Anatomy of a precision-voltage reference

VOLTAGE REFERENCES ARE CRITICAL COMPONENTS in any system because they determine system accuracy. They determine the accuracy of ADCs, DACs, and feedback systems. For example, in a correctly designed linear-feedback system, multiplying the voltage reference by the system-transfer function gives the output voltage (current). The voltage-reference tolerance and drift transfer to the output, and Murphy's Law usually ensures that these errors show up in the most disadvantageous manner.

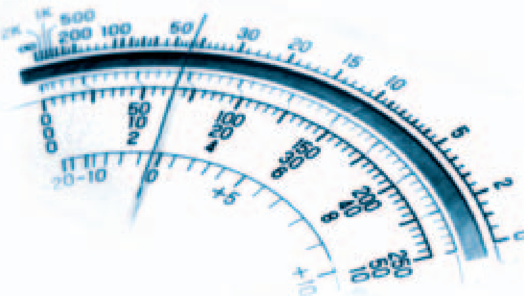
A good place to start the study of voltage references is by looking at zener diodes, which have been around for a long time. A semiconductor diode is a pn junction you make in a semiconductor material, such as silicon. You make this junction by diffusing (doping) an excess of electrons (phosphorus) into one side of the bar (n) and diffusing a deficiency of electrons (holes caused by boron) into the other side of the bar (p). The diffusions leave impurities—phosphorus and boron atoms—that lower the silicon-bar resistance. When you forward-bias the pn junction (diode), current readily flows. When you reverse-bias the pn junction, the area surrounding the junction is charge-depleted. However, a small current, known as "reverse-saturation current," flows when you apply reverse voltage because the doping is not perfect.

As the reverse-junction voltage increases beyond the voltage-breakdown point, reverse-current conduction across the junction interface increases rapidly. The transition from the reverse-saturation current to heavy reverse conductance is sharp and well-defined in most diodes and is known as the "zener knee." Small reverse-voltage increases beyond the breakdown voltage produce large current changes; thus, the reverse-biased diode becomes a constant-voltage device when limited current exists. Different doping schemes create two breakdown mechanisms: zener breakdown and avalanche breakdown. Although engineers often confuse the breakdown mechanisms, it is important to know that zener breakdown has a negative temperature coefficient, and avalanche breakdown has a positive temperature coefficient.

A GOOD PLACE TO START THE STUDY OF VOLTAGE REFERENCES IS BY LOOKING AT ZENER DIODES, WHICH HAVE BEEN AROUND FOR A LONG TIME.

Zener diodes range from 2 to 200V, but they have lots of problems, such as output impedance of 5Ω or greater, poor initial tolerance (5% nominal), temperature coefficients of −4 to +100 mV/°C, and voltage noise of 400 μV rms. Furthermore, zener diodes often have a soft knee, so they require bias currents as large as 20 mA to obtain the specified accuracy. Engineers have over the years reduced but not eliminated these problems, so they still exist in discrete diodes.

The zener-diode-regulator circuit consists of a bias resistor that connects to the power supply, a zener diode that connects from the bias resistor to ground, and the output voltage across the zener diode. When the temperature coefficient gets out of hand, you add another diode in series with the zener diode in an attempt to cancel the temperature coefficients. When the output current ruins the regulation because of the voltage drop across the zener impedance, an amplifier buffers the zener diode.



When you require more accuracy, put the zener diode in a temperature-controlled oven. Manufacturers often grade and bin zener diodes to obtain improved initial tolerances. IC manufacturers recognize that zener diodes have problems, so they have begun to use IC-design and -manufacturing techniques to offer temperature-compensated, high-accuracy, buffered zener diodes. These ICs have transmuted into IC voltage references.□

Ron Mancini is staff scientist at Texas Instruments. You can reach him at 1-352-569-9401, rmancini@ti.com.