Choose resistors to minimize errors in grounded-load current source

David Guo - April 19, 2013

Operational amplifiers are frequently used to make high-quality current sources in a variety of applications, such as industrial process control, scientific instrumentation, and medical equipment. *Single Amplifier Current Sources*, published in Analog Dialogue, Volume 1, Number 1, 1967, introduces several current source circuits that provide a constant current through floating loads or grounded loads. In industrial applications, such as pressure transmitters and gas detectors, these circuits are widely used to provide 4 mA to 20 mA or 0 mA to 20 mA currents.

The improved Howland current source, shown here, is very popular because it can drive a grounded load. The transistor, which allows relatively high currents, can be replaced by a MOSFET to achieve even higher currents. For low cost, low current applications, the transistor can be eliminated, as shown in *Difference Amplifier Forms Heart of Precision Current Source*, published in Analog Dialogue, Volume 43, Number 3, 2009.

The accuracy of this current source is determined by the amplifier and the resistors. This article shows how to choose the external resistors to minimize errors.
Analysis of the improved Howland current source yields the transfer function:

\[ I_o = I_{IV} \times \frac{R_2R_3 + R_2R_4 + R_2R_5}{R_5(R_3 + R_5)R_L - R_3R_4R_L + R_4R_5R_L + R_2R_3R_L} \]  

(1)

**Tip 1: Set \( R_2 + R_3 = R_4 \)**

In equation 1, the load resistance influences the output current, but if we set \( R_1 = R_3 \) and \( R_2 + R_5 = R_4 \), the formula reduces to:

\[ I_o = I_{IV} \times \frac{R_4}{R_1R_4} \]  

(2)

Here, the output current is only a function of \( R_3, R_4, \) and \( R_5 \). With an ideal amplifier, the resistor tolerances determine the accuracy of output current.

**Tip 2: Set \( R_L = n \times R_5 \)**

To decrease the total number of resistors in the component library, set \( R_1 = R_2 = R_3 = R_4 \). Now, equation 1 simplifies to:

\[ I_o = I_{IV} \times \frac{R_1 + 2R_2}{R_5(R_L + 2R_5)} \]  

(3)

If \( R_5 = R_L \), it further simplifies to:

\[ I_o = I_{IV} \times \frac{1}{R_5} \]  

(4)

Here, the output current only depends on the resistance of \( R_5 \).

In some cases, the input signal may need to be attenuated. For example, with a 10-V input signal and \( R_5 = 100 \) Ω, the output current would be 100 mA. To get a 20 mA output, set \( R_1 = R_3 = 5R_2 = 5R_4 \). Now, equation 1 reduces to:

\[ I_o = I_{IV} \times \frac{5R_5 + 6R_2}{5R_5(R_3 + 6R_5)} \]

If \( R_L = 5R_5 = 500 \) Ω, then:

\[ I_o = I_{IV} \times \frac{1}{5R_5} \]  

(5)

**Conclusion**

When designing an improved Howland current source, choose external resistors to make the output current independent of the load resistance. Resistor tolerance influences the accuracy, but a trade-off between accuracy and cost must be made. The amplifier’s offset voltage and offset current will also affect the accuracy. Consult the data sheet to check if the amplifier can meet the circuit requirements. An integrated difference amplifier—with its low offset voltage, offset voltage drift, gain error, and gain drift—can implement accurate, stable current sources.
About the author

David Guo [david.guo@analog.com] is a field applications engineer in ADI’s China Applications Support Team in Beijing. After earning a master’s degree in electronic and mechanism engineering from Beijing Institute of Technology, David spent two years as a navigation terminal hardware engineer at Changfeng Group. He joined ADI in 2007.

References

Bill Miller, Single Amplifier Current Sources, Analog Dialogue, Volume 1, Number 1, 1967

James M. Loe, Grounded-load current source uses one operational amplifier, Analog Dialogue, Volume 1, Number 3, 1967

Reza Moghimi, Ways to Optimize the Performance of a Difference Amplifier, AN-589

Zhao, Neil, Reem Malik, and Wenshuai Liao, Difference Amplifier Forms Heart of Precision Current Source, Analog Dialogue, Volume 43, Number 3, 2009