Op Amp Noise—but what about the feedback?

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Last month we explored noise of the non-inverting amplifier < http://www.edn.com/electronics-blogs/the-signal/4404375/op-amp-noise-the-non-inverting-amplifier> but I dodged the issue of the feedback network's noise contribution. A reader, Jim, challenged me—he wanted more detail. So what about the noise from R1 and R2 in figure 1?

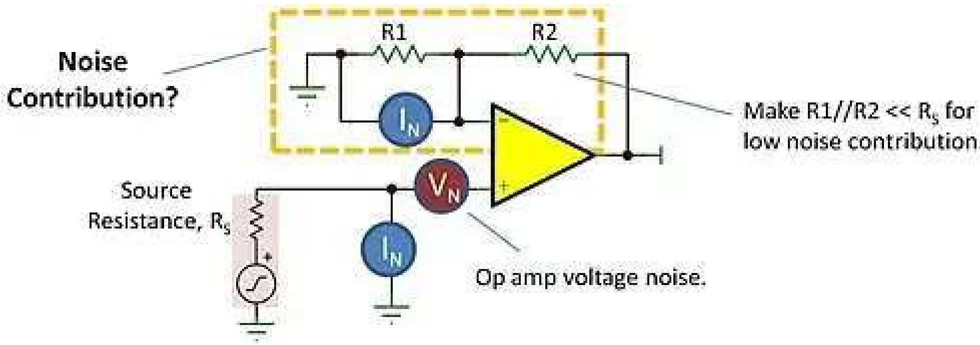

Figure 1.

The noise contribution at the inverting input is comprised of the thermal noise of the feedback resistors and op amp’s current noise reacting with these components. The ***output*** contribution of these noise sources can be calculated using basic op amp assumptions:

- R1’s thermal noise voltage is amplified to the output by the inverting gain of the circuit, -R2/R1.
- R2’s thermal noise contributes directly to the output noise.
- The inverting input current noise flows through R2, resulting in an output noise contribution of IN·R2.

These noise sources are uncorrelated so they “add” by the root sum of the squares.

But there’s a more intuitive way to look at this. It’s handy to refer the noise sources as if they all occur at the non-inverting input. Output noise contributions are divided by the non-inverting gain. This *RTI* (*referred to input*) approach makes it easy to compare noise sources and to the input signal.

The noise occurring at the inverting input relates to the **parallel combination of R1 and R2** . When referred to the non-inverting input, the combined RTI thermal noise of R1 and R2 is equal to the thermal noise of R1//R2. The current noise RTI contribution at the inverting input is equal to I_N ·(R1//R2). **It's all about R1//R2.**

Noise contribution of R1 and R2 and inverting current noise:

$$\text{Output Noise}^2 = [V_{NR1} \cdot (R2/R1)]^2 + (V_{NR2})^2 + (I_N \cdot R2)^2 \qquad (1)$$

Dividing by non-inverting gain to refer to input...

$$\text{RTI Noise}^2 = \underbrace{(V_{NR1//R2})^2}_{\textit{Thermal noise of R1//R2}} + (I_N \cdot R1//R2)^2 \qquad (2)$$

This result reveals an important factor for a low noise design. **Make R1//R2 S** and the noise contribution at the inverting input is negligible. If R1//R2 = R_S then the feedback network contributes equal noise to that of the source resistance. That may be too much for some designs.

In high gains, it's easy to keep the parallel resistance low—R1 can be made much less than Rs and R2 is big. At moderate gains it gets more difficult. G=2 is the worst case when R1 and R2 are equal. If you want to make the parallel resistance 100Ω, for example, R1 and R2 need to be 200Ω.

The feedback network then imposes a 400Ω load on the op amp—too low in most circumstances. It gets easy again very close to G=1 when R1 is big and R2 small. This case is not common because you generally want significant **gain in the first low noise stage < http://e2e.ti.com/blogs-/b/thesignal/archive/2013/01/21/put-gain-up-front-waxing-philosophical.aspx>** .

Addressing a common concern—there is no noise inherent noise penalty in making R2 a high resistance. If higher gain is achieved by increasing R2 and decreasing R1, while maintaining a constant parallel resistance, noise performance remains constant.

You can download **an Excel file < http://e2e.ti.com/blogs-/b/thesignal/archive/2013/02/10/op-amp-noise-but-what-about-the-feedback.aspx>** to calculate the noise of this commonly used input amplifier stage, including the op amp and source resistance noise. It shows the percentage contribution of each noise source and graphs the total noise over a range of source resistance. It also calculates *noise figure* , the noise (in dB) that the amplifier adds to thermal noise of the source. This is a handy measure of the noise performance of the amplifier. Tinker with it and you will quickly get a feel for the issues and trade-offs. **Download it here < http://e2e.ti.com/blogs-/b/thesignal/archive/2013/02/10/op-amp-noise-but-what-about-the-feedback.aspx>** .

Thanks for reading and your comments are welcome.

Bruce email: (Email for direct communications.)

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9 COMMENTS ON "OP AMP NOISE—BUT WHAT ABOUT THE FEEDB

ChristopherH

February 12, 2013

Thank you Bruce!

In the case of low gain, you can use a T-network in the feedback path to achieve both low-noi and high impedance load (c.f. "Op Amps For Everyone", pg 422, **http://www.ti.com/lit/an/slod006b/slod006b.pdf < http://www.ti.com/lit/an/slod006b/slod006b.pdf>**)

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Guru of Grounding

February 12, 2013

Inserting a "T-network" in the feedback also increases gain. I understand it's usefulness in avo very high values of feedback R in high-gain circuits (to reduce capacitive parasitics and bias c induced offsets) but I don't understand how it impr

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Oliver Sedlacek

February 12, 2013

I don't think that's right, a T network doesn't improve the ratio of load resistance (as seen by tl opamp output) to source resistance (as seen at the inverting input). As mentioned, the worst c is at a gain of two, but then that's a very low gain to

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BradWood

February 12, 2013

Agree with Oliver and Bill here. The noise gain goes up and the loop gain goes down, making distortions and errors larger, including sensitivity to offset voltages. But yes, high-value resisto often quite a bit less than ideal, so for some appl

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Sergio Franco

February 13, 2013

May I suggest using separate symbols for the inverting-input and non-inverting input noises, s
as INN and INP, or IN- and IN+. Using the same symbol may lead especially the beginner to
erroneous simplifications such as (Rs + R1//R2)^2xIN^2 instead of [

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Bruce Trump

February 13, 2013

Thanks, Sergio. Yes, perhaps I should have used different variables for inverting and non-inve
input current noise sources. I assume that the two are equal in magnitude and uncorrelated, a
assumption for virtually all common op amps, but certainl

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tweet

February 14, 2013

Thermal noise isn't the only thing that can ruin the picnic. Will you be doing an article on 1/f no

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Bruce Trump

February 15, 2013

Thanks, tweet, 1/f noise (also called flicker noise) would be an excellent topic. It's not importa
all applications but it can be critical in slow, precision low-level measurements. Not sure I'll tak
on next month but I'll put it on my short list

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Sergio Franco

June 15, 2013

Ok, looks like now I am on camera too, with my own EDN blog (courtesy of Steve Taranovich)
Here's more about op amp noise: **http://www.edn.com/electronics-blogs/analog-bytes/4416424/Op-amp-input-current-noise- < http://www.edn.com/electronics-blogs/an bytes/4416424/Op-amp-input-current-noise->**

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