Precision Voltage Sources You Can Build

How to design and build simple, stable precision reference supplies

By Joseph J. Carr

A source of accurate voltages can open up new circuit-measuring vistas for you. With it you can check out the accuracy of that nifty new digital multimeter you just bought or see if your old meter has maintained its calibration over the years. The same can be applied to oscilloscopes, power supplies, and other equipment. You might even wish to improve the voltage reference source of an A/D or D/A converter in the event that a shabby reference supply is giving you 4-bit performance out of an 8-bit data converter.

This article discusses how to design and build simple, but effective, reference supplies that can be used for the cited applications.

Zener Diodes

The simplest device that can be used for voltage regulation, and hence also for some reference applications, is the lowly zener diode. Figure 1 shows the circuit symbol (inset) and transfer characteristic curve for a zener diode. The diode is little more than a special *pn* junction diode, so will behave like any other *pn* diode in the forward bias region (+V). When the applied voltage is positive, a forward current (+I) will flow. Below a certain threshold voltage (V_g), current is the reverse leakage current (I_r). Above this threshold, however, forward current increases in a linear manner.

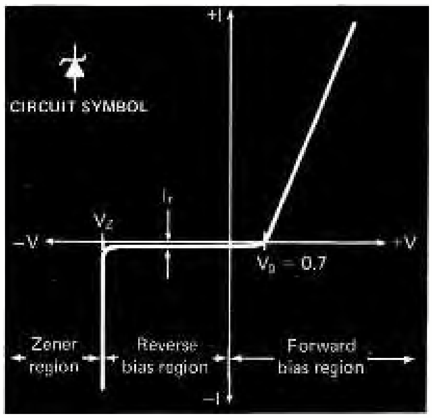


Fig. 1. The characteristic curve of a zener diode. Note very sharp bend at the beginning of the zener region.

In the reverse-bias region, conditions are a little different from ordinary *pn* junction diodes. Leakage current is all that flows for applied voltages (−V) of 0 to V_Z, but when V_Z is reached the diode avalanches. In this condition, the diode will regulate the applied voltage to the value of V_Z.

The basic zener regulator circuit is shown in Fig. 2. This circuit is not used directly as a reference supply, but is included here because it forms the basis of such supplies. Zener diode *D1* is in parallel across load *RL*. Series resistor *R1* limits the current to a safe value (recall from Fig. 1 that −I increases dramatically at V_Z). The output voltage will be regulated to $+V_Z$ in this circuit.

There are some problems with the basic zener diode, which become especially acute when it is used as a reference source. (Remember, "reference" implies accuracy.) First, the voltage specification is only nominal. In other words, a 6.8-volt zener produces a voltage close to—but not necessarily exactly—6.8 volts dc. Another problem is that the voltage drifts somewhat with temperature, hardly a characteristic desired in a reference supply.

Figure 3A shows one crude attempt at stabilizing the temperature-drift problem. In this circuit, a number of zener diodes are connected in a series-parallel arrangement. Each series string produces a voltage drop (V1 and V2), so the differential output voltage is V1 − V2). The idea here is that all diodes, assuming they are identical and in the same thermal environment, will drift the same amount so that the differential effects of drift are zero.

A superior idea is shown in Fig. 3B. The regulator shown here is the National Semiconductor LM-199 (or LM-399) device. It consists of a 6.95-volt zener diode embedded in an electrical heater. (One source told me that the heater was little more than a class-A amplifier with the input shorted, with the zener built on the same substrate to share the thermal environment.) The heater keeps the diode at a constant temperature that is somewhat above ambient room

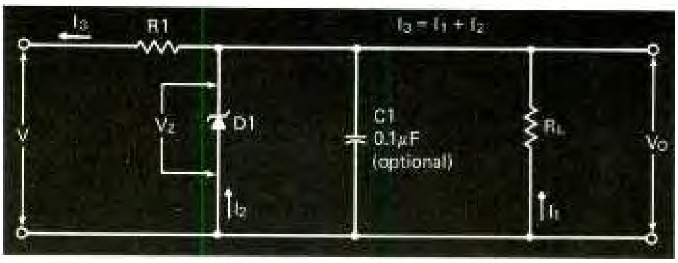


Fig. 2. The basic zener regulator circuit.

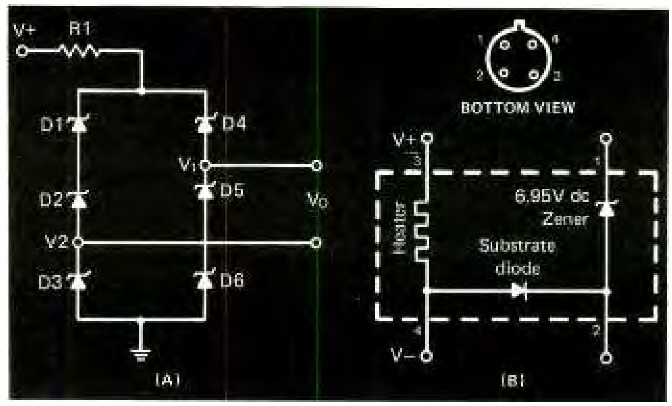


Fig. 3. Crude attempts to stabilize temperature drift (A) have given way to the superior LM339 approach (B).

temperature. With the temperature constant, the diode voltage drop will not drift. The LM-199/ LM-399 offer some startling voltage-drift specifications. There are also other (similar) devices on the market.

