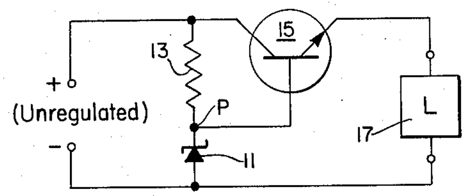
Oct. 26, 1965 J. F. BRINSTER 3,214,668

TRANSISTORIZED VOLTAGE REGULATOR

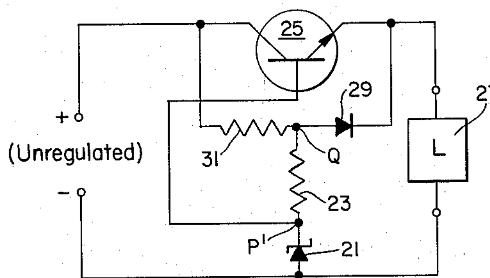
Filed Dec. 4, 1962

Fig. 1



PRIOR ART

Fig. 2



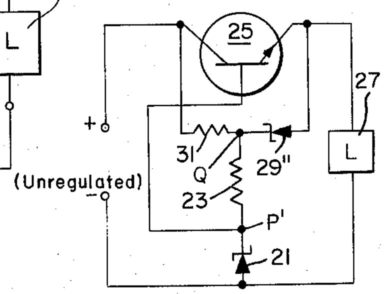


Fig. 5

Fig. 3

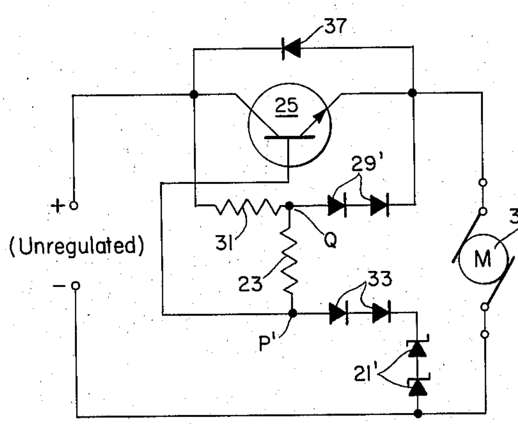
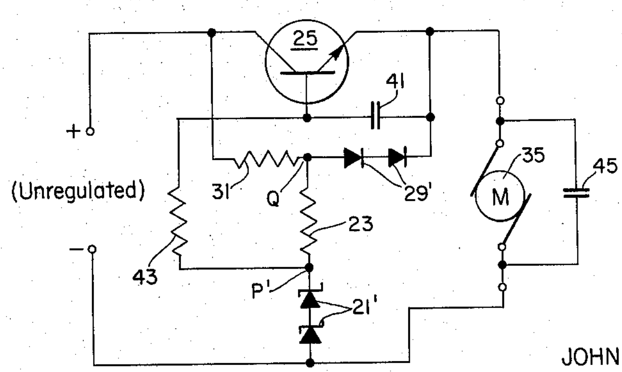


Fig. 4



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TRANSISTORIZED VOLTAGE REGULATOR

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This invention relates to voltage regulator circuits supplying a constant output voltage when energized by a variable unidirectional input voltage. More particularly, it refers to regulator circuits employing transistors.

The circuit of the invention constitutes an improvement over related circuits of the prior art in that it provides voltage regulation with decreased energy dissipation in the circuit components which, therefore, may be of a reduced size for a given output. This is of importance in view of the demand for the miniaturization of electrical assemblies, for example, for missile use. The circuit also provides improved operational reliability by assuring a continued output to a load in the event of transistor failure. Furthermore, compensation may readily be provided for certain adverse effects of temperature changes on the performance of a load member, such as a motor, and provision also made for reducing the effect of electrical noise due to a motor or other load.

It is, then, an object of the invention to provide an improved voltage regulator circuit for D.C. applications.

Another object is to provide a voltage regulator circuit comprising transistors, diodes and the like, wherein relatively low energy dissipation occurs in these components, thereby permitting a reduction in their size in comparison with similarly operating components in prior art circuits.

