

How to Optimize Differential Amplifier Noise



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Signal gain and noise gain are both important to amplifier circuit design. Signal gain is obviously important because you want to have accurate control of your signal amplitude. Noise gain is also important, even though it does not directly impact signal amplitude, because it impacts amplifier stability and loop gain, both of which have an impact on signal quality. Thus, it's important to be able to calculate both noise gain and signal gain for a particular circuit. Once you have these numbers, you can use the [datasheet](#) guidelines to optimize your circuit.

Let's quickly review signal gain with fully differential amplifiers, both inputs are inverting inputs; there is no

$$v = \frac{RF}{RG}$$

noninverting input, so your signal gain is . When you build the board, you physically solder RF onto the board, so you know the value of RF – or do you? Depending on the particular amplifier and board design, you may need to consider extra resistance. TI's [LMH5401](#) fully differential amplifier has an extra 25Ω on chip between the amplifier output and the feedback connection pins on the amplifier package. Because this amplifier is only 3mm by 3mm, and because the feedback connection pins are directly adjacent to the amplifier input pins, any measurable board resistance is not likely. You should, however, consider any board traces longer than 1cm possible sources of extra resistance. So if you're using the [LMH5401](#), you'll need to add onboard feedback resistance to the on-chip resistance.

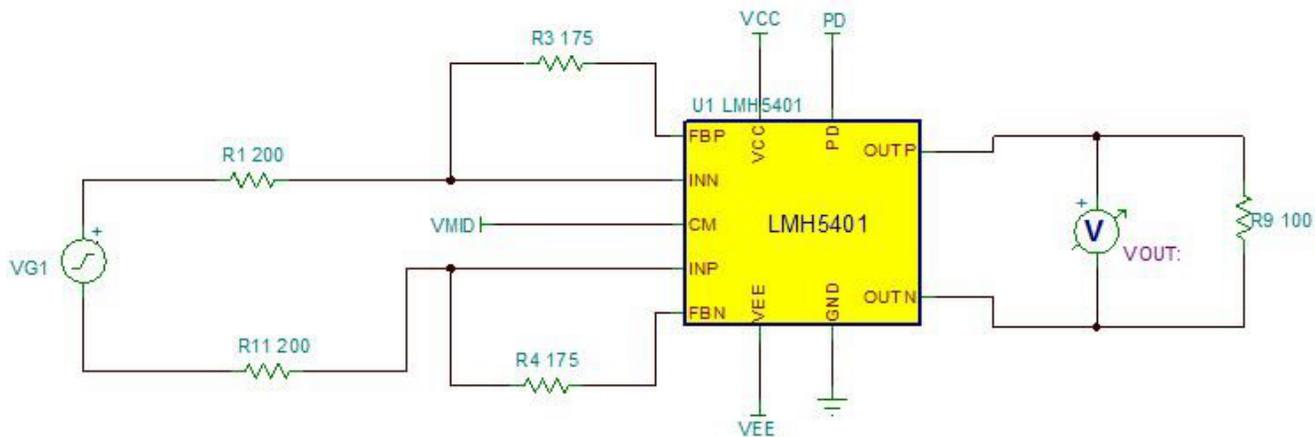


Figure 1. Circuit with a Signal Gain of 1 and Noise Gain of 2

$$Av = \frac{RF+25}{RG} = \frac{175+25}{200} = 1.$$

As shown in [Figure 1](#), the signal gain is equal to . But when I run a TINA-TI™ simulation, I don't get the expected 0dB of gain. The [LMH5401](#) has two 10Ω resistors, one on each output pin.

$$Av = 1 * \frac{100}{120} = 0.8333$$

Adding those resistors into the equation gives you or -1.6 dB, which does match the TINA-TI simulation.

Something else also shows up on the TINA-TI simulation: gain peaking on the frequency response, indicating possible instability. The [datasheet](#) states that, "For the [LMH5401](#), $Ng > 3$ creates a stable circuit independent of how the signal gain is set." What's the noise gain of the circuit in [Figure 1](#)? In the circuit shown in [Figure 1](#),

noise gain: $Ng = 1 + \frac{RF}{RG} = 2 = 6dB$. Thus, this circuit is not stable according to the [datasheet](#). Note that the

resistive loss on the output resistors is not included in noise gain, even though they do contribute to loss in the signal path.

