Regulator excels in noise and line rejection

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Certain electronic circuits require extremely low-noise power supplies. Low-phase-noise phase-locked loops and high-gain preamplifiers are two examples. "Low noise" here implies self-generated noise as well as unregulated-dc-line noise. The regulator in **Figure 1** exhibits low noise in both these regards, yet is reasonably simple, considering its features. The regulator uses an op amp to amplify a stable voltage reference, V_{REF}. With control transistor Q_1 selected for adequate output current, the circuit produces a regulated output, V_{OUT}, determined by the following expression:

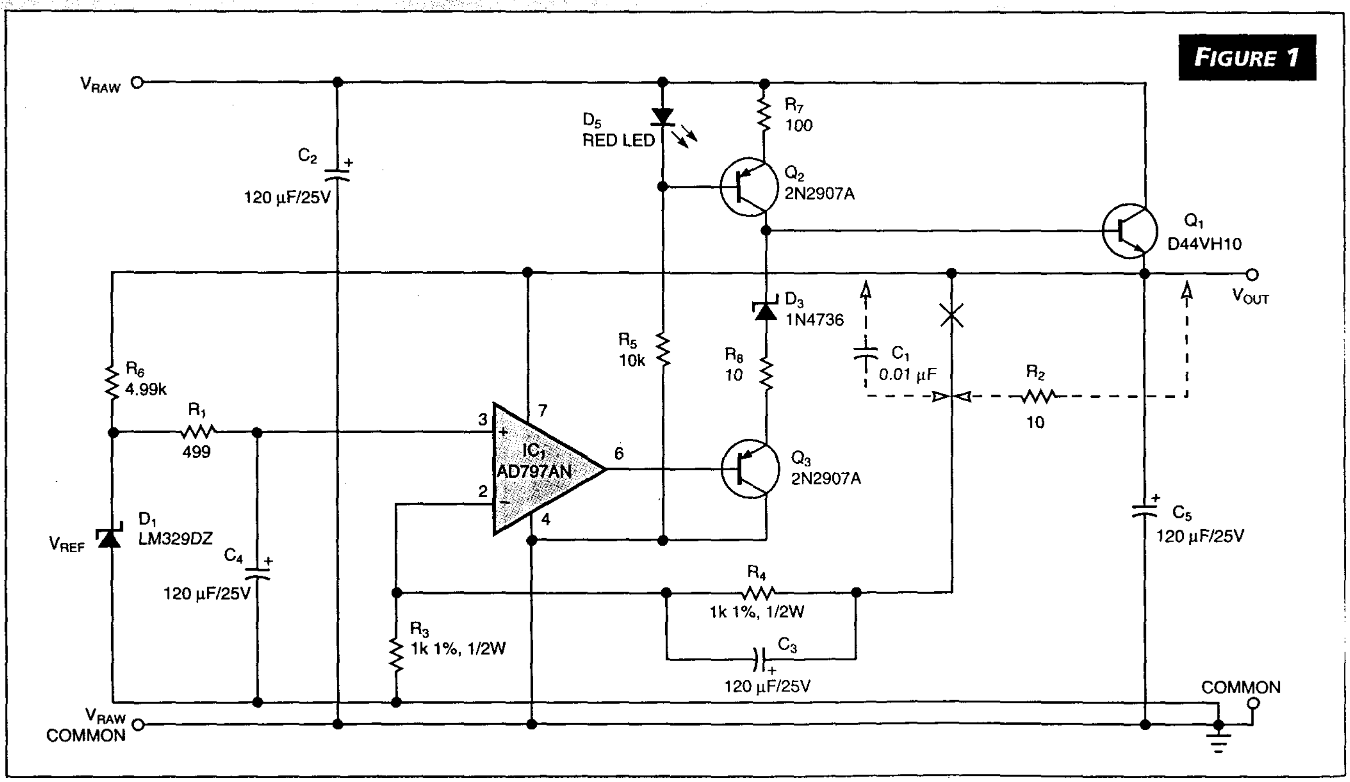
$$V_{OUT} = V_{REF}\left(1+\frac{R_4}{R_3}\right),$$

where V_{REF} is the reference voltage of D_1.