Another object is to provide a voltage regulator circuit in which the regulating current drawn is minimized and a high ratio of output voltage to minimum input voltage is achieved.

Another object is to provide a voltage regulator circuit in which a decreased range of variation of the current passed by the regulating elements is attained by pre-regulation of the voltage applied thereto.

Another object is to provide a transistorized voltage regulator circuit which permits the maintenance of an output in the event of transistor failure.

Another object is to provide in a voltage regulator circuit embodying one or more of the foregoing features, means compensating for change-of-temperature effect adverse to load operation.

A further object of the invention is to provide in a voltage regulator circuit embodying one or more of the foregoing features, means for preventing output circuit noise from being reflected back to the supply circuit.

These and other objects and advantages of the invention will be more clearly apparent upon consideration of the following detailed description of preferred embodiments thereof, and of the accompanying drawings, in which:

FIG. 1 is a circuit diagram of a transistorized voltage regulator typical of the prior art, for purposes of comparison;

FIG. 2 is a circuit diagram of an improved voltage regulator circuit, constructed in accordance with the principles of the present invention;

FIG. 3 is a modification of the circuit of FIG. 2, including additional temperature compensation means;

FIG. 4 is another modification of the circuit of FIG. 2, including noise filter means; and

FIG. 5 shows a further modification of the circuit diagram of FIG. 2.

Referring, first, to FIG. 1 as a showing of a circuit representative of the prior art, the unregulated unidirec-

tional supply voltage is applied to a series circuit or chain comprising diode **11**, reverse biased by this voltage to operate as a Zener diode, and limiting resistor **13**. Over a suitable range of current the voltage drop across a diode so connected tends to remain constant. The potential of junction point P, thus regulated, is applied to the base of transistor **15** which has its collector connected to the positive side of the supply and its emitter connected to the negative side of the supply by way of load **17**, these connections constituting an "emitter follower" type of circuit analogous to a cathode follower circuit employing vacuum tubes. Operated in this manner the transistor supplies a regulated voltage to the load.

In the circuit of FIG. 2, embodying the principles of the present invention, diode **21**, operating as a Zener diode, and resistor **23** correspond, generally, to diode **11** and resistor **13**, respectively, of FIG. 1, with transistor **25** corresponding to transistor **15** of the latter figure. In distinction to the circuit arrangement of FIG. 1, however, the positive terminal of resistor **23** is not directly connected to the positive side of the supply but instead is connected to junction point Q in a series circuit comprising a resistor **31** and a diode **29** (shown in this figure as forward biased) that is connected between the collector and emitter of the transistor as a by-pass which diverts from the transistor a certain amount of the current that would otherwise be passed thereby. Point P′ in the Zener circuit **21, 23** has a regulated potential, as before described in connection with point P of FIG. 1, which is applied to the base of transistor **25** to produce a regulated voltage output therefrom to load **27** in the emitter circuit, the arrangement of the connections again being that of an "emitter follower" circuit.

It is to be particularly noticed that in the foregoing arrangement the potential of point Q of the by-pass path differs from that of the transistor emitter only by the voltage drop across diode **29**. For a forward biased diode this drop can be relatively small and its value will vary very little with such changes in diode current as may occur in the normal operation of the circuit. The important result is that the voltage applied to the Zener circuit **21, 23** is pre-regulated, that is, it is made very nearly proportional to the regulated output voltage instead of being the variable supply voltage, as in the prior art circuit of FIG. 1. The ultimate regulation of the output voltage supplied to the load then will be seen to be achieved by a cumulative action whereby the voltage applied to the Zener circuit or chain is pre-regulated in accordance with the value of the output voltage which in turn is controlled by the Zener-regulated potential of point P′ of the Zener circuit.

