BY BONNIE BAKER

Outputs don't swing rail to rail

Single-supply amplifiers do not truly swing rail to rail at the output. Near the rail, the amplifier is nonlinear. For linear operation, the output of single-supply amplifiers can come within only 50 to 300 mV of each rail (**Figure 1**). Single-supply-amplifier, rail-to-rail-output ads can give a false sense of security. **Figure 1** shows a typical single-supply amplifier's output swing as you drive the output to the rails. The amplifier's linearity starts to degrade long before reaching the output-swing maximums, and the amplifier output never reaches either rail.

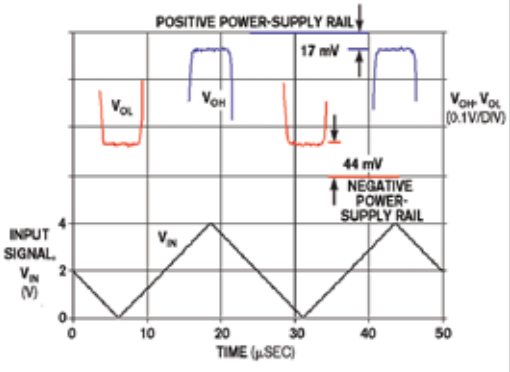

Figure 1 The lower plot illustrates the amplifier's input-voltage swing at a gain of 2V/V. The upper plot shows the amplifier's magnified output voltage.

The conditions of the dc-open-loop-gain specification define the amplifier's linear operating output range. The dc open loop gain in decibels is 20 $\log(\Delta V_{OUT}/\Delta V_{OS})$, where V_{OUT} is the output voltage and V_{OS} is the input offset voltage. When you drive the output high, V_H is the maximum voltage level at the output in the dc-open-loop-gain measurement. V_{OH} is the absolute maximum voltage level with respect to V_{DD} (drain-to-drain voltage) that the output can reach. V_L is the minimum voltage level at the output in the dc-open-loop-gain measurement, and V_{OL} is the absolute minimum voltage level that the output can reach. V_H is less than V_{OH}, and V_L is greater than V_{OL}.

From a signal-chain perspective, you can see an op amp's output limitations to swinging rail to rail when the op amp is driving an ADC. The FFT plot in **Figure 2a** shows the amplifier/ADC-combination response to a 1-kHz signal in a 5V system. The amplifier's typical closed-loop bandwidth is about 3 MHz with a typical slew rate of 2.3V/µsec. The amplifier output voltage swings from 140 mV to 4.66V. In this 5V-supply system, the headroom between the signal and rails is 140 mV. For this amplifier, the V_{OL} minimum specification is 15 mV above ground. The V_{OH} maximum specification is $V_{DD}-20$ mV.

Figure 2a illustrates the nonlinearity-output-stage effects with a single-supply CMOS amplifier by showing distortion at 2, 3, and 4 kHz and so on. By reducing the amplifier's output signal to 272 mV from each rail, the data looks perfect with only the ADC distortion (**Figure 2b**).

When using a single-supply amplifier, read the fine print! Some single-supply amps have output-stage charge pumps, allowing the amplifier's output swing to go to and well beyond the power-supply rails. In every case, read your data sheet and refer to the conditions on the open-loop-gain test. EDN

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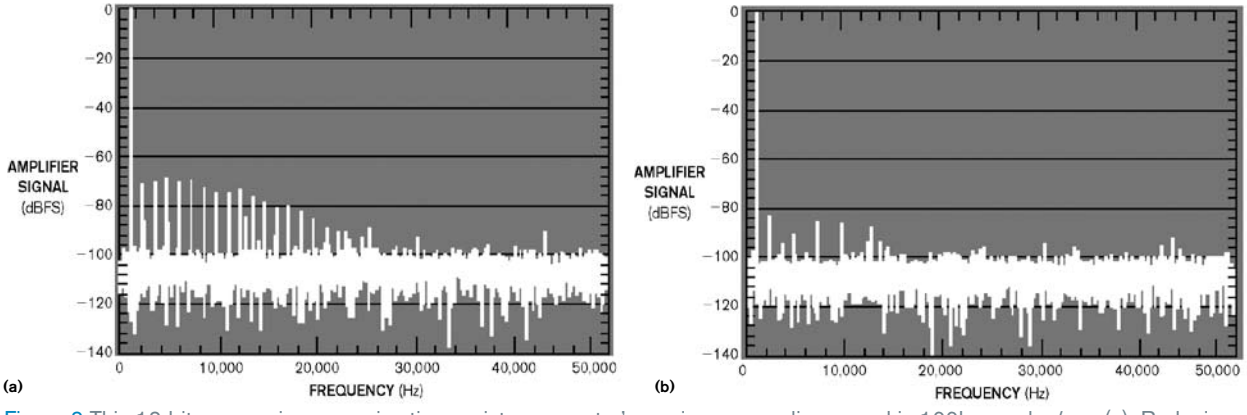

Figure 2 This 12-bit successive-approximation-register converter's maximum sampling speed is 100k samples/sec (a). Reducing the amp's output signal to 272 mV produces better results (b).