Designing voltage reference circuits

It is often necessary in electronic circuit design to provide a stable voltage source for reference purposes. In this short article the author describes low cost ways of providing such a voltage reference.

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The need frequently arises in electronic circuits for the provision of a stable voltage source for reference by comparators, level detectors, current and voltage regulators and so on. In many cases the prime requirement in the case of the reference voltage is not so much its absolute precision, but rather its stability with respect to supply voltage and ambient temperature variations. It is normal practice to connect only a small and fixed load to such a reference supply, so that unlike voltage regulator circuits load regulation is not a problem.

The simplest approach to providing such a referenceis to use a zener diode. This is connected in shunt mode, in virtually the same manner as used for a simple regulator (Fig. 1). The zener is operated in its "reverse breakdown" mode, where its terminal voltage remains substantially constant over a wide range of current. This is illustrated by the graph in Fig. 2, where you can see that in the breakdown region the diode's voltage drop remains substantially constant at Vz for a significant range in current Iz.

The equation used to calculate the circuit values for Fig. 1 is:

$$R = (Vs - Vz)/(Iz + Il)$$

As an example let us say Vs is 12V and the zener voltage is to be 6.2V, with a load current Il of 0.8mA. Most low power zener diodes have their nominal terminal volage specified at a current of 5mA, so we can set Iz at this value. Hence

$$R = (12-6.2)/5.8 \times 10^{-3}$$
$$= 1k$$

If the zener diode current is reduced much below 5mA, the diode voltage will drop as the device operating point approaches the "knee" of its characteristic. On the other hand if the zener current is increased the diode voltage increases (as does its power dissipation). The voltage increase is due to the finite slope of its characteristic in the breakdown region (see Fig. 2).

Obviously the steeper the slope of the characteristic, or the lower its "slope resistance", the more stable will be the zener voltage with variations in unregulated supply voltage.

Low power zener diodes are readily available in a range of voltages in preferred value steps from 2.7 volts to 75 volts or more, usually with tolerances of ±5%. However, on closer observation it is seen from data on these devices that the zener diode with the lowest slope resistance in any particular production series occurs at about 6.2 volts. Hence for best results a 6.2 volt zener should be used where possible. If a lower reference voltage is required a potential divider may be used, preferably using metal film or metal glaze resistors for stabilily. Such a circuit is shown in Fig. 3. As you can see an op-amp is used as a buffer, to prevent load current from disturbing the divider ratio.

If a reference voltage higher than 6.2V is required, the circuit shown in Fig. 4 may be used. The DC gain of the amplifier is set by the ratio of two resistors:

$$\text{Gain} = (1 + R1/R2).$$

Because the most readily available zener diodes have a tolerance around

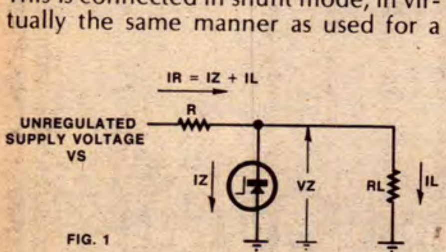


FIG. 1

Simple zener diode voltage reference.

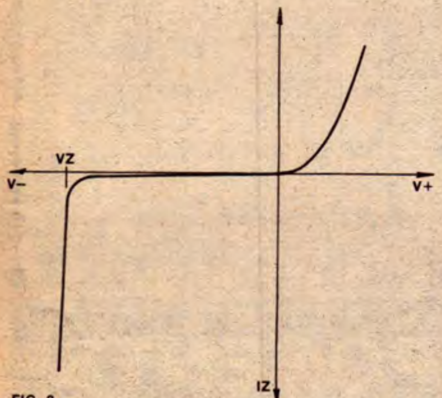


FIG. 2

Graph showing how zener diode voltage drop remains substantially constant at Vz for a large range in current Iz.

