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[54] **SERIES VOLTAGE REGULATOR WHEREIN AN FET SUPPLIES A CONSTANT CURRENT REFERENCE VOLTAGE TO A DIFFERENTIAL COMPARATOR**

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[56] **References Cited**

UNITED STATES PATENTS

3,509,448	4/1970	Bland	323/22 T X
3,571,604	3/1971	La Porta et al	323/22 T X
3,577,063	5/1971	Hurd III	323/16
3,441,833	4/1969	Bahrs et al	323/9

OTHER PUBLICATIONS

Electronics World – Pages 38–41, 60; Dec. 1968 "-Troubleshooting FET Circuits" By Allen & Haskett.

Electronic Design – Vol. 16, No. 2; Jan. 18, 1968 Page No. 128.

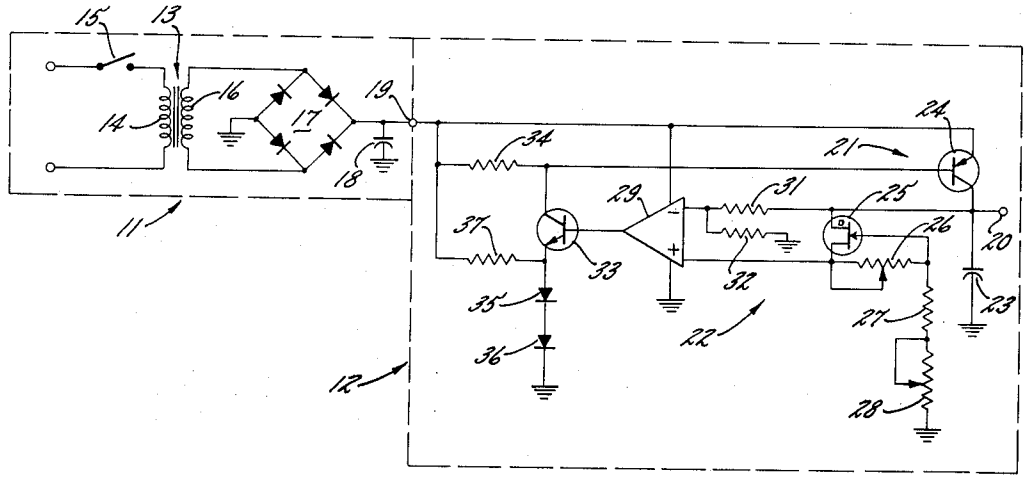
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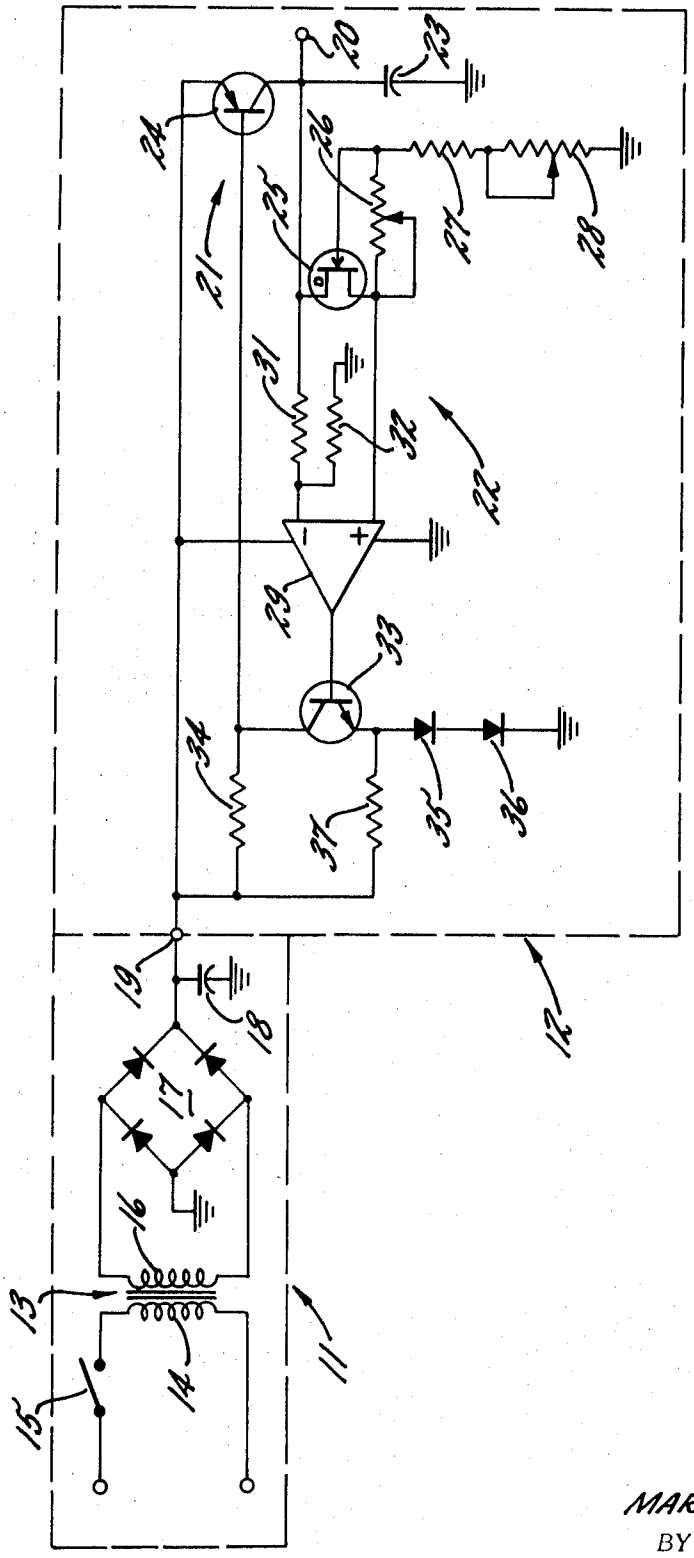
Attorney—C. Frederick Leydig, Richard L. Voit and Edward W. Osann et al.

