Dec. 31, 1968 J. R. GATELY 3,419,789

HIGH PRECISION DC VOLTAGE REGULATOR

Filed April 19, 1966

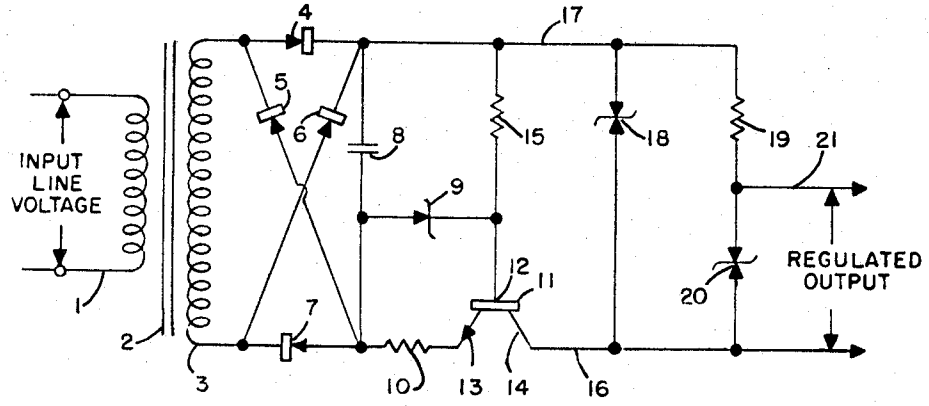


FIG 1. PRIOR ART

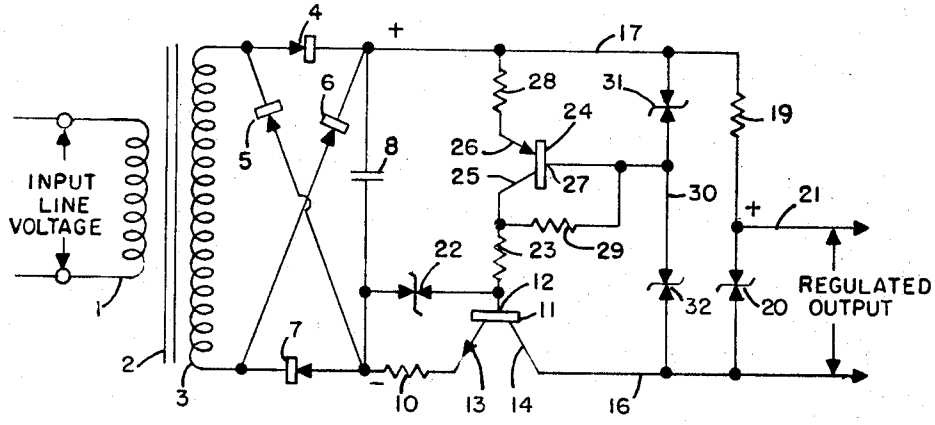


FIG. 2

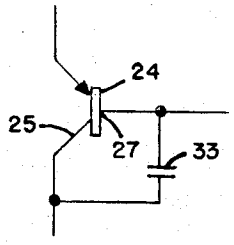


FIG. 3

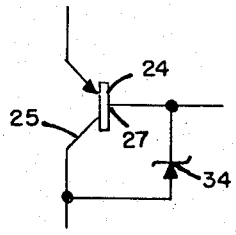


FIG. 4

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HIGH PRECISION DC VOLTAGE REGULATOR

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ABSTRACT OF THE DISCLOSURE

A DC voltage regulator with two constant current Zener diode controlled transistor circuits. Each circuit controls the current to the other circuit in a reciprocal fashion. Self starting is provided.

The present invention concerns voltage regulating circuits and, in particular, a high precision DC voltage regulator suitable for use as a reference voltage source and the like.

Zener diodes are widely used as voltage regulating devices utilizing their well known characteristic of avalanche breakdown wherein at some predetermined reverse bias voltage such diodes conduct and exhibit a relatively low impedance. If the impedance of the conduction region were zero, it would have no slope and the voltage across the diode would be constant regardless of the current passed. However, Zener diodes have a finite conduction resistance and hence, to utilize them for precise voltage references, the current is kept as constant as possible. Another characteristic of Zener diodes which make them less than ideal is their voltage/temperature coefficient. Temperature compensated Zener diodes have been developed comprising two back-to-back connected Zener diodes wherein the negative temperature coefficient of the forward conducting or temperature compensating diode off-sets the positive temperature coefficient of the reverse or Zener connected diode and in which these oppositely directed temperature effects are matched at a predetermined or rated current. These temperature compensated diodes require not only a constant current for constant voltage but a particular constant current for minimum temperature coefficient as well. The present invention is concerned with improvements in temperature compensated Zener regulated voltage circuits.

