Keywords: linear amplifier response, feedback distortion, perfect-diode comparator, slew-rate, Op Amp, frequency response, bias, gain, low pass filters, signal bandwidth

APPLICATION NOTE 4295

Small-Signal Bandwidth in a Big-Band Era

By: Bill Laumeister, Strategic Applications Engineer
Jun 24, 2011

Abstract: The popular music of several decades ago required many instruments, hence the name "big band era." Today, bandwidth increase is again a sign of the times. The explosion of Internet usage, network-capable cellular phones (3G, 4G, LTE, and Wi-Fi®), music players, and digital video cameras has expanded consumers' expectations for bandwidth. We are on the cusp of wholesale data transfer to all portable devices. Bandwidth has become king, and we are therefore again in a "big bandwidth era." So, why discuss small-signal bandwidth?

A similar version of this article appeared in the April 8, 2011 issue of *Planet Analog* magazine.

Many operational amplifiers (op amps) include a specification of small-signal bandwidth in their data sheets. (All op amps have a "sweet spot" for better bandwidth, even if it is not mentioned in the data sheet.) This specification is typically based on a signal amplitude limited to about one-tenth of a volt, and at first glance seems primarily for use in comparison and for "boasting rights" with other op-amp companies.

Some applications, however, can take advantage of the small-signal bandwidth, which can be many times greater than the large-signal bandwidth for an op amp. For example, the MAX4104 op amp has a small-signal bandwidth (0.1V or less) of 625MHz, and a large-signal bandwidth (2V peak-to-peak) of 11MHz. Most applications make use of the large-signal bandwidth. Small-signal bandwidth is high because the op amp is operating in its midrange sweet spot (**Figure 1**).

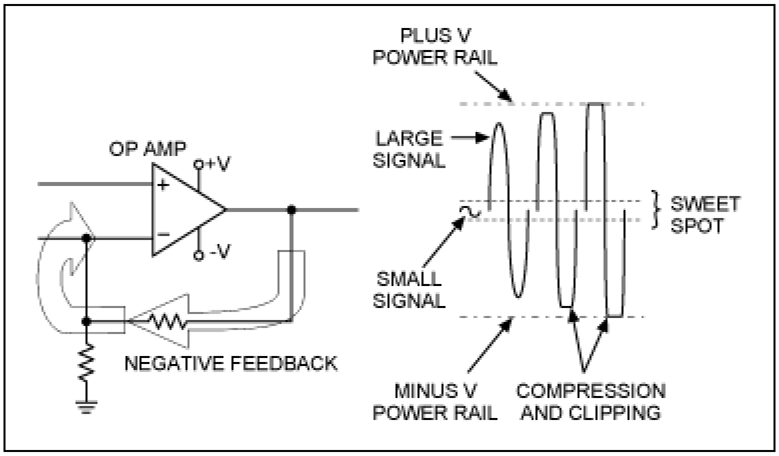

Figure 1. Signal conditions determine the bandwidth through an op amp.

Typically, the sweet spot for input signals is near one-half the power-supply voltage. The amplifier is most linear in that region, and produces the best signal quality. Op amps have a large open-loop gain, and they employ negative feedback to control the amplifier by trading this open-loop gain for stability and linearity. As the amplifier output approaches either power rail, less feedback is available, which in turn, diminishes the ability of feedback to linearize the amplifier response. As feedback is reduced outside the sweet spot, the frequency response decreases and distortion increases. Op amps that offer "rail-to-rail" operation use special circuit configurations to minimize distortion near the power rails, but a careful reading of the data sheet for a typical "rail-to-rail" output shows that the output current diminishes to zero at the rails.

Modern op amps are fabricated with processes in which individual transistors have multi-gigahertz bandwidths. An op amp, however, is composed of tens or hundreds of transistors, resistors, and capacitors, and the net effect of that circuit structure is to reduce the overall bandwidth—often by an order of magnitude or more. Among the effects of this natural bandwidth reduction are phase and amplitude errors caused by the stray interstage capacitance and resistance. Bandwidth reduction limits slew rate, and is amplitude-sensitive as one would expect. Thus, small signals have larger bandwidths than large signals.

