Bruce Trump Jul 31, 2012

Offset Voltage and Open-Loop Gain—they're cousins

Everyone knows what offset voltage is, right? In the simplest G=1 circuit of figure 1a, the output voltage is the offset voltage of the op amp. The offset voltage is modeled as a DC voltage in series with one input terminal. In unity gain the offset is passed directly to the output with G=1. In the high gain circuit on the right the output voltage is 1000·Vos, right?

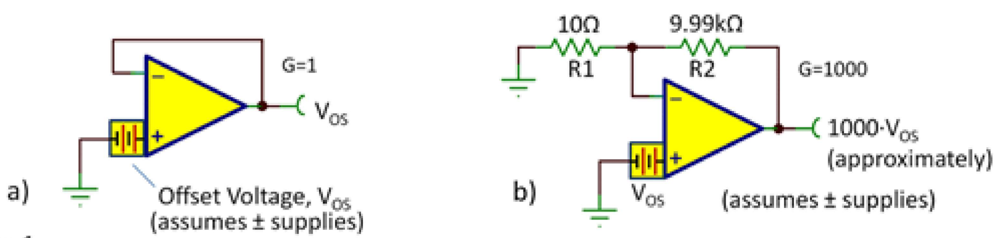

Figure 1.

Well, nearly so, but not quite. Understanding the "not quite"can help you understand errors in your op amp circuits.

In the first case the output voltage was very near mid-supply (we're assuming ± supplies). This is the output voltage at which we define and test offset voltage. But in the second case, the output may be several volts, assuming several millivolts of offset. That requires a small additional differential voltage at the input of the op amp to create that output swing (according to open-loop gain of that amplifier). Let's do some numbers:

If the DC open-loop gain is 100dB, that amounts to 1/10^(100dB/20) = 10uV/V. So for every volt of output swing from mid-supply, the input voltage must change by 10uV. **Think of it as an offset voltage that changes with DC output voltage**. With 9 volts of output swing it's 90uV change. Maybe that's insignificant in your circuits. Maybe not.

The point is that thinking of finite open-loop gain as a changing offset voltage with a change in output voltage provides an intuitive way to size up the error. And the character of that error may matter, too. To test offset voltage and open-loop gain, we use a fancy two-op loop circuit. With it we can control the output voltage and measure the offset voltage. If we sweep the output voltage through its full output range the change in offset voltage often looks something like figure 2.

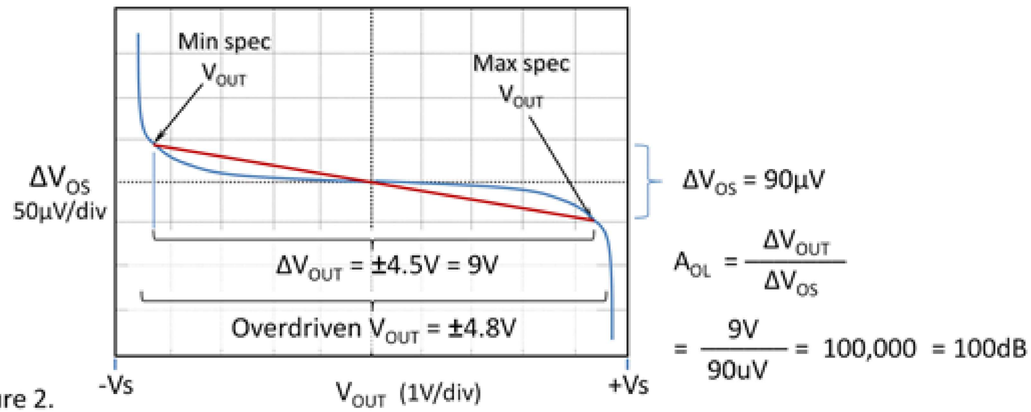

Figure 2.

Note that the greatest change in offset voltage tends to occur at the output extremes, near the positive and negative rail. The op amp is "straining" to produce its maximum output. The incremental open-loop gain is higher in the middle and falls near the output nears the rails. As you plan your circuits, expect that this is the case. Offset voltage will increase more dramatically as you push the op amp to its swing limits.