Op-Amp Reference Source

Even the LM-199 produces only a nominal output voltage. While that voltage remains constant, it may not be exactly the rated 6.95 volts. The circuit in Fig. 4 can be used to adjust the voltage to any desired value within reason and make it precise. In addition, the operational amplifier buffers the reference supply against changes in load conditions.

The basic circuit of Fig. 4 is the noninverting follower with a gain op-amp configuration. The LM-199 is used to supply the input voltage on pin 3; so the output voltage will be $V_O = V_Z [(R2/R1) + 1]$.

Selection of appropriate values for *R2* and *R1* will produce the desired output voltage. If *R1* is 1000 ohms, a 10.00-volt power supply can be made if *R2* is 438.8 ohms. In most cases, *R2* will be a combination of a fixed resistor (low temperature coefficient) and multi-turn trimmer potentiometer. The trimpot is adjusted for the desired output voltage.

Intersil's ICL-8069

Another form of simple reference source is the Intersil ICL8069 band-

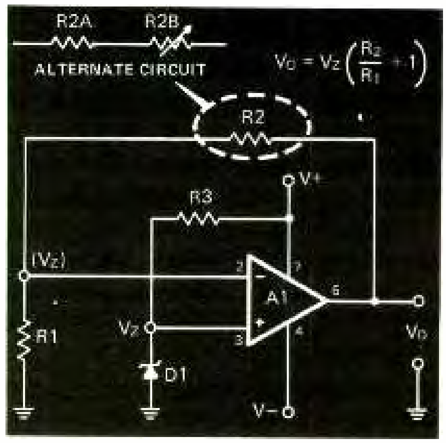


Fig. 4. Noninverting op-amp follower provides means for adjusting precise output voltage from an LM339.

gap zener device, shown in Fig. 5A. This device is a 1.2-volt temperature-compensated zener diode that is designed to operate with low noise at zener currents down to 50 μA. There are several versions of the device, differing mostly in stability and accuracy specifications.

Figure 5A shows the basic circuit for this diode. Note that an output potentiometer is used to pick off the correct voltage from the 1.2 volts available open-terminal. The same circuit is shown in Fig. 5B, with the difference that a fixed resistor is added in series with the potentiometer so that the resolution of the circuit can be increased. The potentiometer selects a potential over a narrower range of total resistance.

Neither of the circuits in Fig. 5 offers the same benefits as the operational-amplifier circuit. Both the earlier op-amp circuit and the circuit of Fig. 6 can be used to overcome some of the limitations of the simpler circuit. In Fig. 6, we see an operational amplifier used in a slightly unusual configuration to produce an output of 10.000 volts, adjustable with *R3*. The operational amplifier's gain is set by the resistance of the potentiometer.

Although an LM-308 is used for the operational amplifier in Fig. 6, almost any quality op-amp could be used. I recommend against using the 751, however, because its drift might tend to decrease the accuracy of the output voltage over time.

In all operational-amplifier circuits, incidentally, it is desirable to keep the op amp itself from drifting. In most cases, this means that the power supply voltages (V − and V +) must be kept as close as feasible to the output voltage being used. This means you must know how close to the supply voltage the output voltage will rise. In some op amps, it is several volts (as low as 0.5 volt in BiMOS devices). In one popular unit, the output voltage can rise to within 1.4 volts of the power supply voltage. For a 10.00-volt reference supply, therefore, we would want to use a standard power supply voltage close to (10.00 + 1.4 = 11.4) volts. In that

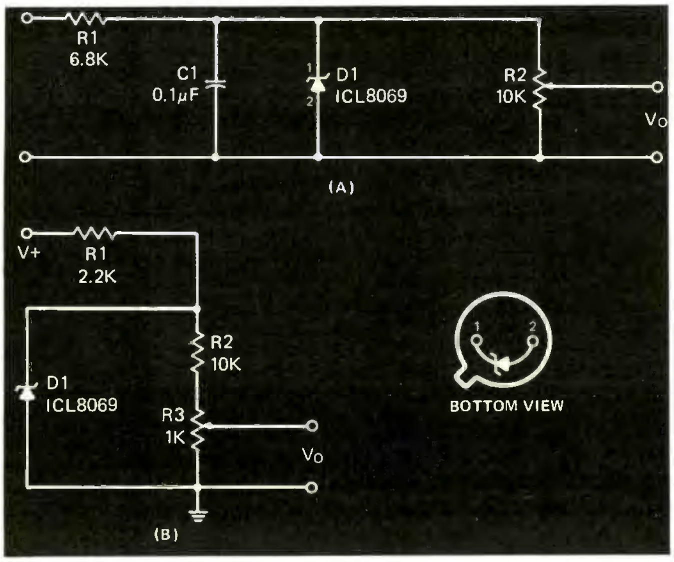


Fig. 5. The basic circuit for the band-gap zener diode in (A) is shown slightly modified in circuit (B).