Some applications, however, can use the small-signal bandwidth. In one such application—an impedance converter for a remote sensor—a small signal drives a relatively long cable. System requirements may include amplification up to a tenth of a volt, and the capability to drive 50Ω or 75Ω coax. The first amplifier in the system usually sets the signal-to-noise ratio. Obviously bandwidth and signal-to-noise ratio are tied together. Thus, utilizing the small-signal bandwidth by limiting the signal amplitude may allow use of a less expensive op amp that draws less power-supply current.

Leveraging the Op-Amp Frequency Characteristics

Although bandwidth limiting detracts from an op amp's performance, you can leverage bandwidth limiting to get the most from an inexpensive op amp. For instance, what if you need to limit the signal bandwidth with a simple 1MHz lowpass filter? For noncritical applications, you might use an inexpensive op amp like the MAX4245 (**Figure 2a**). For a 3MHz lowpass filter, you could use a MAX4330 (**Figure 2b**). For more critical applications, a Sallen-Key active filter that precisely controls the cut-off frequency and slope is more appropriate.

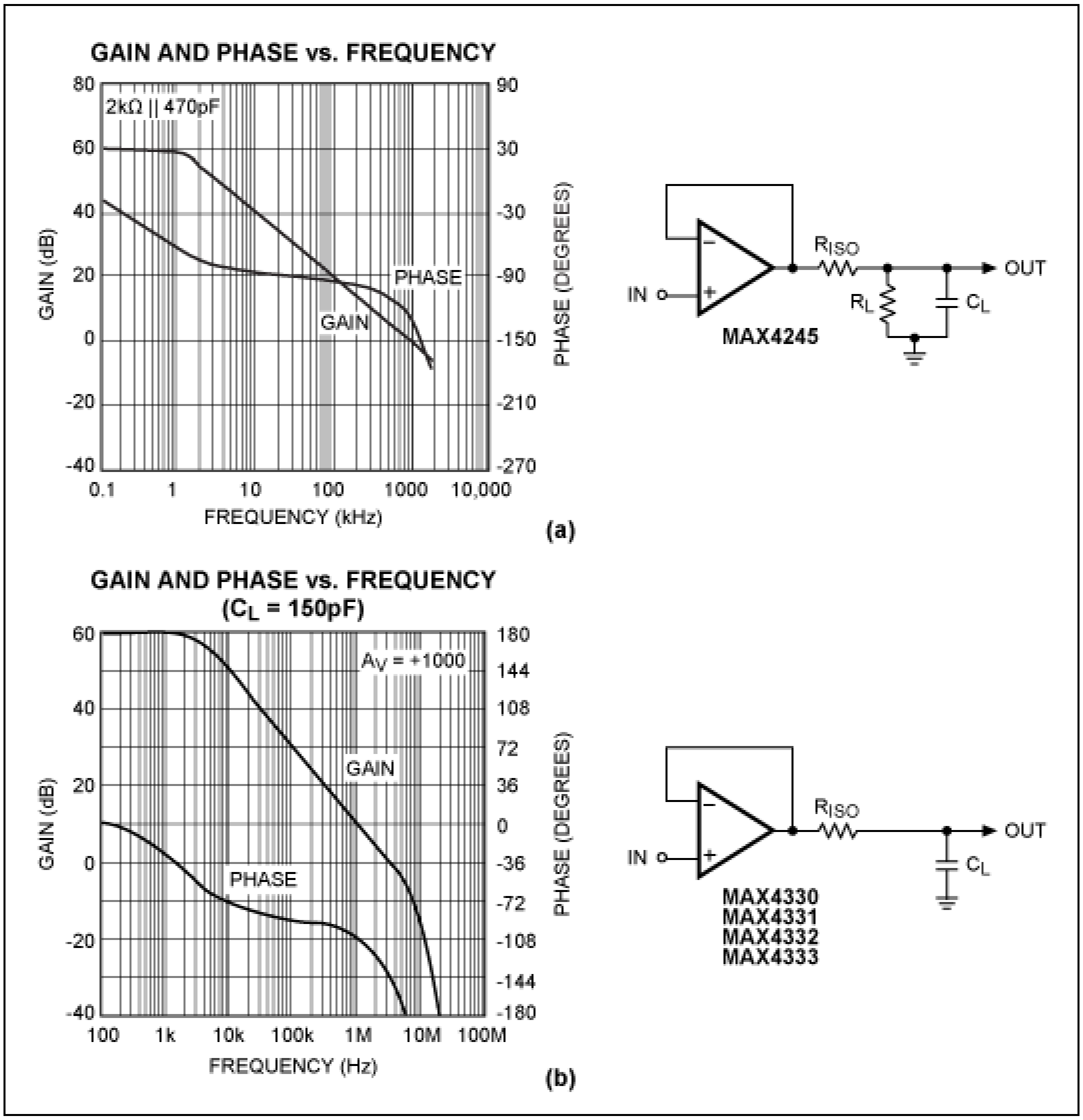

Figure 2. These circuits operate with inexpensive op amps because they deliberately limit the signal bandwidth to 1MHz (a), and 3MHz (b).