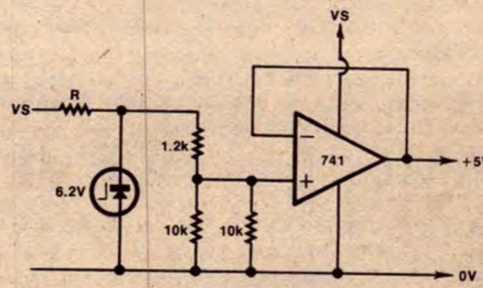
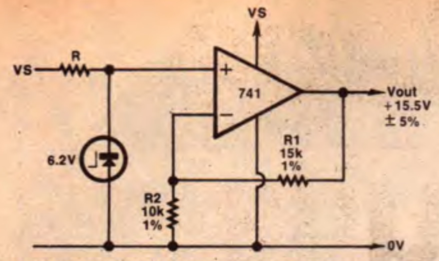


FIG. 3

A 6.3V zener, a voltage divider, and a 741 op amp make up this +5V reference.



VS MUST BE AT LEAST 2V HIGHER THAN Vout

FIG. 4

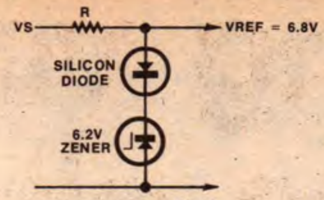


FIG. 6

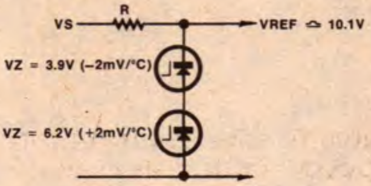


FIG. 7

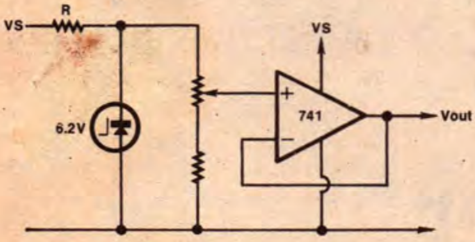


FIG. 5

Fig. 4: obtaining a reference voltage higher than the zener voltage. Fig. 5: using a preset pot to trim output voltage. Figs. 6 & 7: temperature compensated zener reference circuits.

±5% it is a good idea to include a preset potentiometer to trim the output voltage to the required level. If the wiper of the potentiometer is connected to an operational amplifier, as shown in Fig. 5, then any variations in load resistance will have no affect on the reference voltage (within the output capability of the op-amp).

On further investigation of the data sheets for zener diodes, it is also found that the ambient temperature has a marked effect on the zener voltage of any particular diode. The figure quoted is usually the temperature coefficient in mV/°C temperature change.

The lowest temperature coefficients are for zener diodes in the range 5.1 to 5.6 volts, the typical figures being -1mV/°C for 5.1 V, +0.5 mV/°C for 5.6V and + 2 mV/°C for 6.2V.

If the unregulated supply voltage variations and load variations are not severe then a single 5.1V or 5.6V zener may be used, giving a reference voltage only changing by 1% for a temperature change of 50°C. Generally this is adequate for most purposes.

If better temperature stability is required a good trick is to use an ordinary forward-biased silicon diode in series with a 6.2V zener diode (Fig. 6). This makes use of the fact that the forward voltage temperature coefficient of a silicon diode is approximately -2mV/°C. The temperature coefficient of the silicon diode and the zener diode cancel out or compensate each other, giving a reference voltage with a temperature coefficient very close to zero. Alternatively two zeners may be used in series, with equal and opposite temperature coefficients as in Fig. 7.

This gives a much better performance than a standard 10V zener, which has a temperature coefficient of about + 7 mV/°C. In both Fig. 6 and Fig. 7 the two diodes should be mounted close together so that they are at substantially the same temperature.

Several monolitic precision voltage reference ICs are available with typical output voltage temperature coefficients of less than 0.01% /°C change.

These references also usually have a very high degree of precision of the output voltage; however, they usually cost several dollars each. If precision is of secondary importance, and stability is the main criterion, and if the load is constant, then another approach is to use one of the wide range of readily available 3 terminal monolithic voltage regulators, e.g. 7805, 7812, 7815, LM 340, LM 320 etc.

If these regulators are used with a constant and low load of about 10-20mA, then they will also have a temperature coefficient of about 0.01% /°C, while the output voltage variation is about 0.25% of any variation of the unstabilised input voltage. This represents a very cost effective alternative. No heat sinks are needed in this mode of operation, and a wide range of voltages from 5V to 24V is obtainable.