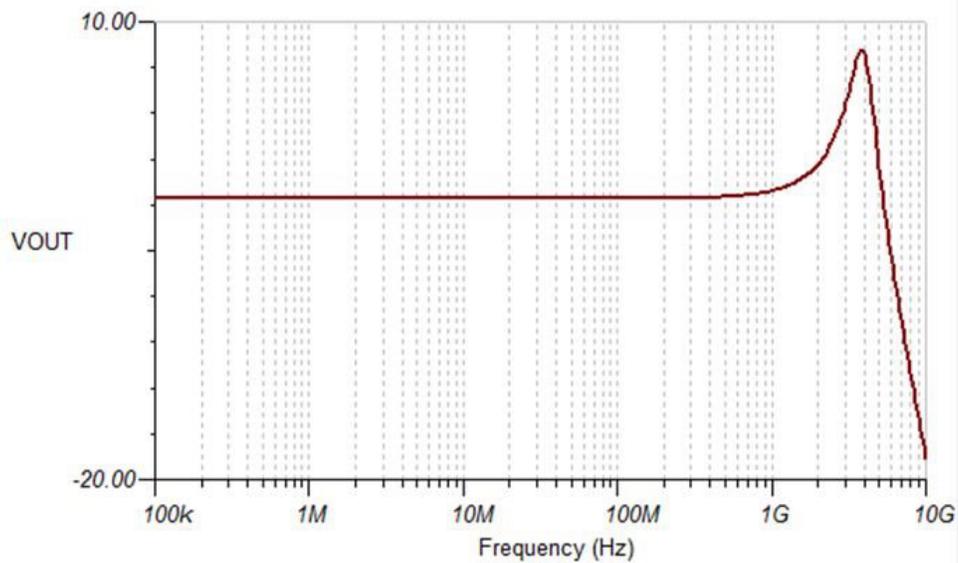


Figure 2. Frequency Response for the Circuit Shown in Figure 1

Just for curiosity's sake, let's run a TINA-TI simulation and see what the noise looks like.

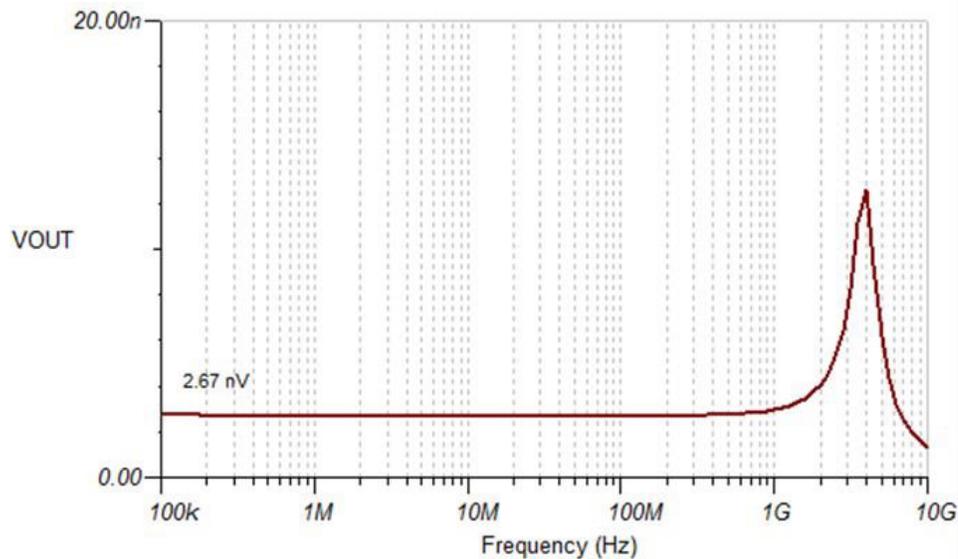


Figure 3. Noise Response for the Circuit Shown in Figure 1

Notice the peak in noise amplitude in [Figure 3](#). This instability also shows up in the noise response. The [datasheet](#) states that the input-voltage noise for the [LMH5401](#) is 1.25nV/rtHz. If the noise gain is indeed 2, you would expect to see the amplifier output noise to be approximately 2.5nV/rtHz. The results are very close. The extra noise in the simulation is due to current noise as well as the resistors in the circuit. So the noise gain is indeed 2.