The lowpass bandwidth can be combined with other functions to reduce system cost. A precision rectifier made of "perfect diodes," for example, can smooth the edges of a signal by reducing the signal bandwidth. (A "perfect diode" is an op amp with a diode in the feedback loop, which produces a diode response without the usual forward-voltage drop. See **Figure 3**.)

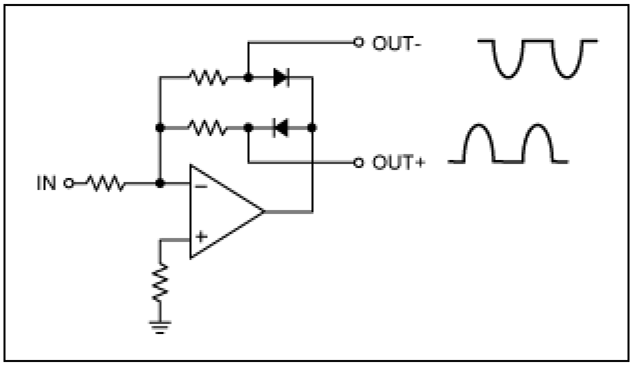

Figure 3. Diodes in the feedback path enable this op-amp circuit to perform full-wave rectification without the loss associated with forward-voltage drops in the diodes.

A circuit that converts differential to single-ended signals while reducing high-frequency noise can also operate with an inexpensive op amp. And as another example, you can construct a comparator with hysteresis (a Schmitt trigger) that ignores high-frequency noise in its threshold voltage (**Figure 4**). Noise below the threshold is ignored, and positive feedback latches the output state until the opposite threshold is exceeded. The output is slew-rate limited by the op-amp response.

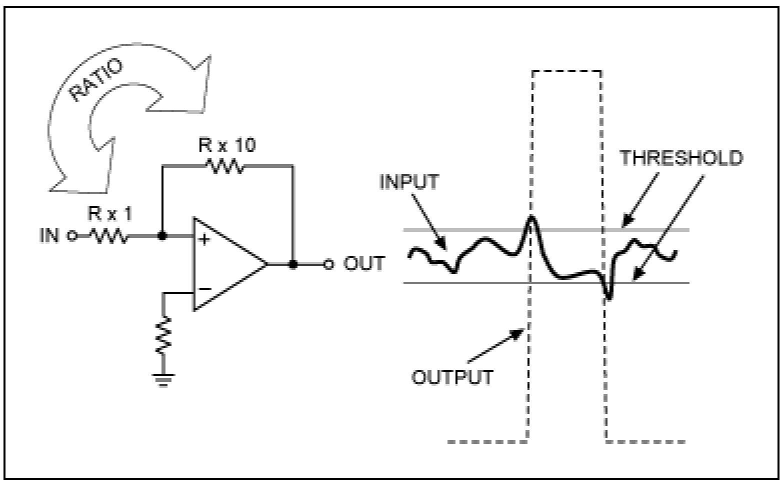

Figure 4. The modest bandwidth of this inexpensive op amp allows the Schmitt-trigger circuit to ignore high-frequency noise.

