## Rarely Asked Questions—Issue 125 O CMRR, CMRR! Wherefore Art Thou CMRR?

By Gustavo Castro





Figure 1. CMRR test circuit.

Question:

Why is the effect of common-mode signals at the output larger than the CMRR specification?

## Answer:

The concept of common-mode rejection ratio (CMRR) is fundamental when working with differential input circuits, yet it is often misunderstood. When working with instrumentation amplifiers, it is not unusual to encounter incorrect expectations regarding the effect of common-mode signals in the circuit.

For example, a popular CMRR test for instrumentation amplifiers consists of measuring the output while applying the same signal to both inputs. An example test circuit for the AD8422B (configured for gain of 10 V/V) is shown in Figure 1. The second amplifier, an AD8428, works in a gain of 2000 to amplify the small error generated by the device under test to make it easier to measure with standard lab equipment, like a scope.<sup>1</sup> is equivalent to 20  $\mu$ V at the output of AD8422B. This is not bad at all, but one might argue that 10  $\mu$ V/V corresponds to 100 dB of rejection, while the data sheet guarantees a CMRR of at least 114 dB! Have we found a defective part? Where did the CMRR go?

With this setup, it is possible to observe an output change

of 40 mV for a 2 V common-mode change at the input, which

If you read "The Diamond Plot" RAQ, you'll remember that the first condition that must be verified is to confirm that the test is being performed inside the common-mode range of the amplifier. This takes less than a minute with the new Diamond Plot tool on analog.com! If everything looks good there, the next step is to review the CMRR definition.

CMRR is simply the quotient of the differential gain divided by the common-mode gain. It can be expressed in V/V or in dB according to the following expressions:

$$CMRR_{V/V} = A_{DIFF}/A_{CM}$$

$$CMRR_{dB} = 20log(A_{DIFF}/A_{CM}) = 20log(A_{DIFF}) - 20log(A_{CM})$$

<sup>&</sup>lt;sup>1</sup> Please note that noise and high gain (20,000) makes this measurement challenging. For this reason, it is necessary to filter the source to minimize its noise contribution. AD8428 uses a capacitor between its filter terminals to reduce the measurement bandwidth. Moreover, proper shielding and wiring is required to avoid external noise pickup.

The 10  $\mu$ V/V measured before is equivalent to –100 dB of common-mode gain, not CMRR. Because the amplifier is set to a gain of 10 V/V (or 20 dB), the total CMRR is 20 dB – (–100 dB) = 120 dB, which is greater than the 114 dB in the part's specification. If the gain is increased to 100 V/V, then the CMRR goes up by another 20 dB to 140 dB! Nevertheless, with the new gain and the same 2 V signal applied to the input, the output of AD8422 still changes by 10  $\mu$ V. You may ask, how is this better? Does that mean that we are cheating?

Well, not really; the definition of CMRR is the same for everyone. It's important that it remains this way, and we're not going to change it. While the undesired common-mode signal pollutes the output, it remains constant independent of the gain. But if the differential gain is large, this "pollution" also gets smaller. In other words, if we divide the common-mode error by the gain to compare it to the input signal, it really becomes very small. So, the 10  $\mu$ V/V error at the output is equivalent to 1  $\mu$ V/V at a gain of 10, and 100 nV/V at a gain of 100. It should be obvious why that's a good thing when measuring small signals.

Note that not all in-amps have their CMRR increase with gain, and some even start to taper off with larger gains. In other words, an in-amp with CMRR of 120 dB may only go to 130 dB when the gain increases by 20 dB. We call this effect CMRR *compression*. Yet, we have seen the AD8422 increase its CMRR to 160 dB with no compression. Now that, folks, is a CMRR performance that's really hard to find.

Gustavo Castro [gustavo.castro@analog.com] is a system applications engineer in the Linear and Precision Technology Group in Wilmington, MA. His main interests are analog and mixed-signal design for precision signal conditioning and electronic instrumentation. Prior to joining Analog Devices in 2011, he worked for 10 years designing high performance digital multimeters and precision dc sources at National Instruments. Gustavo received his B.S. degree in electronic systems from Tecnológico de Monterrey and his M.S. degree in microsystems and materials from Northeastern University. He holds three patents.



Figure 2. AD8422 CMRR vs. frequency.

## References

AD8422 Data Sheet. Analog Devices.

AD8428 Data Sheet. Analog Devices.

Gustavo Castro. "The Diamond Plot." Analog Dialogue Rarely Asked Questions, Issue 107.

Instrumentation Amplifier Diamond Plot Tool—BETA. Analog Devices.



## Gustavo Castro

Rarely Asked Questions-

Issue 119, July 2015 The Ingenious Gentleman and the Mysterious Paddle

