Series-Pass Regulators

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Design of a 11- to 32-volt, 700-mA power supply which has good regulation and built-in overcurrent protection.

AN ideal voltage-regulated power supply has zero output impedance so that the output voltage remains constant for any load current requirements. But, zero output impedances cannot be achieved, although supplies with impedance levels of a milliohm can be constructed. And, too, semiconductor device characteristics place a limit on the current and voltage that can be supplied to a load.

Two simple series-pass voltage regulators are shown in Figs. 1 and 2. Transistor $Q1$ in each of these circuits controls the output voltage; thus the collector-emitter voltage rating of $Q1$ determines the maximum input-to-output voltage. All the current delivered to the load passes through $Q1$. Therefore, the power dissipated in $Q1$ is $(V_{in}-V_{out})$ times I_{Load}. If high input voltages and low output voltages and/or large load currents are necessary, it is possible that $Q1$ will have to dissipate large amounts of power. Obviously, under these conditions the regulator efficiency is low and the power rating (for the particular heat sinking) limits regulating capacity. For limited load variations, $Q1$ can be shunted by a resistor, thus shifting some power from $Q1$ to the resistor. The output voltage of the circuit (Fig. 1) is the zener voltage minus the base-emitter voltage of $Q1$. $R1$ must provide enough current to the base of $Q1$ and to $D1$ to keep the voltage of $D1$ above its knee at all times. If the temperature characteristic of $D1$ is equal and opposite that of the base-emitter junction of $Q1$, the output voltage will remain constant with temperature.

When variable output voltages are required, a circuit similar to that of Fig. 2 can be used. Here, the lowest possible output voltage is the breakdown voltage of $D1$ plus the base-emitter voltage of $Q2$.

Maximum output voltage is limited by the changes in the unregulated input plus the drive requirements of $Q1$. $R1$ provides the bias current for $D1$ whose voltage is compared to that at the potentiometer arm. If the load increases and causes the output voltage to drop, $Q2$ conducts less and $Q1$ conducts more, restoring the voltage to the original level.

Basically, series-pass regulators are current, voltage, and power limited; and the circuit's control transistor must always be run in the safe operating area—the region where there is no danger of secondary breakdown. However, series-pass regulators do provide extremely good regulation, fast response time, low output impedance, and low ripple. Their performance is almost independent of input frequency fluctuations and they have excellent dynamic response. They also provide variable output voltages and are readily adaptable to remote voltage sensing, remote programming, and current limiting or current regulating applications. The circuit output is virtually transient free.

Overcurrent Protection

The circuit shown in Fig. 3 is a regulated power supply with overcurrent protection and an output of 11 to 32 volts d.c. The maximum output current with the specified circuit components is 700 mA. The diode bridge consisting of $D1$ through $D4$ provides full-wave rectification of the 25-volt secondary of $T1$. Capacitor $C1$ is used to filter the rectified current and keep a positive voltage on the collectors of $Q1$ and $Q2$. Resistor $R1$ and capacitor $C2$ further reduce the ripple to maintain a stable d.c. voltage as a collector supply for $Q3$ and $Q4$, and for driving the base of $Q1$. Transistor $Q2$ is the series-pass device which regulates the output voltage. The resistor divider, $R4$-$R5$-$R6$, forms a sensing network. The voltage at the arm of potentiometer $R5$ is applied to the base of $Q4$, which compares the voltage to that of zener diode $D5$.
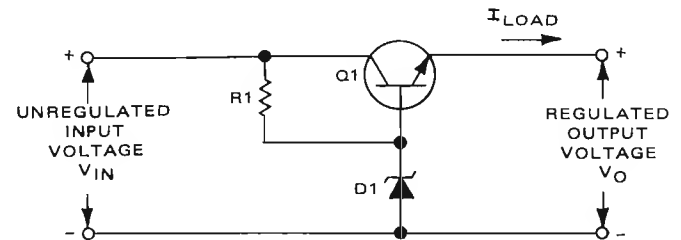

Fig. 1. In this simple series-pass fixed-voltage regulator transistor Q1 controls the regulated output voltage, V_o.
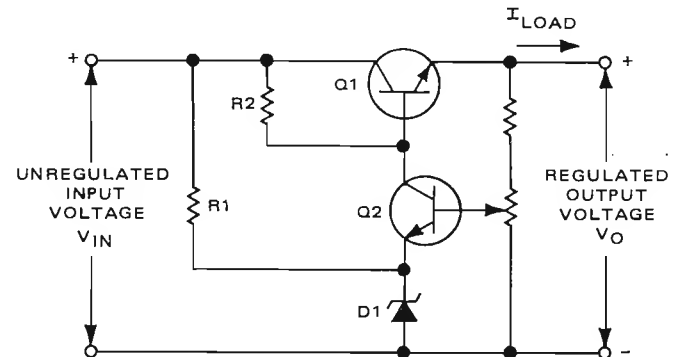

Fig. 2. In this variable-voltage series-pass regulator, transistor Q2 and a potentiometer are used to set voltage level.
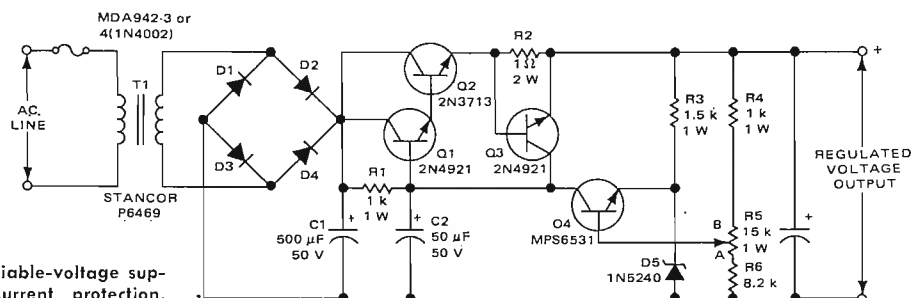

Fig. 3. This variable-voltage supply has overcurrent protection.