Accordingly, one object of the present invention is to provide improved voltage regulating characteristics in temperature compensated Zener diode circuits.

Another object is to provide methods of and means for utilizing temperature compensated Zener diodes in a circuit having improved voltage regulating characteristics.

These and other objects of the present invention will be apparent from the detailed description of the invention given in connection with the various figures of the drawing.

In the drawing:

FIGURE 1 is a circuit diagram of a prior art concept of a Zener diode regulator.

FIGURE 2 is a circuit diagram of a Zener diode regulator in accordance with the present invention.

FIGURE 3 is an alternate starting circuit suitable for use in the circuit of FIGURE 2 shown only as a detail.

FIGURE 4 is another alternate starting circuit suitable for use in the circuit of FIGURE 2 shown only as a detail.

FIGURE 1 showing a prior art circuit diagram shows a regulating circuit utilizing a line voltage input transformer including a primary **1** for connecting to a source of alternating current line voltage, a core **2**, and a secondary **3** providing suitable voltage to a rectifier network including rectifiers **4**, **5**, **6** and **7** which in turn charge capacitor **8** to a suitable DC voltage for use in powering the

balance of the circuit. A first Zener diode **18** to be fed with a constant current is connected between lines **16** and **17**. Constant current to this Zener is provided by the circuit including transistor **11** and second Zener diode **9**. Transistor **11** is operated in a constant current mode since current to its emitter **13** is controlled by Zener **9** and emitter resistor **10**. The current to emitter **13** is equal to the voltage drop across Zener **9** minus the base to emitter drop of transistor **11** divided by resistance of resistor **10**. Current to Zener **9** and base **12** is supplied through resistor **15**. Under these conditions the current from collector **14** to Zener **18** will be controlled and equal to the above described substantially constant emitter current less current to base **12**. The voltage across Zener **18** thus regulated by its own avalanche characteristic and the substantially constant current from transistor **11** is applied through fixed resistor **19** to a third Zener diode **20** so that the voltage across Zener **20** is thus doubly regulated and provides the regulated output across lines **16** and **21**. Since the voltages across Zener **18** and **20** are substantially constant, the current to Zener **20** is constant and equal to the difference between the voltages across these Zeners divided by the resistance of resistor **19**.

While this prior art circuit provides a well regulated output voltage, it has some limitations. The voltage applied to resistor **15** and Zener **9** varies as the power line voltage varies and hence the current to Zener **9** varies and this variation results in a slight change in the voltage regulated by Zener **9**. This in turn causes a slight variation in the current from transistor **11** to Zener **18** and there is a slight variation in the regulalted voltage across Zener **18**. This again causes a slight variation in current to the final Zener **20** and results in less than perfect regulation of the regulated output voltage across lines **16** and **21**. This whole chain of events is particularly enhanced by the use of temperature compensated Zeners **18** and **20** which have a higher regulating impedance than non-compensated Zeners. Also Zener **9** is not temperature compensated in order to provide a lower regulating impedance for its function. So we have in this prior art circuit some effect of line voltage and temperature on the regulated output voltage.

The circuit of FIGURE 2 provides a method of and means overcoming the limitations of the prior art circuit as described above. Since certain portions of the circuit of FIGURE 2 function in a similar manner to corresponding portions of FIGURE 1, the corresponding circuit elements in the two circuits are designated by the same numbers. In FIGURE 2 an additional constant current transistor circuit is provided utilizing transistor **24** which regulates the current to Zener **22**. The circuit of transistor **24** includes Zener **31** connected between base **27** and line **17**, emitter current determining resistor **28** connected between line **17** and emitter **26** and resistor **23** connected between collector **25** and the junction between one end of Zener **22** and base **12** of transistor **11**. The current supplied to Zener **22** is controlled in a similar manner to the controlled current functioning of transistor **11** as described above. The current to emitter **26** is equal to the Zener voltage of Zener **31** less the base to emitter voltage of transistor **24** divided by the resistance of resistor **28**. This controlled current is fed to Zener **22**. Resistor **23** is provided merely to lessen the voltage drop across transistor **24**. The first regulation between lines **16** and **17** is provided by the two temperature compensated Zeners **31** and **32** connected in series. The second stage of regulation is supplied by current determining resistor **19** and Zener **20** to provide the final highly regulated voltage across lines **16** and **21**.

With the constant current supply to Zener **22**, line voltage variations effects on the current to Zener **22** are

greatly reduced providing an improved constancy of regulated voltage across Zener **22** and with this constant current the higher impedance but temperature compensated Zener may be used as Zener **22**. In this way improved regulating characteristics in the presence of line voltage variations is obtained and at the same time improved temperature characteristics are provided. The circuit also provides the critical operating current required for minimum temperature coefficient of the temperature compensated Zener **22**.

