analog**angle** *By Ron Mancini*

Filter your voltage reference for low-noise performance

THE SHORT-TERM VARIATION in output voltage from a voltage reference is noise. Reference-voltage noise occurs in two frequency ranges: 0.1 to 10 Hz for short-term, peak-to-peak drift, and 10 Hz to 1 kHz for wideband noise. Expressing noise in parts per million is popular because the noise voltage is usually proportional to the reference voltage, thereby keeping the parts-per-million value relatively constant. Bandgap-voltage references have noise voltages ranging from 3 to 16 ppm, but buried-zener voltage references are quieter, with noise voltages ranging from 0.1 to 0.5 ppm. Noise decreases with increased reference current, but increasing the reference current is not an option for most references. Thus, the path to improved noise performance is an external noise filter. Filters are effective noise reducers: A reduction in the noise bandwidth of 100-to-1 results in a noise reduction of 10-to-1 (**Reference 1**).

The circuit in **Figure 1a** shows a typical voltage-reference filter in which the load current flows through R_1, causing a voltage drop across R_1. R_1C_1 provides the filtering function, but the loss of regulation that the voltage drop across R_1 causes demands the addition of a buffer (**Figure 1b**). The buffer reduces the current through R_1 to 1 nA maximum. When you can accomplish the noise filtering with R_1 of 50Ω and a ceramic capacitor, the voltage drop across R_1 is 0.05 μV, and you can ignore it. Use the circuit in **Figure 1** when C_1 is a ceramic capacitor and if the low-frequency breakpoint is adequate for the desired noise performance. The buffer contributes noise to the reference voltage, so configure it as a lowpass filter with a breakpoint that eliminates its internally generated noise.

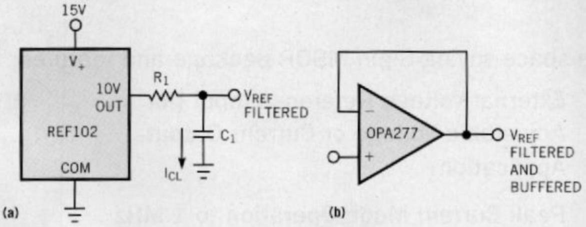

Figure 1 You reduce noise with an R_1C_1 filter, but the filter introduces an error due to output current flowing through R_1, so reducing this current requires a buffer.

When the filter's −3-dB breakpoint has to be low, this circuit configuration has some problems. Increasing R_1 has limitations because its voltage drop limits the reference-voltage accuracy. You can't use a ceramic capacitor because of its poor volumetric efficiency, so select a tantalum or an aluminum-electrolytic capacitor. These capacitor types have appreciable current leakage that is a function of their operating voltage and temperature. Thus, the capacitor-leakage current, I_{CL}, flows through R_1, causing the dreaded voltage drop that ruins the regulation.

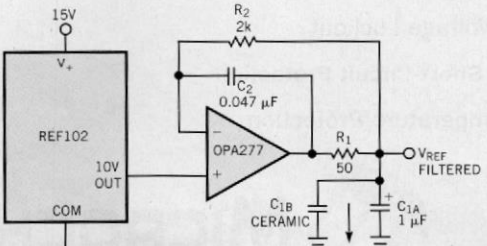

Figure 2 Incorporating a lowpass filter into the feedback loops improves regulation.

The circuit in **Figure 2** solves the resistor problem. Enclosing R_1 in the feedback loop minimizes the effect of the voltage drop across R_1 by dividing it by the op-amp gain of approximately 134 dB. Thus, the effect of the capacitor-leakage currents is negligible. The voltage drop across R_1 subtracts from the output-voltage swing, but if the load current is less than the op-amp output-current capability of 10 mA, the voltage drop is less than 0.5V. The voltage drop across R_2 that the op-amp bias current causes is critical because it adds to the voltage-reference error. When R_2 is 2 kΩ, its voltage drop is 2 μV (1-nA input-bias current); if this voltage drop is too large, reduce the value of R_2.

The filter is at the op-amp output, so a lowpass filter with a −3-dB breakpoint of $1/2\pi R_1C_1$ reduces both the voltage-reference and the op-amp noise. The R_2C_2 network ensures stability by adding a zero into the bode plot. The R_2C_2 network can cause noise-gain peaking, so you should maintain the $R_2C_2=2R_1C_1$ relationship to minimize amplifier-noise-gain peaking. C_{1A} can be an aluminum-electrolytic capacitor that has a low self-resonant frequency; hence, C_{1B}, a ceramic-dielectric capacitor, parallels C_{1A} to keep the total reactance low. This filter can drive high-capacitance loads (consider them part of C_1) if you retain the peaking relationship.□

REFERENCE

1. Stitt, Mark, Voltage-Reference Filters, Burr-Brown application note SBVA002, 1990.

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