I should also point out that the extra high-frequency noise (centered at 4GHz) is not due to noise gain but to the loss of phase margin. As phase margin decreases, the feedback circuit begins to dramatically add gain as the feedback transitions from negative feedback to positive feedback.

The [datasheet](#) gives you the option to increase noise gain (and not signal gain) to make the amplifier stable. [Figure 4](#) shows one simple way to accomplish this.

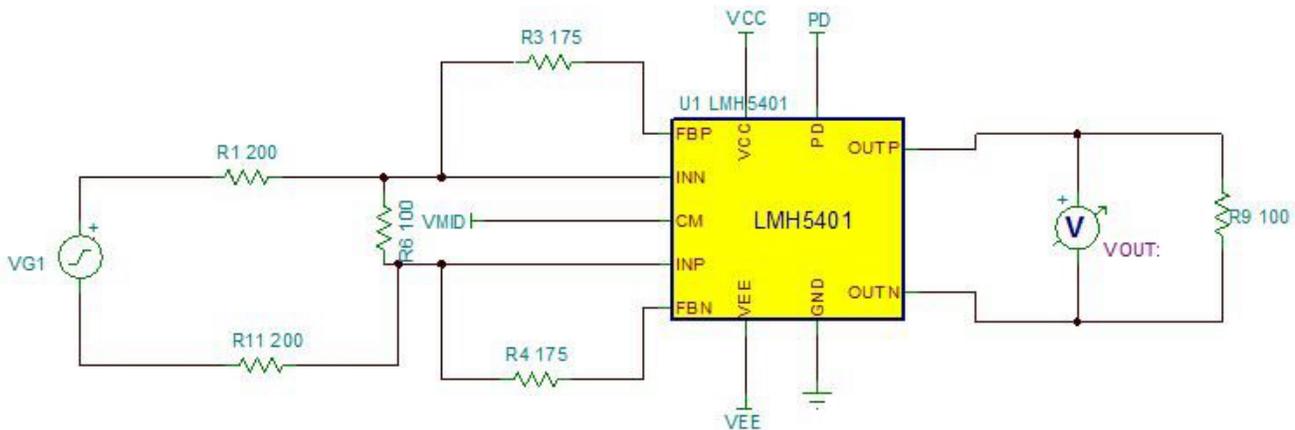


Figure 4. Circuit with a Signal Gain of 1 and Noise Gain of 6

In [Figure 1](#), noise gain was $1 + \frac{RF(Total)}{RG}$. While [Figure 4](#) has only one more component, it is easier to calculate the noise gain if you imagine that R6 is two resistors of 50Ω each, connected to an ideal (noiseless) voltage source of 0V. In this case, half of R6 is in parallel with RG, so the noise gain is now

$$1 + \frac{RF(Total)}{RG || 0.5 * R6} = \frac{200}{40} = 6.$$

A noise gain of 5 works, but the [datasheet](#) specifies a noise gain of 3 as the minimum required. In order to reduce the amount of output noise, let's go with the [datasheet's](#) minimum noise

