Measuring Noise of Low-Fixed-Gain Differential Amplifiers

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Noise, composed of small, random voltages, can be difficult to measure. Lab instruments add their own noise, further complicating the measurement. Special techniques are often used when measuring noise. For example, amplifiers are typically configured with high closed-loop gains, multiplying their input noise to make it easier to measure. Low-fixed-gain differential amplifiers present a greater challenge, however, as their integrated feedback and gain resistors preclude the use of a high-gain configuration. Additionally, differential-to-single-ended conversion is needed to interface with available spectrum analyzers. A second amplifier stage can provide gain and the differential-to-single-ended conversion, neatly solving both of these problems.

Figure 1 shows an ADA4950-1 selectable-gain (1, 2, or 3) differential amplifier followed by an AD8099 low-noise, low-distortion op amp. The AD8099, configured for a gain of 10, converts the differential output into a single-ended signal. Its 1-nV/√Hz input-referred voltage noise is negligible compared to that of the ADA4950-1. The output of the ADA4950-1 is multiplied by 10, making its noise proportionately larger as well. With a 0.5-pF compensation capacitor and gain of 10, the AD8099 has enough bandwidth to measure the noise of the ADA4950-1 up to 10 MHz before the system's frequency response starts to roll off.

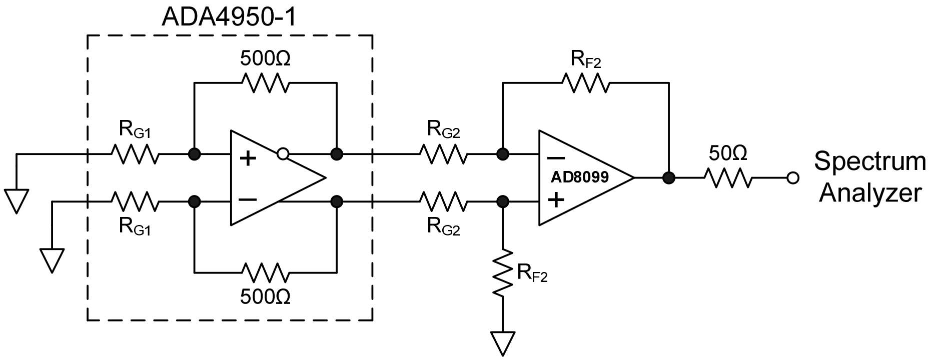


Figure 1. The AD8099 low-noise, low-distortion op-amp is used to measure the noise of the ADA4950-1 selectable-gain differential amplifier.

The output voltage of the AD8099 is simply:

$$V_{OUT} = V_{OUT,\,DIFF} \times \frac{R_{F2}}{R_{G2}} \qquad (1)$$

The noise contribution of the AD8099, measured with inputs grounded, is treated as the noise floor of the measurement system. The total output noise including the ADA4950-1 was then measured, with the contribution from the AD8099 subtracted using root-sum-square math, as shown in Equation 2, where V_{n1} is the output noise of the ADA4950-1 and V_{n2} is the output noise of the AD8099.

Total output noise:

$$V_{total}^{2} = \left(V_{n1} \times \frac{R_{F2}}{R_{G2}} \right)^{2} + V_{n2}^{2} \qquad (2)$$

A few other techniques were implemented to accurately measure the system noise:

- When measuring the noise of the AD8099, its inputs were grounded with SMA connectors that had their center conductor shorted to the ground pins of the connector. Additionally, the SMA connectors were soldered together, creating a shared electrical connection to ground directly at the connectors, instead of through the board.
- An analog-controlled power supply was used for the AD8099 and the ADA4950-1. Compared to digitally-controlled power supplies, analog-controlled power supplies are better at rejecting 60-Hz noise and harmonics that couple in from the power line.
- All nearby instruments were turned off unless they were being used for the measurement. This minimized oscillations generated by the instruments to control their digital circuitry. These oscillations can couple through the air and into the amplifiers. For the same reason, 4-ft cables were used to connect the circuit boards to the spectrum analyzer, which was picking up the refresh frequency of the display and affecting the output of the AD8099.
- Low-value resistors ($R_F = 250\Omega$; $R_G = 25\Omega$) were used to configure the AD8099's gain in order to keep their noise contribution small. Lower values caused the AD8099 to oscillate. When the ADA4950-1 was connected to the AD8099 with a short cable, an oscillation was observed at 250 MHz. When a 1-ft cable was used, the oscillations went away.

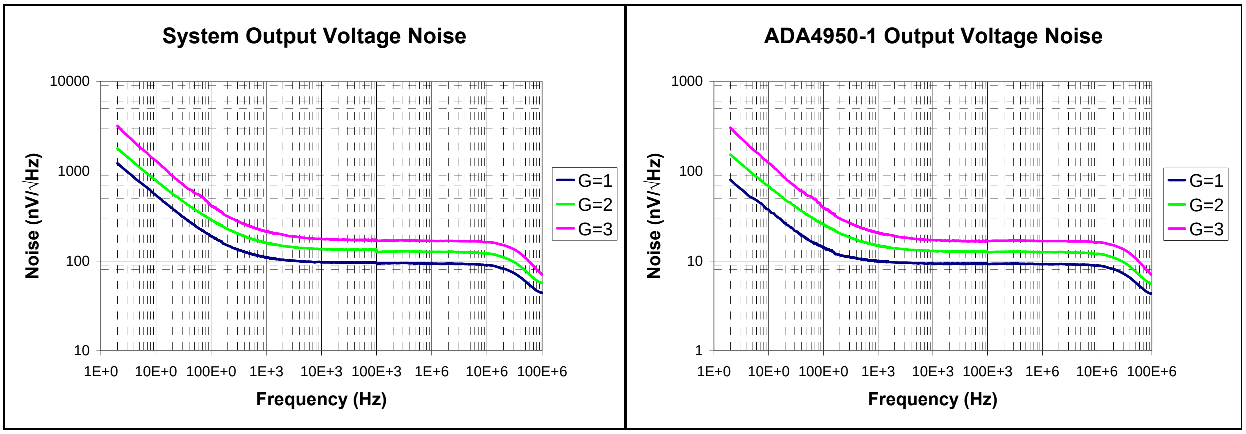
The AD8099 itself contributed only a small amount of noise:

$$v_{OUT}^{2} = \left[\left(1+\frac{R_{F2}}{R_{G2}}\right)v_n\right]^2 + R_{F2}^{2}\left(n_{i+}^{2} + n_{i-}^{2}\right) + 2\left(n_{RG2}\times\frac{R_{F2}}{R_{G2}}\right)^2 + 2n_{RF2}^{2} + n_{50}^{2} \tag{3}$$

where v_n is the input voltage noise; and n_{i+} and n_{i-} are the input current noise of the AD8099.

Measuring the ADA4950-1's current noise is impossible because a large feedback resistor is needed to amplify the noise, but the value of the internal feedback resistor cannot be changed.

The Stanford Research Systems SR785 was used to measure noise up to 100 kHz, while the Agilent E4440 PSA spectrum analyzer was used for noise beyond 100 kHz.


System Output Voltage Noise

ADA4950-1 Output Voltage Noise

Figure 2. Test Results