Designing a zener-diode regulator

IC REFERENCES ARE POPULAR with circuit designers because they are accurate and exhibit low drift. Some of my future columns will cover the three types of IC references: buried zener, bandgap, and XFET. You develop the reference-design procedure with a zener diode; the zener's simplicity illustrates the design procedure, and its problems make you appreciate IC references. The circuit specifications are V_{CC}=30V±10%, 8.445≤V_{REF}≤9.555, ΔV_{REF}≤200 mV, 100 kΩ≤R_{LOAD}≤200 kΩ, and 0°C≤T_A≤80°C.

Select a 1N757 9.1V zener for the first try. Note that the maximum temperature coefficient is 6 mV/°C, and the zener-voltage tolerance is ±5%. The calculated reference voltage equals the maximum specification, V_{REF}=(1.05)(9.1)=9.555V, but the temperature-induced drift is ΔV_{REF}=(80−25)(6 mV)=0.330V, thus exceeding the maximum-drift voltage specification.

Connect a signal diode in series with a 1N756 8.2V zener so that the diode's negative-temperature coefficient cancels part of the zener's positive-temperature coefficient (**Figure 1**). The diode's temperature coefficient ranges from −2.1 to −2.3 mV/°C, and the 8.2V zener's temperature coefficient is 5.4 mV/°C, so the combination's maximum temperature coefficient is 3.3 mV/°C. This scenario yields ΔV_{REF}=181.5 mV, which meets specifications, but the minimum reference voltage, V_{REF}=(0.95)(8.2)+0.5=8.29V, is less than the specified limit of 8.445V.

This analysis is incomplete because additional zener characteristics, such as zener impedance and bias current, affect ΔV_{REF}. Now's the time to give up on a pure zener diode and go to a temperature-compensated zener. The 1N935 has a zener voltage of 9.075V; a tolerance of 5%; a temperature coefficient of 2 mV/°C; and a zener impedance of 20Ω at I_Z=7.5 mA, where I_Z is the zener-test current. The reference-voltage range is 8.62≤V_{REF}≤9.53. A quick calculation of the temperature-coefficient error yields a maximum voltage change of ΔV_{REF1}=110 mV. So far, so good, but you need to do further calculations to get the complete picture.

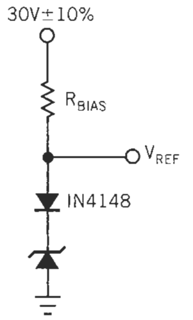

Figure 1

This zener-regulator circuit includes a temperature-compensation diode.

Calculate R_{BIAS} as R_{BIAS}=(V_{CC}−V_{REF})/I_Z=(30−9)/7.5=2885Ω; select R_{BIAS}=2800Ω±2%. (The temperature-compensated zener includes the diode in **Figure 1**.) Because of power-supply and resistor tolerances, the change in I_Z ranges from [(30)(0.9)−9.53−0.11]/2.8(1.02)=6.07 mA to [(30)(1.1)−8.62−0.05]/2.8(0.98)=8.86 mA. The load-resistance change causes about 90 μA of change in I_Z, which is insignificant. This change in the temperature-compensated-zener current corresponds to a zener-impedance change of approximately ±5Ω (**Reference 1**), but ΔV_{REF} changes only about ±37.5 mV. You should also consider the zener-voltage change: Because of the I_Z shift, the zener-operating point changes when V_{REF} varies by ±50 mV. Also, keep in mind that the maximum wideband semiconductor noise that the dc voltage contains is 20 μV.

The final voltage-reference change is 110+37.5+50=197.5 mV.

THE ZENER'S SIMPLICITY ILLUSTRATES THE DESIGN PROCEDURE, AND ITS PROBLEMS MAKE YOU APPRECIATE IC REFERENCES.

Some people say that this analysis is not the most rigorous, and they are right, but it gives you an idea of what using a zener reference involves. If V_{CC} had been as low as 12V, a zener diode would fail to meet specifications. The load-resistance variation does not affect design calculations, because R_{LOAD} is large. A smaller, 2-kΩ load resistance with a variation of 1 kΩ causes a great change in I_Z, necessitating a zener-diode buffer. If the zener diode is part of an IC, then you can trim R_{BIAS} with a laser, and adding a buffer is trivial. This buried-zener-voltage-reference method seems like a better way to build a voltage reference.□

REFERENCE

1. *Motorola zener-diode manual*, Motorola Inc, 1980.

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