[57] **ABSTRACT**

A series-type dc. voltage regulator includes an operational amplifier as a very sensitive differential comparator for comparing the regulated output voltage against a very stable reference so as to provide an error signal for correctively adjusting the collector-emitter impedance of a series regulating transistor in response to even very small deviations of the output voltage from its set point. The reference voltage is developed internally by using a field effect transistor, biased to operate in a temperature stabilized constant current mode, to drive current through a voltage dropping resistance. The operational amplifier is powered by the dc. source with which the voltage regulator is employed and has an output offset to foreshorten the rise time of the regulated output voltage.

7 Claims, 1 Drawing Figure





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SERIES VOLTAGE REGULATOR WHEREIN AN FET SUPPLIES A CONSTANT CURRENT REFERENCE VOLTAGE TO A DIFFERENTIAL COMPARATOR

BACKGROUND OF THE INVENTION

This invention relates generally to dc. voltage regulators and, more particularly, to voltage regulators which are especially, although not exclusively, suitable for very low voltage dc. power supplies.

Dc. voltage regulators are often incorporated into dc. power supplies and are available in a wide variety of configurations. Generally stated, their principal purpose is to provide a relatively stable or closely regulated dc. output voltage in response to a relatively unstable or poorly regulated dc. input voltage. The input voltage may be supplied by any one of a number of different dc. sources, including a full wave rectifier energized by commercial ac. line power or a motor driven dc. generator. Similarly, there are a variety of different end uses for the output voltage, such as to provide a reference or calibration standard for a control system or for a measuring or testing instrument.

The more common requirements for dc. voltage regulation can usually be satisfied by selecting one o4 the well known voltage regulators. The advent of the so-called temperature stabilized Zener diode voltage regulator has enabled a high degree of voltage stability to be achieved even at relatively low dc. levels down to about 6.0–6.5 volts. If, however, even lower dc. voltages are to be stabilized by means of any of the available voltage regulators, it is necessary to include a voltage divider or the like for reducing the output voltage from the regulator to the desired lower level, which means that provision must be made for the increased power dissipation and that care must be exercised to insure that the voltage regulator retains its characteristic temperature stability.

