Rarely Asked Questions—Issue 128
Citius, Altius, Fortius

By Gustavo Castro

Question:

The data sheet for the amplifier that I've chosen for my application specifies a small signal bandwidth along with a large signal bandwidth, and they are quite different specs. How do I determine if my signal qualifies as small or large?

Answer:

When we talk about the bandwidth of an amplifier, we are really talking about the frequency response of the amplifier using the small signal model. This model is derived assuming the circuit is linear around a bias point or, in other words, its gain remains constant independent of the applied signal. If a signal is small enough, the model works very well and its deviation from reality is impossible to detect.

Everybody likes working with this model because it simplifies the design and analysis process. If we were to use large signal models—that is, include all the nonlinear equations—circuits would get awfully complicated, at least for mortals like myself.[1] Therefore, small signal models and sinusoidal signals bring the complexity to a manageable level.

Strictly speaking, though, even the smallest practical signal changes the bias point of a transistor circuit (for example, an op amp) by a little. The larger the signal, the more difficult it gets to ignore nonlinear effects, which most evidently manifest as distortion. At some point, the signal gets too fast and so large that the amplifier reaches its slew rate limit—equivalent

to the maximum rate of change of the amplifier output, and typically expressed in volts per microsecond (V/µs). When the slew rate is limited, the amplifier falls behind, it does not reach the signal peak before the signal starts to ramp down, and the overall result is that the signal amplitude is smaller than expected. At that point, the amplifier has about reached the large signal bandwidth. Normally this happens at frequencies below the small signal bandwidth, and the signal is most definitively distorted. But the signal does not suddenly turn into a distortion fiasco; instead, distortion gradually increases with both amplitude and frequency. We could say that the signal is too large when the distortion is more than the system can tolerate.
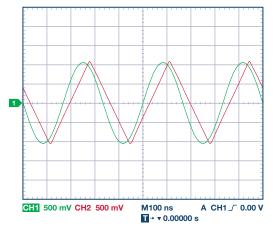

Figure 1. When an 80 MHz amplifier has reached the large signal bandwidth conditions, the output signal (red) can no longer follow the 3 MHz input sine wave (green).

So, how do we know if an amplifier is fast enough to handle a signal? First, and as usual, make sure the small signal bandwidth is enough for the desired gain. If it is, then look for a large signal bandwidth specification (or plot) in the data sheet. If not available, the easiest solution is to go to the fundamentals and use the formula

$$SR \text{ [V/µs]} = Peak\_Amplitude \times 6.28 \times Frequency \text{ [MHz]}$$

A good rule of thumb is to choose an amplifier with 10× more slew rate than required. Then, take a look at the distortion curves on the data sheet at the desired frequency and amplitude to make sure the signal is small enough for the amplifier.

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[1] That's a job better suited for computers running simulations, and even then, we opt for simplifications that allow them to reach a numerical solution in a reasonable amount of time.

For example, ADA4807-1 as a voltage follower has a slew rate of 225 V/µs with ±5 V supply. Even though the amplifier's small signal bandwidth is around 180 MHz, the amplifier wouldn't be able to exceed 36 MHz with a 2 V p-p signal. And for a 4 V p-p, the same theoretical limit would come down to about 18 MHz. Moreover, slew rate is usually measured with a step, under which internal slew enhancement circuits kick in to improve settling time, but response to sinusoidal signals can actually be a bit slower (the data sheet specifies 28 MHz for large signal bandwidth with 2 V p-p). The distortion plots in the typical characteristics section show the harmonic distortion increase with frequency and amplitude, from which it is possible to determine if you can take your signal *citius, altius,* and *fortius* (faster, higher, and stronger).

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