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What's All This Output Impedance Stuff, Anyhow? (Part 1)

A few engineers were having a debate. According to all the books, some of them said, op amps are supposed to have zero output impedance, or very low. That means the output voltage won't change, just in case the output current changes. Some older op amps had an output impedance of 600 Ω or 50 Ω. So, the gain of the amplifier won't change just because the load changes. That must be good.

But a couple of other engineers pointed out that many modern op amps have a very high output impedance. The advantage of high output impedance (for the op amp) is that when the load gets lighter, the gain goes up. Is there any harm in having a higher gain?

Sometimes it's advantageous to have high gain, and higher gain isn't necessarily bad. This high output impedance usually occurs on rail-to-rail outputs, which are "drain-loaded." You can't have an emitter-follower or source-follower output on a rail-to-rail output! If you did, it wouldn't swing rail-to-rail.

FOOLISH IDEA

Let's have a little more insight on this gain stuff. "Nobody needs an op amp with gain higher than 200k," I once heard one foolish engineer say. "Besides, nobody would want to measure an op amp's gain at 2 million or 6 or 10 million, because it would take many seconds of test time, at 0.1 Hz or slower, and nobody wants to pay for that test time."

Wrong! We can test op amps for a gain of 1 million or 10 million in just a few dozen milliseconds. We read the summing-point voltage, put in a suitable step, and wait a couple milliseconds for the summing-point voltage to settle. Then we wait a few milliseconds more, read the changed voltage, and average for a few milliseconds more (perhaps for 16 ms).

The voltage gain is related to the reciprocal of those few microvolts of error. We measure gain for a step, not for sines. So does everybody else in the industry. The settling time is related to the amplifier's gain bandwidth, not to its low-frequency "pole," which is just a fiction.

This same guy argued that when you use an op amp with a gain of 2 million or 10 million, "You can only see higher accuracy when you have signals well below 1 Hz." Wrong again! If you put in a +1-mV square wave at 10 Hz into a good op amp set up with feedback resistors for a gain of +1000, the amplifier with 2M will settle in a few milliseconds to 999.5 mV.

The output for the gain of 20M will settle to 999.95 mV. If you had a gain of just 200,000, it would settle to 995 mV. Even with sine waves at 10 Hz, you can see the difference in better gain accuracy. The output would be 999.5 mV or 999.95 mV p-p, not 995 mV p-p, even at 10 Hz! Higher gain is better.

A SECOND OPINION

"If an op amp has a high gain at rated load, and its output impedance is high, then the gain gets higher when the rated load is taken off," another engineer argued. "The dc gain goes up, and then the gain rolloff will be steeper, and you'll get more phase shift, which will make the loop less stable."

Well, I haven't seen any op amps whose rolloff gets steeper when the rated load is taken off, not for 35 years—an amplifier whose phase-shift goes bad. All modern op amps have Miller feedback from the output, so when the gain gets higher, the low-frequency break just goes back even further—even slower than 0.01 Hz. I've seen that a lot. So, there's no danger there if the gain gets "too high." A gain of 1M or 10M or 100M does no harm.

What is an example of an op amp where the gain goes up when the rated load is taken off? A lot? The LMC662 or the LMC6482. These are CMOS amplifiers with ~ "rail-to-rail" output capability. Of course, it makes a difference how the output is controlled.

If there is a Miller integrator (capacitive feedback loop around the output stages) to make the gain rise smoothly at low frequencies, that can make the gain smooth indeed. The gain could rise smoothly at 6 dB per octave, even back below 1 Hz or 0.1 Hz.

Okay, where is the proof of the pudding? What does the gain look like? What does it do for a closed-loop gain of 10? More in the next issue!

The real performance of an op amp driving a load is also related to the g_M, or transconductance. If an op amp can't put out much current, no matter how you try, then it won't have good performance when you ask it to drive heavy load currents. That's generally true if the Z_{OUT} is high or low. You gotta have some g_M. (As the old trucker used to say, you can't climb hills with paper horsepower.)

Let's look at examples of both types. If the load is lowered, does it hurt the gain accuracy? The distortion? If the load is lightened, does it hurt the gain accuracy ? The distortion? The settling time? In the next column, we will put these questions to the test using the test circuit shown for the "best" amplifier of 2006 *(see "What's All This Best Stuff, Anyhow?" at* www.electronicdesign.com, *ED Online 14109).*

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