SUMMARY OF THE INVENTION

The primary aim of this invention is to provide a dc. voltage regulator which is capable of directly stabilizing even extremely low dc. voltages without the use of a voltage divider or the like. It is often necessary, or at least desirable, to avoid the increased power dissipation inherent in the use of conventional techniques for regulating very low dc. voltages because the power dissipation creates heat which must be taken into account in designing the heat sink for the voltage regulator. Indeed, if only a very small heat sink with a limited capacity can be provided because of, say, the packaging requirements for the voltage regulator, the amount of power dissipation within the voltage regulator may be critical.

In keeping with the primary aim of the invention, one of the objects of this invention is to provide an extremely sensitive dc. voltage regulator which retains its sensitivity even when employed to regulate dc. voltages which are substantially lower than 6.0–6.5 volts. Although no attempt has been made to specifically identify the lowest regulated output voltage that may be provided by the voltage regulator here disclosed without resorting to the use of voltage dividers or the like to reduce the regulated output voltage, it is at least as low as 4.5 volts. Specifically, it has been demonstrated by actual practice that the illustrated embodiment is capable of providing an output voltage of 4.5±0.001 volts given a dc. input or source voltage of 8 ± 3 volts.

A further object of this invention is to provide a temperature stabilized voltage regulator of the foregoing type. Unlike many of the prior art voltage regulators, the temperatures stabilization or compensation for the voltage regulator of this invention is achieved straightforwardly by means of a very stable reference voltage which may be derived from the output of the voltage regulator.

Still another object of this invention is to provide a series-type voltage regulator in which the rise time for the regulated output voltage is foreshortened.

BRIEF DESCRIPTION OF THE DRAWINGS

Other objects and advantages of the present invention will become apparent when the following detailed description is read in conjunction with the attached drawing in which the sole FIGURE is a simplified schematic diagram of a regulated dc. power supply which includes a voltage regulator embodying the present invention.

DETAILED DESCRIPTION

While the invention is described in detail hereinafter with reference to a single embodiment, it is to be understood that the intent is not to limit it to that embodiment. To the contrary, the intent is to cover all modifications, alternatives and equivalents falling within the spirit and scope of the invention as defined by the appended claims.

Turning now to the drawing, it will be seen that the illustrated dc. power supply includes a dc. source **11** and a voltage regulator section **12.** It is, therefore, what is commonly referred to as a regulated dc. power supply.

As will be appreciated, the dc. source **11** is a conventional ac.-to-dc. converter, which is representative of one of the several different types of dc. sources with which the voltage regulator section **12** might be advantageously employed. As shown, the source includes an input transformer **13** which has its primary winding **14** connected by means of a manually operable switch **15** across a suitable ac. power supply, such as a commercial power means (not shown). The secondary winding **16** of the transformer is, in turn, connected across the input terminals of a diode bridge-type full wave rectifier **17,** and a smoothing capacitor **18** is connected across the rectifier output terminals. Thus, when the switch **15** is closed, the source **11** supplies a dc. voltage which has a magnitude dependent on the turns ratio of the transformer windings **14** and **16.** This voltage is substantially free of high frequency components because of the filtering afforded by the capacitor **18,** but it may exhibit some low frequency variations. For example, if commercial power is used, the demand on the power generating facility may change from time-to-time thereby causing the line voltage to vary between, say, **105– 120** volts ac. As a result, the source voltage (the voltage between a terminal **19** and a reference such as ground) will also vary and, therefore, be relatively unstable or poorly regulated.

The voltage regulator section **12** embodies the present invention to provide a relatively stable or well regulated output voltage in response to the source voltage and despite normal variations in the source voltage, output load, and operating temperature conditions. To that end, there is a series regulator circuit **21** connected

between the input and output terminals **19** and **20** of the regulator section and a temperature stabilized error detector **22** for correctively adjusting the series regulator section **21** as necessary to maintain the regulated output voltage developed across a smoothing capacitor **23** substantially constant at a desired or set point value. The capacitor **23** is connected between the regulator output terminal **20** and ground to filter out the high frequency output voltage component caused by adjustment of the series regulator section.