Under the above conditions the range of current over which Zener diode **21** is called upon to operate is considerably reduced in comparison with the current range experienced when the supply voltage, with its full variation above a minimum value, is applied to the Zener chain, as in FIG. 1. Since the diode is not called upon to handle the relatively large currents and current swings that can occur when the latter condition obtains, a significant reduction in the size of this component is possible. Moreover, reduced variation of the regulating current tends toward better regulation of the output voltage. The application to the Zener chain of a voltage approaching the regulated output voltage instead of the application of the variable supply voltage also results in lower losses chargeable to the regulating function and a high ratio of output voltage to the minimum value of the supply voltage, because of the reduced Zener current drawn.

The parallel path or by-pass about transistor **25** comprising diode **29** and resistor **31** relieves the transistor from handling the entire current supplied to the load. In fact the values of the two conponents **29, 31** preferably are so chosen that at the maximum value of the supply voltage almost all of the load current is supplied over this path. This makes possible a reduction in the size of the transistor, also, relative to that of one passing the full load current, under comparable load conditions. A further advantage of the parallel path is that in the event of transistor failure current by way of the by-pass will continue to be supplied uninterruptedly to the load. This is an important feature in many applications.

As may be appreciated, instead of single diodes being used in the circuit positions of diodes **21** and **29**, a plurality of similarly poled, series-connected diodes may be specified in view of the magnitudes of the operating voltages or for other reasons. Therefore, the term "diode rectifier" or "diode" as used herein may apply to such a group of jointly acting members as well as to a single unit. Moreover, diode **29** may be reversed in polarity from that shown in FIG. 2 to operate as a Zener diode as **29''** seen in FIG. 5. In this case, as in forward operation, this provides a member across which a substantially constant voltage drop is maintained with operational changes of the current therethrough, whereby the potential of point Q in the transistor by-pass is related to the regulated potential of the emitter of transistor **25** by a substantially constant differential. As to the character of the transistor, this component may be of the p-n-p type instead of the n-p-n type here shown if it is connected in the negative side of the supply and all diodes are suitably poled to operate as described.

The circuit of FIG. 3 is a modification of that of FIG. 2 which is adapted to provide compensation for the effect of changes of temperature on the operation of the load. Diodes **21'** and **29'** correspond, respectively, to diodes **21** and **29** of FIG. 2 but are shown in plural form, as referred to above. Diodes **33** are compensating, forward-biased, temperature-sensitive diodes in series with Zener diodes **21'**. Usually these compensating diodes will be physically located adjacent the load, here shown as D.C. motor **35**. It is known that at low temperatures the increased viscosity of the lubricating grease, and other factors, tends to cause a lowering of the speed of a D.C. motor supplied with a constant voltage while higher temperatures tend to cause an increase in speed. In the present circuit which basically is designed to supply a non-varying voltage to a load in the face of supply voltage variations, compensation for temperature effects may be attained by varying the value of the otherwise steady output voltage in accordance with the temperature. This is accomplished by the operation of diodes **33**, the voltage drop across which has a negative temperature coefficient. Thus, as the temperature falls this drop rises and increases the potential of the point P' and that of the base of transistor **25**. The result is that a higher voltage is applied to motor **35** which tends to prevent its slowing down. Conversely, an increase in the environmental temperature lowers the voltage drop across diodes **33**, thereby decreasing the potential of point P' and that of the transistor base and causing a lower voltage to be delivered to motor **35** to overcome its tendency to speed up. In this manner, by a suitable choice of the characteristics of diodes **33**, a substantially constant motor sped may be maintained regardless of change of temperature or, if preferable, one which is some selected function of temperature. In similar manner loads other than motors may be supplied with a temperature-controlled voltage.

A feature of the circuit of FIG. 3 is a protective diode **37** connected between the collector and emitter of transistor **25** and reverse biased by a supply voltage of the indicated polarity. This provides that if, for some reason, the supply voltage reverses its polarity, the effect is only to cause motor **35** to reverse its direction of rotation due to current passed by this diode. In comparison with the known use of a forward biased diode connected in series between the supply and transistor as a reverse-current blocking device the parallel arrangement of FIG. 3 has

the advantage that substantially no increase in supply voltage is required to maintain a given output voltage because of the inclusion of the diode and there is no increase in the power consumed by the regulating circuit.