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The difference between the two voltages determines how much $Q4$ conducts. If the output voltage increases, the base voltage of $Q4$ increases and pushes it farther into the conduction region. This reduces the base current of $Q1$, which in turn reduces the current through $Q2$, lowering the output voltage. If the output voltage drops, $Q4$ moves toward cut off and $Q1$ and $Q2$ turn on. This increases the output voltage. In essence, the circuit is a feedback amplifier which tries to maintain the output voltage at a constant level independent of load condition.

The output voltage is determined by the potentiometer setting according to the following equation:

$$V_{out} = \frac{(V_{D5} + V_{BEQ4})(R4 + R5 + R6)}{R6 + R5 \text{ (setting)}}$$

If $R5$ is set at the low end (A), the output is maximum and is given by:

$$V_{out \, (max)} = \frac{(10.7)(24.2 \text{ kohms})}{8.2 \text{ kohms}}$$

$$= 31.7V$$

The minimum output voltage (11.2 V) occurs when the arm of $R5$ is set to the high side (B).

The regulation is a function of the potentiometer setting since this determines the amount of feedback. The closer the base of $Q4$ is to the positive output the greater the feedback.

Overcurrent protection is provided by $R2$ and $Q3$. Since $R2$ is in series with the output, the voltage across it is proportional to the output current. This voltage is used to drive $Q3$ so that the larger the output current becomes, the more $Q3$ conducts. When $Q3$ is turned on, the base drive is removed from $Q1$ and this turns off power regulator $Q2$, thus limiting the output current. In this example, component values were chosen to limit the maximum current to approximately 700 mA. Fig. 4 shows the effectiveness of the current limiter.

Load regulation at several output voltage levels is shown in Fig. 5. The overcurrent actually degrades the performance of the regulator circuit, particularly at the higher current levels, since it decreases the base drive of $Q1$.

The power stage transistors, $Q1$ and $Q2$, were selected for high gain at $-55°C$. This maximizes the voltage and current regulator's control. At maximum output voltage and at low temperatures, $Q1$ requires a base current of about 1 mA. $R1$ was selected to deliver approximately 2.5 mA. This sets the minimum voltage regulator current in $Q4$ (MPS6531) at 1.5 mA, when the current regulator is not working. When the current regulator $Q3$ (2N4921) comes on, it must handle this current. For the opposite condition at high temperatures and low output voltages, $R1$ provides about 25 mA maximum current. The drive requirement for the power stage is not critical here, but $Q3$ and $Q4$ must be able to handle this current for effective control.

The maximum temperature at which the circuit will operate is set by the heat sinking of $Q1$ and $Q2$. If these transistors are mounted directly to a heat sink and a good silicone grease is used, then the worst-case temperature rise above the temperature of the heat sink for $Q2$ is 25°C, while that for $Q1$ is about 20°C. Since the maximum operating temperature of $Q1$ is 150°C, this means the heat-sink temperature must be kept less than 130°C. ▲

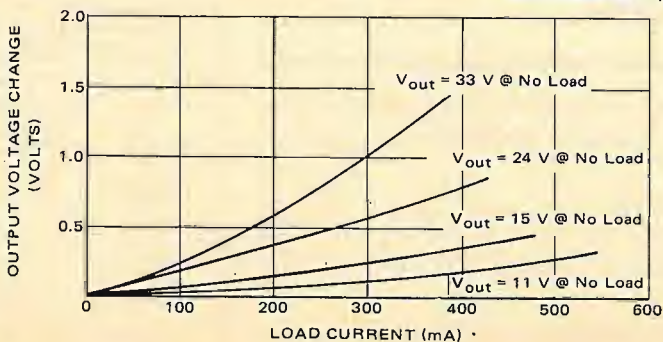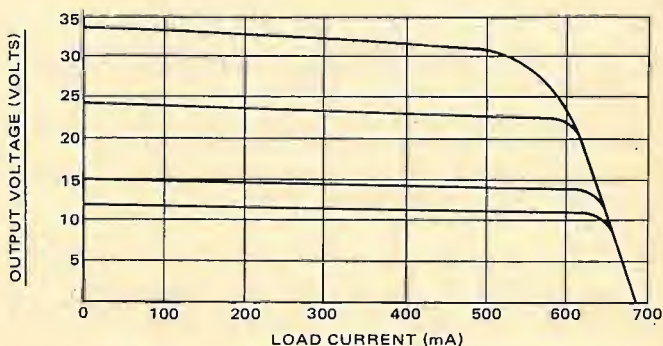Fig. 4. Voltage output versus load current for the circuit of Fig. 3.

Fig. 5. Regulation versus load current for the circuit shown in Fig. 3.