More particularly, the series regulator circuit **21** comprises a three terminal active element, namely a transistor **24,** which has its collector-emitter power circuit connected in series between the input and output terminals **19** and **20** of the regulator section. As will be appreciated, the impedance presented by the collector-emitter circuit of the transistor **24** is inversely related to its conductivity, ranging from a very low level on the order of one ohm or less when the transistor is in a state of saturated conduction to several thousand ohms when the transistor is in a non-conductive state.

As a general rule, with prior art Zener diode-type voltage regulators, the source voltage must exceed the rated breakdown potential for the Zener diode by 1.5–2.0 volts. In contrast, with the voltage regulator here disclosed, the voltage supplied by the dc. source **11** need exceed the set point for the regulated output voltage by no more than the voltage drop across the series regulator circuit **21** when the transistor **24** is in a state of saturated conduction. Within that general constraint, there are very few limitations. For example, while it is preferable from the standpoint of minimizing the power dissipation to have the collector-emitter impedance of the transistor **24** the only lumped impedance in the series regulator circuit **21,** additional voltage dropping resistance (not shown) may be inserted if there is any risk that the source voltage will exceed the set point for the regulated voltage by more than the rated or permissible maximum collector-emitter voltage drop for the transistor **24.** Normally, however, any such risk may be obviated simply by adjusting the source voltage, say, by appropriate selection of the turns ratio for the transformer windings **14** and **16,** so that the additional voltage dropping resistance is not required. In that event, the source voltage may fall as low as only about 0.3 volts above the set point for the regulated output voltage without adversely affecting the performance of the voltage regulator.

In keeping with the present invention, the error detector **22** is extremely sensitive to even very slight deviations of the regulated output voltage from its set point regardless of whether such deviations are caused by changes in the source voltage, operating temperation, or output load. Moreover, the error detector has a positive response to the initial appearance of the source voltage which foreshortens the output voltage rise time.

To enable the error detector **22** to sense deviations of the regulated output voltage from its set point, a very stable reference voltage, which is substantially insensitive to the normal variations in the operating conditions of the power supply, is provided. In accordance with one of the more detailed aspects of this invention, the reference voltage is developed within the error detector itself by routing a substantially constant current flow from the output of the regulator through a resistance connected in parallel therewith. Thus, in the illustrated embodiment there is a field effect transistor **25** which has its drain connected directly to the output terminal **20** and its source returned to ground through a resistance string **26–28.** The field effect transistor **25** is biased for operation in a temperature stabilized constant current mode. This may suitably be accomplished by connecting the resistor **26** across the gate-source circuit of the transistor to serve as a self-biasing resistance therefor. In that event, the resistance **26** is preferably variable, say a rheostat, to permit easy adjustment of the source-gate bias until the desired operating point for the field effect transistor is established. Thereafter, the resistance **26** is not further changed. But, the resistance **28** may also comprise a rheostat or the like so that the reference voltage may be readily adjusted to accommodate the particular set point selected for the regulated output voltage.

The extreme sensitivity desired of the error detector is provided by employing an operational amplifier **29** as a differential comparator for comparing the voltage at the output of the regulator section **12** against the reference voltage to provide an error signal and a current amplifier for amplifying the error signal. The operational amplifier may advantageously be powered by the dc. source **11** and have a substantial offset to its output voltage to more or less artificially indicate the presence of a significant error under quiescent conditions (i.e., when the output and reference voltages are zero) and thereby minimize or at least reduce the output voltage rise time. As shown, the operational amplifier **29** has the reference voltage applied to its non-inverting input and the output voltage applied by a voltage divider **31, 32** to its inverting input. The voltage divider is included because the reference voltage is always somewhat lower than the set point for the output voltage because of the inherent voltage drop across the source-drain circuit of the field effect transistor **25.** Consequently, the voltage dividing ratio of the divider **31, 32,** the set point for the regulated output voltage, and any output offset built in to the operational amplifier **29** should be kept in mind when selecting the reference voltage to assure that the error signal to the operational amplifier **29** is substantially zero when the regulated output voltage is at its set point.