In the foregoing descriptions of the circuits of FIGS. 2 and 3 the effect of temperature changes on the operation of Zener diodes **21** and **21'** has been neglectd since this effect may be rendered of negligible importance by the use of temperature-compensated units comprising, in one envelope, a temperature-sensitive diode or diodes connected for forward operation in series with the reverse-operated Zener diode or diodes, proper. Advantage is taken in this manner of the opposite signs of the temperature coefficients of the voltage drops across these two classes of diodes to nullify temperature effects. However, in some cases uncompensated Zener diodes may be used to modify the operation of a load. Their characteristics are, in general, a function of the voltage rating of the diode.

It is frequently a requirement, particularly in the case of a voltage regulator supplying a motor load, that little or no electrical noise be contributed to the input or supply circuit by the operation of the load. The regulator of the present invention can readily be adapted to meet this requirement by the modification of the circuit shown in FIG. 4. In this arrangement what is, in principle, a filtering action is obtained by the use of a capacitor **41** in conjunction with a resistor **43**, the former circuit element being connected between the base and the emitter of transistor **25** and the latter element between the transistor base and junction point P' in the Zener chain comprising Zener diodes **21'** and resistor **23**. The combination of capacitor **41** and resistor **43** maintains the base of the transistor at substantially the same A.C. potential as that of the emitter, thereby tending to prevent the normal amplifying action of the transistor from translating relatively small disturbances of an A.C. nature resulting from the operation of motor **35** into relatively large variations of input current. As a further measure, the shunting of motor **35** by a capacitor **45** aids in minimizing the original disturbances. This may form a part of an LC low pass filter including a series inductor if the noise magnitude requires it.

Since all of the disclosed circuit modifications basically operate in the same manner, the temperature compensation means of FIG. 3 and the noise suppression means of FIG. 4 may be used in combination, as well as singly, in any of them.

The embodiments of the invention shown in the drawings and described herein are to be considered by way of illustration and not by way of limitation of the scope of the invention, as set forth in the following claims.

What is claimed is:

1. In a voltage regulator circuit the combination of:

(a) a pair of input terminals for the reception of an unregulated unidirectional supply voltage,

(b) a pair of output terminals for the supply of a regulated voltage to a load,

(c) a transistor having an emitter, a base and a collector,

(d) circuit means providing connections respectively between one of said input terminals and the collector of the transistor, between the emitter of the transistor and one of said output terminals and between the other ones of said two pairs of terminals,

(e) a by-pass circuit connected between the collector and emitter of the transistor comprising a series combination of a plurality of circuit members, the member adjacent the emitter being one across which a substantially constant voltage drop is maintained with operational changes of the current therethrough,

(f) a Zener circuit including a diode rectifier selected and polarized relative to the magnitude and polarity of the supply voltage to operate as a Zener diode together with a resistor in series therewith, said circuit being connected between a pair of points respectively included in the connection between said by-pass member adjacent the transistor emitter and the by-pass member adjacent thereto and in the connection between the other ones of said two pairs of terminals, referred to in (d), above, with the resistor adjacent said first point of connection of said Zener circuit, and

(g) circuit means connecting a point in the connection between said two members in the Zener circuit and the base of the transistor.

2. The combination including that defined in claim 1 which additionally includes a diode rectifier connected between the emitter and collector of the transistor polarized for reverse operation under the influence of the normal supply voltage.

3. The combination including that defined in claim 1 which additionally includes a capacitor connected between the base and emitter of the transistor and wherein the last-mentioned circuit means of said claim in section (g) thereof comprises a resistor, said capacitor and resistor jointly operating as filter means for reducing the effects of emitter circuit noise.

4. The combination defined in claim 1 wherein said by-pass member adjacent the transistor emiter is a diode rectifier polarized to receive a forward bias under the influence of the supply voltage.

5. The combination defined in claim 1 wherein said by-pass member adjacent the transistor emitter is a diode rectifier selected and polarized to operate as a Zener diode under the influence of the supply voltage.

