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Low-voltage reference uses the ΔV_{BE} circuit

SOME OF MY RECENT COLUMNS discuss the functions and advantages of zener-diode references (**references 1, 2, and 3**). Although zener diodes are stable and precise voltage references, they require high bias voltage (usually 8V minimum). The bias-voltage requirement precludes most zener-diode references from circuits with supply voltages of 5V or less. Low-voltage zener diodes are available, but their temperature drift renders them useless in precision applications. All semiconductor structures yield basic circuits that are temperature-sensitive; thus, any semiconductor reference must have some form of temperature compensation built in. Zener-diode references use an internal series diode for temperature compensation. Base-emitter-offset-voltage circuits have the same temperature-drift problem and solution, but because they do not depend on a zener junction, they function at lower voltage.

ΔV_{BE} CIRCUITS HAVE THE SAME TEMPERATURE-DRIFT PROBLEM AND SOLUTION [THAT ZENER-DIODE REFERENCES HAVE], BUT BECAUSE THEY DO NOT DEPEND ON A ZENER JUNCTION, THEY FUNCTION AT LOWER VOLTAGE.

The difference equations for two transistors connected as diodes follow (**Figure 1**):

$$\Delta V_{BE}=V_{BE1}-V_{BE2}=\frac{kT}{q}\ln(J_{E1})-\frac{kT}{q}\ln(J_{E2})=\frac{kT}{q}\ln\left(\frac{J_{E1}}{J_{E2}}\right), \quad (1)$$

where ΔV_{BE} is the base-emitter offset voltage, k is Boltzmann's constant, q is the electron charge, T is the absolute temperature, ln is the natural log, and J_E is the emitter current density. When the units of current density are equal, they cancel each other out, and **Equation 1** reduces to **Equation 2**, which expresses the temperature coefficient as a function of the collector currents.

$$\Delta V_{BE}=V_{BE1}-V_{BE2}=\frac{kT}{q}\ln\left(\frac{I_{C1}}{I_{C2}}\right). \quad (2)$$

You obtain the temperature coefficient by differentiating **Equation 2**.

$$TC=\left(\frac{d\Delta V_{BE}}{dT}\right)=86.3\frac{\mu V}{°C}\ln\left(\frac{I_{C1}}{I_{C2}}\right). \quad (3)$$

You use a diode-base-emitter junction to cancel out the drift that **Equation 3** calculates, so the total drift must equal a diode drift of 2.18 mV/°C; the corresponding offset is 650 mV. You can't achieve the area ratio you need to meet these criteria through dissimilar junction areas because this ratio is too large; thus, use a smaller ratio, such as 12-to-1, and the resulting offset voltage is 63.9 mV. An amplifier with a gain of 10.17 yields an out-

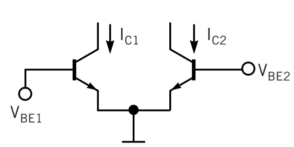

Figure 1 ΔV_{BE} causes a current ratio in the transistors.

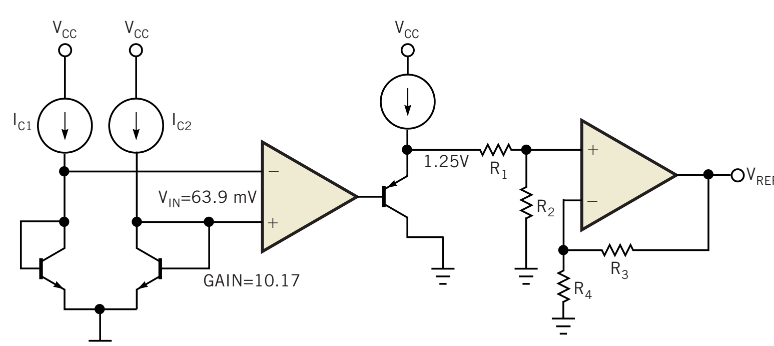

Figure 2 You amplify the ΔV_{BE} and add it to a pnp transistor for V_{BE} to form a bandgap voltage reference.

put voltage of 650 mV (**Figure 2**). Multiplying the 214-μV/°C result of **Equation 3** by the 10.17 amplifier gain yields a drift of 2.18 mV/°C.

The complete bandgap reference uses two transistors for the diodes; these transistors feed current in a 12-to-1 ratio to generate the basic offset voltage and temperature coefficient. An amplifier that increases the offset voltage to 650 mV follows this stage. The output voltage drives the base of a pnp transistor, which has a current source at its emitter. The output voltage is the sum of the pnp base-emitter voltage and the multiplied differential-diode voltage: 1.25V. The final result is that the pnp base-emitter temperature coefficient cancels out the differential-diode temperature coefficient, yielding a stable, low-drift voltage reference. The output stage buffers the voltage reference and provides gain or attenuation to generate different reference voltages. This voltage reference functions in a low-voltage environment with temperature stability and low drift. In schematics, base-emitter-offset-voltage references often look similar to voltage regulators, such as the one in **Figure 3**, but don't confuse them with voltage regulators, because the references have limited current capacity.□

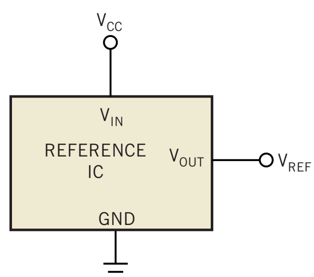

Figure 3

This voltage-regulator schematic resembles the schematic for a ΔV_{BE} circuit.

References

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2. Mancini, Ron, "Designing a zener-diode regulator," *EDN*, Aug 5, 2004, pg 24.
3. Mancini, Ron, "The ultimate zener-diode reference," *EDN*, Sept 30, 2004, pg 26.

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