The current amplifier comprises a transistor **33** which has its base coupled to the output of the operational amplifier **29** and its collector-emitter circuit connected in the return path for current flow through the base-emitter control circuit of the transistor **24.** Thus, the error signal controls the conductivity of the transistor **33** to, in turn, control the conductivity of the transistor **24** so that the current amplification of the error signal is approximately equal to the product of the betas of the two transistors. Power for the transistor **33** is drawn through a load resistor from the dc. source **11,** and its emitter is biased one volt or so above ground by means of the voltage developed across a pair of diodes **35** and **36** which are forwardly biased by current drawn from the source **11** by a resistor **37.** Hence, when the voltage at the output of the regulator section **12** is at or above its set point, the base-emitter junction of the transistor **33** is back biased, and consequently both it and the transistor **24** are in their non-conductive states. Under those conditions, the capacitor **23** begins to discharge through the output load (not shown) which causes the output voltage to drop slightly below its set point. Since the full open loop gain of the operational amplifier **29** is available, even a very slight drop in the

output voltage causes the operational amplifier to produce an error signal of sufficient amplitude to switch the transistor **33** and, in turn, the transistor **24** into conduction. Hence, the output voltage is quickly restored to its set point. The process is then repeated as often as necessary to hold the output voltage substantially constant at its set point.

Because there is an artificial error signal provided by the output offset of the operational amplifier **29** under quiescent conditions, the transistors **24** and **33** switch into conduction almost immediately after the appearance of the source voltage. Thus, the rise time for the output voltage is foreshortened. Indeed, if the output offset of the operational amplifier is sufficient to cause saturated conduction of the transistors **24** and **33**, the rise time for the output voltage is minimized.

CONCLUSION

From the foregoing, it will be understood that the present invention provides a simple but highly reliable dc. voltage regulator which is sufficiently sensitive to regulate even very low dc. voltages. The voltage regulator is a temperature stabilized series-type regulator, and may include provision for reducing or even minimizing the output voltage rise time.

I claim as my invention:

1. An extremely sensitive dc. voltage regulator capable of retaining its sensitivity and providing a stable dc. output voltage in response to a dc. input voltage even when employed to regulate dc. voltages which are substantially lower than 6.0 – 6.5 volts, said regulator comprising an input and an output; a variable impedance means coupled in series between said input and output; a constant current means and a resistance coupled in series across said output for supplying a predetermined reference voltage, said constant current means being a field effect transistor having a source-drain circuit connected in series with said resistance across said output and a gate-source circuit biased for operation of said field effect transistor in a temperature stabilized, constant current mode; a differential comparator means having one input coupled to said output and another input coupled to said resistance for supplying an error signal in response to any deviation of said output voltage from a predetermined set point; and means coupled between said comparator means and said variable impedance means for correctively adjusting said variable impedance means in response to said error signal to restore said output voltage to its set point, whereby said output voltage is held substantially constant at its set point.

2. The voltage regulator of claim **1** wherein a portion of said resistance is connected across the gate-source circuit of said transistor to serve as a self-biasing resistance, said self-biasing resistance being selected to bias said transistor for operation in said temperature stabilized, constant current mode.

3. The voltage regulator of claim **1** wherein said variable impedance means includes a first transistor having a collector-emitter power circuit connected in series between said input and said output and a base-emitter control circuit, and said comparator means comprises an operational amplifier sensitive to even very slight deviations of said output voltage from its set point.

4. The voltage regulator of claim **10** wherein the collector-emitter circuit of said first transistor comprises the only lumped impedance in series between said input and output.

5. The voltage regulator of claim **3** further including another transistor having a base coupled to receive said error signal and a collector-emitter circuit connected in series with the base-emitter circuit of said first transistor, whereby said other transistor is controlled by said error signal to correctively adjust the collector-emitter impedance of said first transistor as necessary to stabilize said output voltage at its set point.

6. The voltage regulator of claim **5** further including bias means coupled to said other transistor for supplying a bias selected to hold both said first and said other transistors in non-conductive states when said output voltage is at least as high as its set point.

7. The voltage regulator of claim **6** wherein said operational amplifier is powered by said input voltage and has a predetermined output offset voltage for switching said first and said other transistors into conduction in response to the appearance of said input voltage to thereby reduce the output voltage rise time.

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