It will be seen that Zener **31** and transistor **24** provide controlled current to Zener **22** while Zener **22** and transistor **11** supply controlled current in turn to Zener **31**. This interdependent circuit may not start unless a starting current is provided to Zener **22**. This may be accomplished by connecting a resistor **29** between base **27** and collector **25**. This resistor should be of a high enough resistance value to draw a current which is small compared with the normal current controlled by transistor **24** in order not to degrade its control.

Restating the mode of operation of the circuit of FIGURE 2, unregulated DC voltage is first produced across capacitor **8**, as described above in connection with FIGURE 1. When line voltage is first applied, the larger part of the DC voltage across capacitor **8** appears across resistor **29**, since it is of high enough resistance value to draw a current small compared with the normal current controlled by transistor **24**. This high voltage between base **27** and collector **25** starts conduction in transistor **24** and the current in Zener diode **31** builds up until transistor **24** is regulating and passing rated current to transistor **11** and hence to Zener diode **22** which in turn starts to regulate the current of transistor **11**. At this point transistor **24** is regulating the current in Zener **22** and transistor **11** is regulating the current in Zener diodes **31** and **32**. This reciprocal action greatly reduces the effects of line voltage on the regulated voltage across Zener diodes **31** and **32** and permits the use of temperature compensated Zener diodes with improved regulation and temperature coefficient. The regulated voltage across Zener diodes **31** and **32** is applied through high stability resistor **19** to the final voltage regulating Zener diode **20** across which the regulated output voltage is taken.

FIGURES 3 and 4 show alternate starting circuits. Capacitor **33** connected between base **27** and collector **25** will supply a starting surge if the line voltage is suddenly applied to the circuit and will carry no degrading current under steady state operating conditions. Another starting circuit utilizes Zener diode **34** connected between base **27** and collector **25**. The Zener breakdown voltage of Zener **34** should be greater than the normal operating drop across transistor **24** but less than the turn-on surge voltage. In this way the circuit will be started but the Zener **34** will draw no degrading current during steady state operation of the regulator circuit.

While one form of the present invention has been shown and described together with some minor modifications, many modifications will be apparent to those skilled in the art and within the spirit and scope of the invention as set forth particularly in the appended claims.

What is claimed is:

1. In a voltage regulating circuit, the combination of;

a source of voltage to be regulated (**8**) including a first side (−) and a second side (+);

first and second transistors each including a base, an emitter and a collector wherein said transistors are complimentary types;

a first Zener diode connected between said first side of said voltage source and the base (**12**) of said first transistor (**11**) for establishing a first predetermined voltage therebetween;

a first resistor connected between said first side of said voltage source and the emitter (**13**) of said first transistor for determining the emitter current in accordance with said first predetermined voltage;

a second Zener diode connected between said second side of said voltage source and the base (**27**) of said second transistor for establishing a second predetermined voltage therebetween;

a second resistor connected between said second side of said voltage source and the emitter (**26**) of said second transistor for determining the emitter current in accordance with said second predetermined voltage;

conductive means connected between the collector (**25**) of said second transistor (**24**) and the base (**12**) of said first transistor (**11**);

a third Zener diode (**32**) connected between the collector (**14**) of said first transistor and said second Zener diode (**31**);

a series circuit comprising a resistor (**19**) and a fourth Zener diode (**20**) shunted across the said second and third Zener diodes (**31** and **32**);

whereby said first transistor (**11**) and first Zener diode (**22**) provide regulated current to said second and third Zener diodes in series and said second transistor (**24**) and second Zener diode (**31**) provide regulated current to said first Zener diode (**22**) and said fourth Zener diode (**20**) provides a regulated output voltage thereacross.

2. A voltage regulating circuit as set forth in claim **1** and including;

a resistor connected across said second transistor for providing a starting current in the said second Zener diode (**31**).

3. A voltage regulating circuit as set forth in claim **1** and including;

a capacitor connected between the base (**27**) and collector (**25**) of said second transistor for providing a starting current in the said second Zener diode (**31**).

4. A voltage regulating circuit as set forth in claim **1** and including;

a fifth Zener diode (**34**) connected between the base (**27**) and collector (**25**) of said second transistor for providing a starting current in the said second Zener diode (**31**).

5. A voltage regulating circuit as set forth in claim **1** and wherein;

said first, second, third and fourth Zener diodes are back-to-back connected temperature compensated Zener diodes.

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U.S. Cl. X.R.

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