$$400\Omega \left(1 + \frac{200}{200 || 200} \right) = 3.$$

gain of 3. This requires an R6 value of

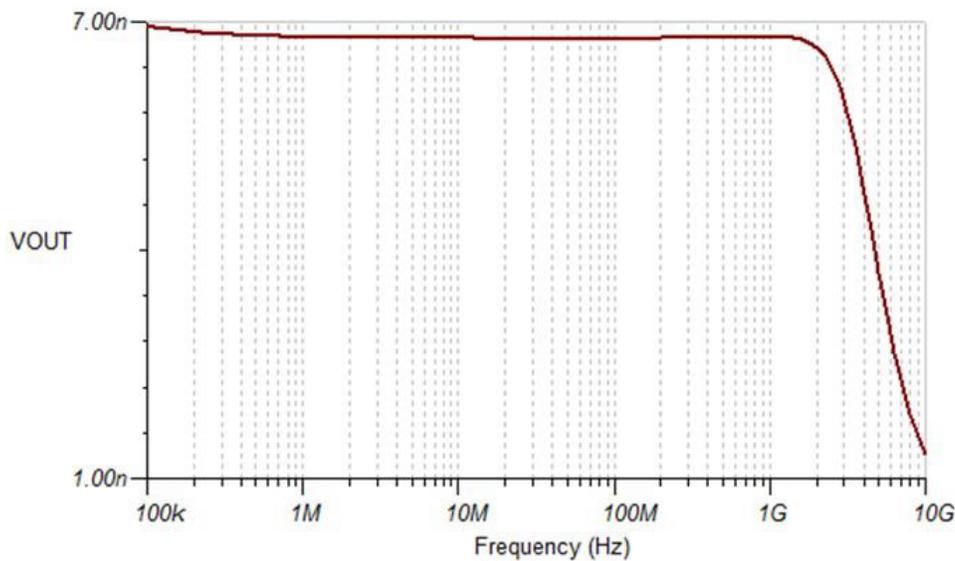


Figure 5. Noise Response for the Circuit Shown in [Figure 4](#) With a Noise Gain of 6

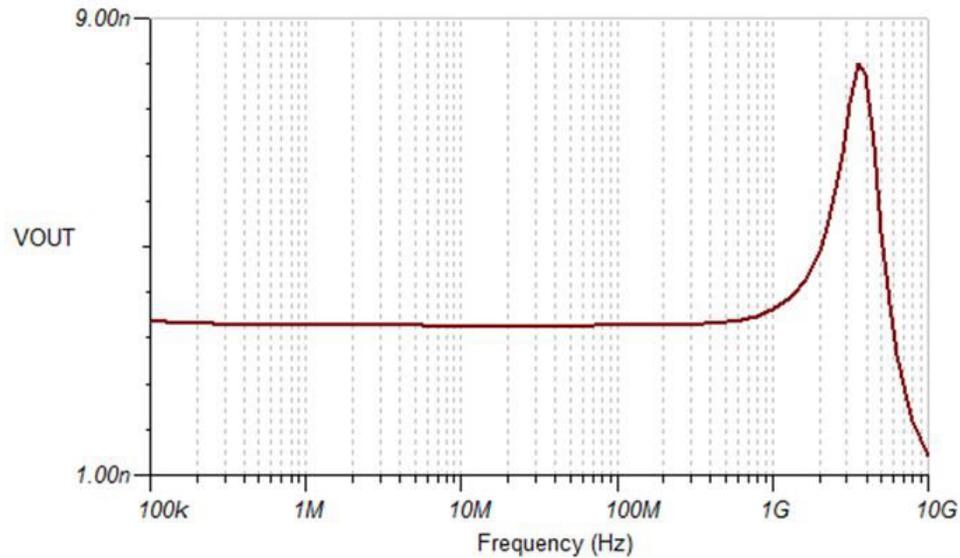


Figure 6. Noise Response for the Circuit with a Noise Gain of 3

The plot in [Figure 5](#) shows that the noise gain has indeed increased (it's equal to 6V/V) and there is no peaking in the noise response. [Figure 6](#) shows that the amplifier is also stable at a noise gain of 3V/V, and the noise level is less than that shown in [Figure 5](#), except at very high frequencies.

I hope I've shown how you can manipulate signal gain and noise gain independently to optimize circuit performance. In what applications could you apply these methods?

Additional Resources

- Download the [LMH5401 datasheet](#).
- Check out my other [high-speed amplifier blog posts](#).
- Search TI [high-speed op amps](#) and find technical resources.

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