Slow op amps tend to be inexpensive, and they can reduce system costs by combining functions that take advantage of the op amp's native frequency response. Bias and reference circuits for power supplies can take advantage of the lowpass characteristics to decouple noise and produce clean power. Op amps can isolate circuits from other circuits and act as lowpass filters. In **Figure 5**, for example, op-amp voltage followers enable a single voltage reference to be shared by an analog-to-digital converter (ADC), a digital-to-analog converter (DAC), and other circuits. The followers' high input impedance and low output impedance serve to isolate the various circuits from one another. This isolation mitigates the effect of trace lengths on the circuit board, and prevents crosstalk between the circuits. Because the voltage reference output is expected to be a single DC value, the low-bandwidth op amps enhance its quality by acting as lowpass filters.

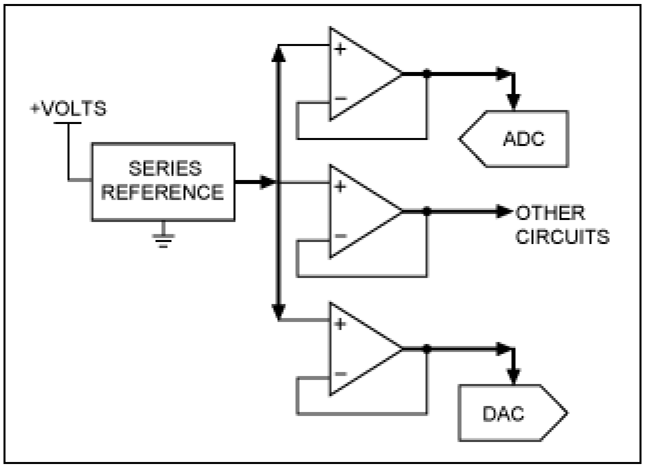

Figure 5. These inexpensive op amps distribute a single reference voltage to various circuits, while their low bandwidth serves as a welcome noise filter.

We are in the midst of an explosion in communications, in which consumers have come to expect high-speed communication networks to be widely available. In the U.S., government agencies have begun to consider universal broadband availability, which is similar to the government's infrastructure mandates in the 20th Century. This infrastructure—rural electrification, universal telephone service, and the interstate highway system—has greatly enhanced our standard of living. When we think about wider and wider communication bandwidths, we should also think about all the systems that control that bandwidth. Circuits for equalization, channel selection, automatic gain and frequency control (AGC and AFC), and many others require slower, low-frequency control. Even in this big band era, low-bandwidth op amps have an established place.

References

1. Application note 656, "Design Trade-Offs for Single-Supply Op Amps."
2. Application note 4287, "Reconstructing Analog Video with the Maxim Video Filter Family."
3. Application note 4345, "Well Grounded, Digital Is Analog."

Related Parts		
MAX4036	Low I_{BIAS}, +1.4V/800nA, Rail-to-Rail Op Amps with +1.2V Buffered Reference	Free Samples
MAX4237	SOT23, Very High Precision, 3V/5V Rail-to-Rail Op Amps	Free Samples
MAX4245	Ultra-Small, Rail-to-Rail I/O with Disable, Single/Dual-Supply, Low-Power Op Amps	Free Samples
MAX4330	Single/Dual/Quad, Low-Power, Single-Supply, Rail-to-Rail I/O Op Amps with Shutdown	Free Samples
MAX4401	Single/Dual/Quad, Low-Cost, Single-Supply, Rail-to-Rail	Free Samples

	Op Amps with Shutdown	
MAX9911	200kHz, 4µA, Rail-to-Rail I/O Op Amps with Shutdown	Free Samples

More Information
For Technical Support: http://www.maximintegrated.com/support
For Samples: http://www.maximintegrated.com/samples
Other Questions and Comments: http://www.maximintegrated.com/contact

Application Note 4295: http://www.maximintegrated.com/an4295
APPLICATION NOTE 4295, AN4295, AN 4295, APP4295, Appnote4295, Appnote 4295