



Bruce Trump Jul 10, 2012

Rail-to-rail amplifiers are able to produce output voltages very close to ground... but how close? We're talking about CMOS op amps that are often used on low voltage designs when you are trying to maximize output voltage swing. Our specifications for these devices generally look something like this:

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
OUTPUT					
Voltage output swing from both rails	$R_L = 10k\Omega$		15	25	mV
	$R_L = 2k\Omega$		35	50	mV

This makes it appear that the output will never swing much closer than 15mV from ground and the last 15mV can be critical for accurate zero-based measurements. But wait... you really need to carefully interpret all the conditions of this specification. The load is assumed to be connected *halfway between the power supply terminals*. These conditions are often found at the top of the spec table where you'll see a statement like this...

R_L connected to $V_S/2$.

In this specified condition the amplifier must sink current through the load resistor as the output approaches ground. This reflects the way the amplifier is tested, assuring that it can properly source *and* sink current. It's a sensible and conservative way to test and specify the amplifier but it may not be the way your load is connected. Suppose your load is connected to ground as in Figure 1. The load resistor actually helps pull the output to ground and the amplifier is not required to sink current.

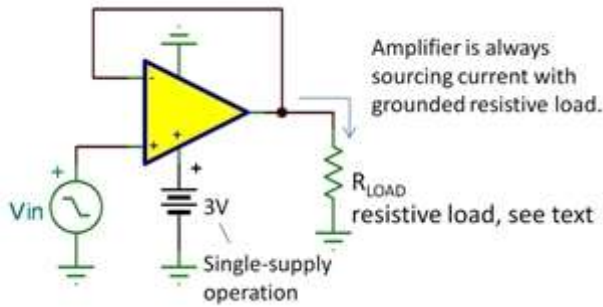


Figure 1.

In this condition, most CMOS op amps can swing very close to ground—within a millivolt or two. The specifications may not highlight this capability but it is hinted in the graph showing the output voltage swing as a function of output current, figure 2. The graph perhaps could benefit from more resolution, but you can see the output voltage converging on the specified voltage rails for this test, $\pm 2.75\text{V}$. For single supply operation, the V- supply is equal to 0V.

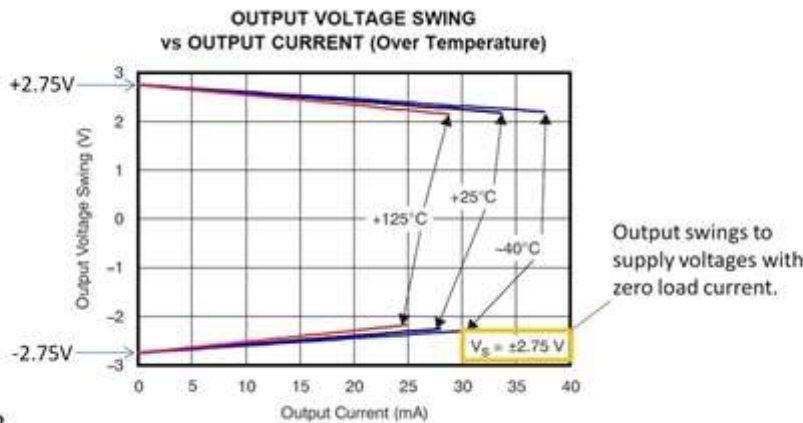


Figure 2.

Now, I need to add a few provisos. Notice in figure3 the feedback network is referenced to ground. You need to consider all sources of load on the amplifier, not just R_L . In this case $R_1 + R_2$ are effectively additional ground-referenced load in parallel to R_L . But if R_1 were referenced to a positive voltage, the amplifier would be required to sink current coming through the feedback network as the output neared 0V and the output would not be able to swing quite so close to ground.

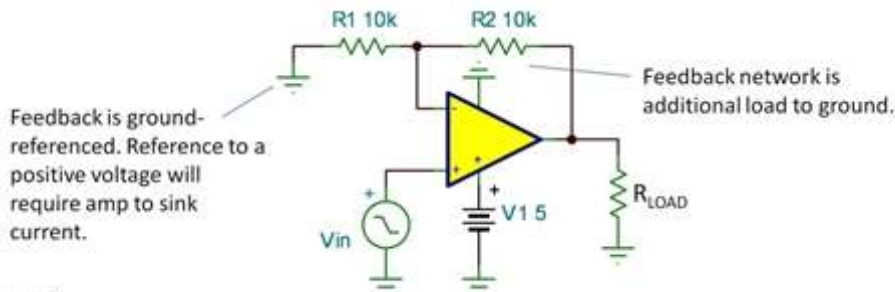


Figure 3.

- **Another proviso.** In this same circuit, if the gain is made high, input offset voltage may affect your *apparent* output swing. For example, in $G=20$, if the input is offset voltage of the op amp is $+1\text{mV}$, zero input will produce a 20mV output. That's not due to an output swing limitation, it's an offset voltage issue. Of course, a small negative input voltage will bring the output very near 0V but your circuit may never have a negative input voltage.

And another—AC signals with reactive loads may be an exception. Load current and voltage are not in-phase with a reactive load so the amplifier may be required to sink current as the output voltage approaches ground.

Yet another—We are referring to CMOS op amps. Bipolar (BJT) op amps cannot swing so close to ground.

Low voltage, battery operated circuits are challenging and it seems that we're always struggling to maximize voltage swings. With a good understanding of op amp capabilities you may squeak out additional output swing close to ground. If you have questions about a specific amplifier or circuit configuration, check with us on our [E2E forums](#).

Thanks for reading and, as always, comments are welcome below. For those who might be allergic to posting a public comment, you can send email to thesignal@list.ti.com.

Bruce

2 comments 0 members are here



[Soufiane Bendaoud](#) *over 12 years ago*

Hi Bruce:

This can become a more serious problem in a two (or more) stage amplification as the saturated output of the first stage is multiplied by the gain of the second stage and so on. Perhaps the easiest way to overcome this problem is to use the LM7705 negative bias generator, designed to work with virtually any single supply amplifier. In short, it can save the user several counts when trying to digitize a signal



[Bruce Trump](#) *over 12 years ago*

Thanks, Soufiane, the LM7705 is a really neat solution when you need to get accurately to 0V . It generates a small (approximately 0.25V) negative supply so you power the V^- rail of an op amp.