detecting transistor to the base-emitter path of said amplifying transistor, an amplifying transistor, a loading resistor, a zener diode, means connecting said loading resistor from the emitter electrode of said amplifying transistor to the collector electrode of said regulating transistor, means connecting the collector electrode of said amplifying transistor to the base electrode of said regulating transistor to con-

trol said regulating transistor in accordance with load voltage variations, and means serially connecting said loading resistor and said zener diode across the emitter-collector path of said regulating transistor such that said zener diode is continuously conductive in the inverse direction to stabilize the potential appearing at the emitter electrodes of said amplifying and regulating transistors and to protect said error detecting, amplifying, and regulating transistors from high inverse transient voltages.

6. A power supply comprising first and second negative line regulators, each of said regulators having an individual source of input potential, an individual load, and individual regulating and amplifying transistors, each of said transistors having base, collector, and emitter electrodes, means in each of said first and second regulators serially connecting said source of input potential, said load, and the emitter-collector path of said regulating transistor, the emitter electrode of said regulating transistor being connected to said load, the collector electrode of said transistor being connected to said source, detecting means in each of said first and second regulators responsive to variations of load voltage from a reference voltage, means in each of said first and second regulators connecting the base-emitter path of said amplifying transistor to said detecting means to receive current variations from said detecting means, an amplifier loading resistor in each of said first and second regulators connected between the emitter electrode of said amplifying transistor and the collector electrode of said regulating transistor in each of said first and second regulators, means connecting one terminal of the load of said first regulator to one terminal of the load of said second regulator, means in each of said first and second regulators connecting the collector-emitter path of said amplifying transistor to supply current to the base-emitter path of said regulating transistor, and a zener diode connected in the zener direction from the emitter electrode of said regulating transistor to the emitter electrode of said amplifying transistor in each of said first and second regulators to maintain a substantially constant voltage insensitive to input or transient voltage variations across said loading resistor between the emitter electrodes of said regulating transistors, whereby the transistors in each of said first and second regulators are also protected from transients in excess of the sum of the voltages appearing across said loads in said first and second regulators.

References Cited

UNITED STATES PATENTS

50	2,693,568	11/1954	Chase	321—18
	2,751,549	6/1956	Chase	321—18
	2,904,742	9/1959	Chase	323—9 X
	2,917,700	12/1959	Chase	323—22
55	3,106,674	10/1963	Hamilton	321—18 X
	3,185,856	5/1965	Harrison	307—55

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