BY BONNIE BAKER

A designer's guide to op-amp gain error

As you sit down to select the proper operational amplifier for your circuit, the first order of business is to determine the signal bandwidth that your system will send through that amplifier. Once you settle on this parameter, you can start to look for the right amplifier. The high-speed-op-amp gurus warn that you should avoid using analog devices that are too fast for your application. So you try to pick an amplifier with a closed-loop bandwidth just a little higher than the maximum frequency of your signal.

This strategy may sound like a good product-selection recipe, but it will probably bring disaster to your application board. In the lab, you may find that, when you put an input-sine-wave signal at the application's maximum frequency into your system, the output signal from your amplifier does not go across the expected full-scale analog range. The gain on the signal is much less than you would expect. If the slew-rate magnitude of your amplifier is more than adequate and you are not driving the amplifier output into the power-supply rails, then what has gone wrong?

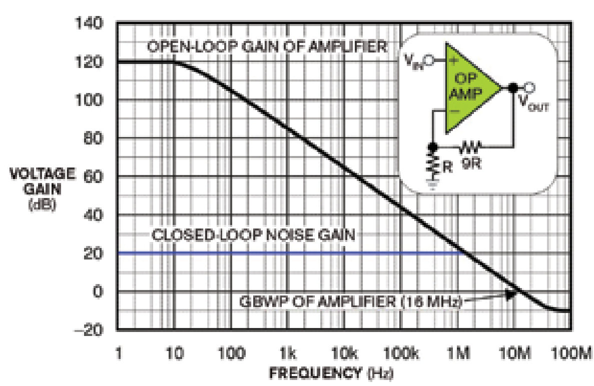

Figure 1 The open- and closed-loop gain of this voltage-feedback amplifier has a gain-bandwidth product of 16 MHz and a circuit noise gain of 10V/V.

Stop double-checking your resistor values! When designing an amplifier into a gain cell, you must know your signal's maximum bandwidth, the amplifier's closed-loop noise gain, the amplifier's gain-bandwidth product, and how much gain error your design can tolerate. The closed-loop noise gain is the amplifier's gain, as if a small voltage source were in series with the op amp's noninverting input.

You can work this problem through by example. For instance, start with a signal bandwidth of 1 MHz. The amplifier's circuit noise gain in **Figure 1** is 10V/V. **Figure 1** also shows the open-loop frequency response of an amplifier that has just enough bandwidth for this circuit—or so you think. The amplifier has a 16-MHz gain-bandwidth product. The op amp looks as though it can support a gain of 10V/V, or 20 dB, out to 1 MHz, but look a little closer. The gain of the open-loop gain curve at the signal's bandwidth is

$$A_{OL-SBW} = \frac{GBWP}{SBW},$$

where A_{OL} is the open-loop gain of the amplifier, SBW is the signal bandwidth, and GBWP is the gain-bandwidth product.

In this case, the amplifier's open-loop gain, A_{OL-SBW}, is 16V/V at 1 MHz. But here's the kicker: The closed-loop gain error in this circuit is $NG/(A_{OL-SBW}+NG)$, where NG is the noise gain. The closed-loop gain error at 1 MHz in this example is 0.385, or a gain error of 38.5%.

For this circuit, if you are willing to tolerate a gain error of 0.05 from your amplifier and you understand that the GBWP of an amplifier can change a maximum of 30% from product to product and over temperature, you need an amplifier that has a GBWP greater than 246 MHz. The guiding formula is

$$GBWP_{OPA} = 1.30 \times \frac{NG \times SBW \times (1-ERROR)}{ERROR},$$

where $GBWP_{OPA}$ is the op amp's gain-bandwidth product.

Use this formula during your first pass when you choose an amplifier for your circuit. After you determine the amplifier's bandwidth, you can start to delve into the other important amplifier characteristics for your application. EDN

REFERENCES

1 Bendaoud, Soufiane "Gain error affects op amp choices," *Planet Analog*, July 14, 2006, www.planetanalog.com/features/analog/showArticle.jhtml?articleID=190400337.

2 Mancini, Ron, "Op-amp-gain error analysis," *EDN*, Dec 7, 2000, www.edn.com/article/CA56190.