6. The combination including that defined in claim 1 which additionally includes a temperature-sensitive forward-biased diode rectifier connected in said Zener circuit in series with the Zener diode therein and wherein the base of the transistor is connected to a point in the connection between the combination of said Zener and said temperature-sensitive diodes and the resistor in series therewith in the Zener circuit.

7. In a voltage regulator circuit adapted to furnish a regulated voltage to a load when energized by the unregulated unidirectional voltage of a supply circuit, said regulator circuit including a transistor having an emitter, a base and a collector and being connected in an emitter-follower circuit with the load serially connected in the emitter-base circuit and with the supply voltage furnishing the collector circuit voltage therefor, one side of the supply being in connection with the transistor collector and the other side in connection with the emitter-base circuit, the combination of circuit means controlling the potential of the base of the transistor comprising

(a) a transistor by-pass circuit connected between the collector and emitter of the transistor comprising a series combination of a plurality of circuit members, the member adjacent the emitter being one across which a substantially constant voltage drop is maintained with operational changes of the current therethrough,

(b) a Zener circuit including a diode rectifier selected and polarized relative to the magnitude and polarity of the supply voltage to operate as a Zener diode together with a resistor in series therewith, said circuit being connected between the terminal of said by-pass member adjacent the transistor emitter which is remote from the transistor emitter and the side of the supply circuit in connection with the emitter-base circuit of the transistor, with the resistor adjacent said first point of connection, and

(c) circuit means connecting a point in the connection between said two members in the Zener circuit and the base of the transistor.

8. The combination defined in claim 7 wherein one of said by-pass members is a resistor and said by-pass member adjacent the transistor emitter is a diode rectifier polarized to receive a forward bias under the influence of the supply voltage.

9. The combination defined in claim 7 wherein one of said by-pass members is a resistor and said by-pass member adjacent the transistor emitter is a diode rectifier selected and polarized to operate as a Zener diode under the influence of the supply voltage.

10. The combination including that defined in claim 7 which additionally includes a temperature-sensitive forward-biased diode rectifier connected in said Zener circuit in series with the Zener diode therein and wherein the point of connection to the Zener circuit of the last-mentioned circuit means (c) of said claim is intermediate the series combination of said two idode rectifiers and the resistor of the Zener circuit.

11. In regulator means for a unidirectional voltage

(a) a supply circuit furnishing an unregulated voltage,

(b) a load circuit receiving a regulated voltage,

(c) a transistor having an emitter, a base and a collector,

(d) circuit means applying the voltage of the supply circuit to the collector circuit of said transistor with the collector connected to one side of the supply circuit,

(e) circuit means for the series connection of said load circuit as a portion of the emitter circuit of the transistor,

(f) a Zener circuit including a diode rectifier selected and polarized relative to the magnitude and polarity of the supply voltage to operate as a Zener diode together with a resistor in series therewith,

(g) circuit means connecting a point in the connection between said two members in the Zener circuit and the base of the transistor, and

(h) circuit means for applying a regulated voltage to the terminals of the Zener circuit comprising

(h1) a by-pass circuit for said transistor connected between the collector and the emitter thereof comprising a series combination of a plurality of circuit members, the member adjacent the emitter being one across which a substantially constant voltage drop is maintained with operational changes of the current therethrough, together with

(h2) a connection between said last-mentioned by-pass member at the terminal thereof remote from the transistor emitter and the terminus of said Zener circuit adjacent the resistor therein and a further connection between the side of the supply circuit opposite said collector-connected side thereof and the other terminus of the Zener circuit.

12. The combination including that defined in claim 11 wherein the load circuit of said claim comprises a D.C. motor and wherein element (g) of said claim, namely, circuit means connecting a point in the Zener circuit and the base of the transistor, comprises a resistor, and which additionally includes a capacitor connected between the emitter and the base of the transistor, said resistor and capacitor constituting filter means for the reduction of electrical noise due to the operation of said motor.

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