Although this basic approach of bootstrapped-reference regulator design is more than 20 years old, some wrinkles in this circuit set it apart. First, the use of a current source to drive the pass device Q_1 yields relatively low dropout (approximately 1.5V), plus the ability to *bootstrap the op-amp power from the regulated output*. The latter trait is particularly helpful, because it affords greater than 100-dB supply rejection in the audio range, or well above frequencies where most op amps suffer from declining supply rejection. As with classic forms of this regulator, the reference diode D_1 derives its feed from the output, thereby eliminating supply-line dependence. Heavy noise filtering of V_{REF} by R_1 and C_4 reduces the diode's typical 100 nV/$\sqrt{Hz}$ to the equivalent of a few nV/$\sqrt{Hz}$ (at 1 kHz) at IC_1's output.

To achieve low noise, amplifier IC_1 must have low input-voltage noise density; in this case, 1 nV/$\sqrt{Hz}$ for the AD797. But the topology itself should also minimize ac gain to hold down noise increases. C_3 reduces the ac gain of IC_1 to unity, with dc gain set by the R_4, R_3 values. The result is that the overall regulator circuit can operate with output noise on the order of about 3 nV/$\sqrt{Hz}$ at 1 kHz. Line-rejection performance is somewhat difficult to assess. In a specialized high-resolution setup, the regulator's rejection measures within a couple of decibels of test-equipment residual noise, as shown in **Figure 2**.

In comparison with the same IC_1 device operated without supply bootstrapping (**Reference 1**), the relative noise improvement with bootstrapping is 30 to 35 dB and is frequency-dependent. The bootstrapped performance is high enough to be comparable with the use of a preregulator, but



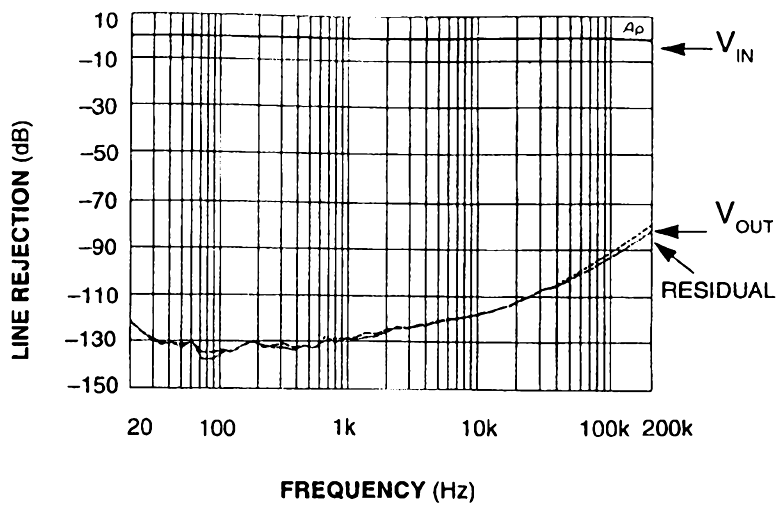
Ultralow noise and high line rejection are the hallmarks of this bootstrapped regulator circuit. Bootstrapping improves the noise performance by 30 to 35 dB.

without its complexity. The output impedance is approximately 1 mΩ at 100 kHz, dropping to a few microhms below 100 Hz. Despite the obvious performance virtues, bootstrapping the reference and op amp is not without some serious application caveats—for example, providing a positive guarantee of circuit startup.

First, you *must* use the op amp in a single-supply mode as shown to prevent possible output state reversal. Second, you should choose level-shift zener diode D_3 for a certain fall-back criterion; namely, the voltage that the output would fall back to should the op amp not initially bias properly. The criterion should provide that, even if IC_1 should momentarily come up in a low-output state, the net bias of the Q_3-D_3 string will still be greater than V_{REF}. Then, with IC_1 not yet fully active, the bias voltage at Q_1 will force V_{OUT} to start positive. Once V_{REF} is exceeded, IC_1 gains control, and the circuit achieves its desired stable state. A suitable selection criterion for D_3 is to simply make its breakdown voltage similar to that of D_1, in this case approximately equal to 6.8V.

As shown, the circuit can supply approximately 250 mA with a nominal output of twice V_{REF}, or approximately 14V. If you need remote sensing, you can add the remote-sense isolation resistor R_2 at the load point. Breaking the normal sense line at X enables the remote-sensing option, with C_1 added to decouple the sense loop at high frequencies. A negative-output version reverses the diodes and capacitors, along with the op-amp supply pins, and substitutes complementary transistors. (DI #1974)

FIGURE 2



The output noise of the regulator in Figure 1 is almost indiscernible from the residual noise in the test equipment. Noise output is lower than -130 dB at 100 Hz and approximately -90 dB at 100 kHz.

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Reference

1. Jung, Walt, "Regulators for high-performance audio, Parts 1 and 2," *The Audio Amateur*, Issues 1 and 2, 1995.