Not all op amp manufacturers specify A_{OL} the same way. Our precision op amps are tested for open loop gain, averaged over a generous output swing range for good linear operation (the red line in figure 2). In the spec table it looks like this:

OPEN-LOOP GAIN	Conditions	Min	Typ	Max	Units
Open-Loop Gain A_{OL}	(V-) + 0.5V < V_O < (V+) - 0.5V, R_L=10kΩ	100	120		dB
	(V-) + 0.5V < V_O < (V+) - 0.5V, R_L=2kΩ	96	116		dB

Shows that min A_{OL} is assured with output swing 0.5V from rails.

Two load conditions shown. Higher A_{OL} with 10k load.

Table A.

When the amplifier is overdriven (creating a larger offset voltage) the output will swing closer to the rails. Sometimes we show output swing that differs from the conditions in table A. The output swing in table B, for example, shows the output voltage with the input overdriven. This is affectionately known as a or "slam spec" in our op amp development group, meaning that the input is overdriven and slammed as far as it can go to the rail.

OUTPUT	Conditions	Min	Typ	Max	Units
Voltage output swing from rails	R_L=10kΩ	0.2	0.15		V
	R_L=2kΩ	0.3	0.2		V

Table B.

Both types of specs are useful, depending on the requirements of your application. The key is to understand and carefully interpret the specifications.

- Thanks for reading and comments welcome.

Bruce email: thesignal@list.ti.com

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Stephen Power *over 12 years ago* +1

Hi Bruce

Would a more correct model of Input Offset Voltage be (Vos + Vo/AOL) in series with the non-inverting op ar

Bruce Trump *over 12 years ago* +1

Yes, Stephen, that is a good way to think of it. You could also add a term for the offset induced by common-r

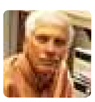
Stephen Power *over 12 years ago*

Hi Bruce

Would a more correct model of Input Offset Voltage be (Vos + Vo/AOL) in series with the non-inverting op amp input rather than just Vos as sometimes depicted in text books? (Vos is the Input Offset Voltage for Vo=0V, Vo is output voltage and AOL is of course open-loop gain)

regards

Steve



Bruce Trump *over 12 years ago*

Yes, Stephen, that is a good way to think of it. You could also add a term for the offset induced by common-mode rejection errors Vcm / CMRR, where CMRR is expressed in V/V, not dB. Vcm is the deviation away from the specified zero common-mode point. And you can add another temperature-dependent term for the offset voltage drift with temperature.

Regards-- Bruce

Carter Liu *over 11 years ago*

Hi Bruce

How do you test the Vol of a certain OpAmp?what signal source do you use and how to eliminate the influence of Vos when testing?

And I also want to know how to test the GBP of a certain OpAmp,because each time I tested an Amp I cannot get the value of GBP specified in the datasheet,especially for those with big GBP products such as OPA847,OPA694...

My email :carter-liu@ti.com;409204017@qq.com wish your response!

Regards

Carter Liu

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[Bruce Trump](#) *over 11 years ago*

Carter,

Your questions would be challenging topics for blogs, each requiring diagrams for full explanation (which I cannot include here in this reply). I am now retired from TI and no longer writing blogs so I'll provide brief answers here:

I believe you are asking how open-loop gain (Aol) is tested. The graph shown in this blog is generally produced by connecting the op amp in a two-op-amp loop configuration that controls its output voltage while measuring offset voltage. This is a DC parameter so the output voltage is stepped slowly, making DC offset measurements throughout the output voltage swing range. Various references discuss this technique and you can probably find more information on-line.

To test gain-bandwidth product, connect the op amp in a non-inverting gain of 10 or greater. The GBP is the product of measured -3dB bandwidth and the closed-loop gain of the circuit (such as 10). Use an even higher closed-loop gain if the op amp is not unity-gain stable. Set the signal amplitude low to avoid slewing. Measurement at G=1 will generally produce an erroneous result as it is affected by the subtle changes in gain and phase near the unity-gain crossing. Current-feedback op amps (such as the OPA694) do not exhibit the classical nearly constant gain-bandwidth behavior of voltage-feedback op amps. For these devices, bandwidth is generally specified and tested with specific gain and feedback network values.

Regards-- Bruce