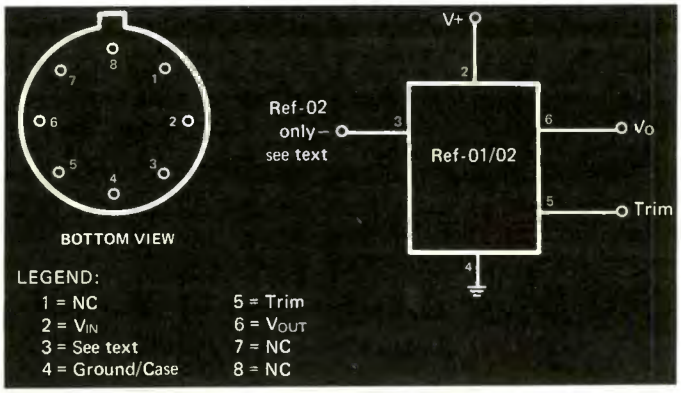
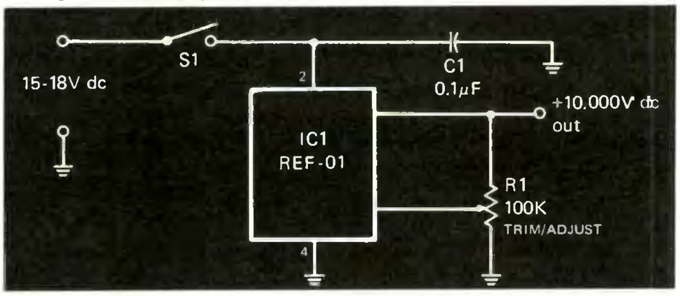


Fig. 7. Drawings show pinouts, case configuration and pin designations of REF-01 and -02 reference devices.

Fig. 8. Usual operating circuit for the REF-01 and -02.



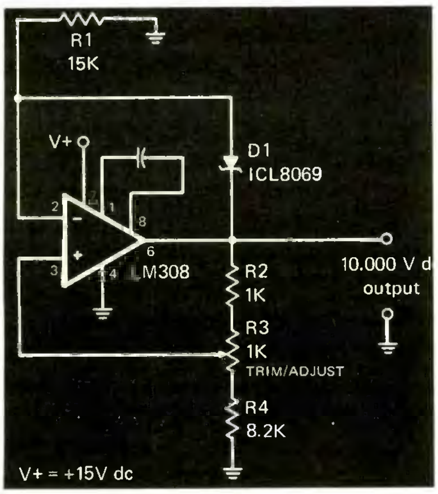


Fig. 6. Using an op amp, exact 10-volt output can be obtained, adjustable with trimmer potentiometer R3.

case, use −12 volts for V− and +12 volts for V+.

IC Reference Sources

A very popular device for use in reference supplies is the integrated-circuit reference supply. Although there are many different types on the market, we will use the Precision Monolithics REF-01 and REF-02 devices as our example (see Fig. 7).

The REF-2 is a +5.00-volt reference source, while the REF-01 is a 10.000-volt unit. Both REF-01 and REF-02 are packaged in an 8-pin metal IC can and use the pin-out definitions shown in Fig. 7. Supply voltage is applied across pins 2 and 4, while output voltage is taken from across pins 6 and 4 (pin 4 is common/ground). Pin 5 is used as a trimmer/adjust input.

The REF-02 uses pin 3 in a unique manner; it is an electronic thermometer transducer. The voltage at pin 3 will have a value of 2.1 millivolts per degree Kelvin ambient temperature. It can be used to form an electronic thermometer.

Figure 8 shows the usual operating circuit for the REF-01 and REF-02 devices. The trimmer circuit consists of a linear-taper potentiometer that selects a sample of the output voltage and inputs it to the trim circuit. This should be a multi-turn pot in order to closely set the output voltage.

I've used the REF-01 device in a number of projects, and found it more than satisfactory. It seems to have even better temperature stability when a Wakefield flexible IC (or TO-5 transistor) heat sink is used on the IC case. Also, keep the input voltage to a minimum required to obtain the output voltage. I have used +12 volts for the REF-01 and +9 volts for the REF-02.

A precision voltage-reference source can be built using a simple zener diode-like device, such as the LM-199 or ICL-8069, or a more complex circuit in which an zener diode is used with an operational amplifier. You can also use a special IC reference device, such as the REF-02 by PMI (or one of the equivalents by

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other manufacturers). Check the linear and power supply IC catalogues from any of the major semiconductor makers for data sheets on other types.

Conclusion

Adjusting the reference source poses another problem. What does one use as a reference? There are several alternatives. For those who are intrepid, take the finished reference source to someone who has a real accurate zillion-digit, multi-kilobuck digital voltmeter and use it as a truth and beauty. For most of us, however, we can adjust the source using a brand new digital voltmeter (or oscilloscope), and then live with any problems that develop. In most cases, we can trust our DMMs (or have them commercially calibrated) so that they can be used to monitor the reference source when calibrating other dc measuring instruments. **ME**