Choose Resistors to Minimize Errors in Grounded-Load Current Source

By David Guo

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 in Figure 1, 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.

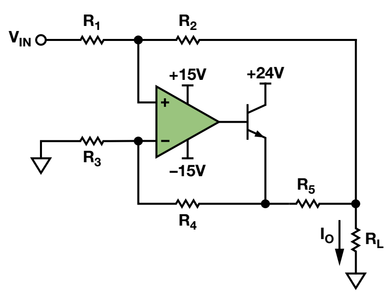

Figure 1. Improved Howland current source drives grounded loads.

Analysis of the improved Howland current source yields the transfer function:

$$I_O = V_{IN} \times \frac{R_2R_3 + R_2R_4 + R_5R_3}{R_3(R_2 + R_5)R_L - R_1R_4R_L + R_1R_3R_5 + R_2R_3R_5} \quad (1)$$

Tip 1: Set $R_2 + R_5 = R_4$

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:

$$I_O = V_{IN} \times \frac{R_4}{R_3R_5} \quad (2)$$

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:

$$I_O = V_{IN} \times \frac{R_5 + 2R_2}{R_5(R_L + 2R_2)} \quad (3)$$

If $R_5 = R_L$, it further simplifies to:

$$I_O = V_{IN} \times \frac{1}{R_5} \quad (4)$$

Here, the output current depends only 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 $R_5 = 100\ \Omega$, the output current would be 100 mA. To get a 20-mA output current, set $R_1 = R_3 = 5R_2 = 5R_4$. Now, Equation 1 reduces to:

$$I_O = V_{IN} \times \frac{5R_5 + 6R_2}{5R_5(R_L + 6R_2)}$$

If $R_L = 5R_5 = 500\ \Omega$, then:

$$I_O = V_{IN} \times \frac{1}{5R_5} \quad (5)$$

Tip 3: Larger value for $R_1/R_2/R_3/R_4$ improves the current accuracy

In most cases, $R_1 = R_2 = R_3 = R_4$, but $R_L \neq R_5$, so the output current is as shown in Equation 3. With $R_5 = 100\ \Omega$ and $R_L = 500\ \Omega$, for example, Figure 2 shows the relationship between the resistance of R_1 and the current accuracy. To achieve 0.5% current accuracy, R_1 must be at least 40 kΩ.

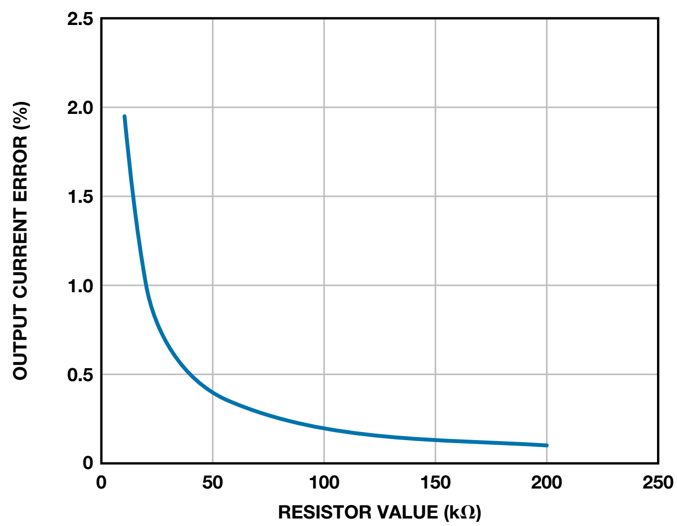

Figure 2. Relationship between R1 and output current accuracy.

Tip 4: Resistor tolerance affects current accuracy

Real world resistors are never ideal, with each having a specified tolerance. Figure 3 shows an example circuit, where $R_1 = R_2 = R_3 = R_4 = 100\ k\Omega$, $R_5 = 100\ \Omega$, and $R_L = 500\ \Omega$. With the input voltage set to 0.1 V, the output current should be 1 mA. Table 1 shows the output current error caused by different resistor tolerances. To obtain 0.5% current accuracy, choose 0.01% tolerance for $R_1/R_2/R_3/R_4$, 0.1% for R_5, and 5% for R_L. Resistors with 0.01% tolerance are expensive, so a better choice would be to use an integrated difference amplifier, such as the AD8276, which has better resistor matching and is more cost effective.

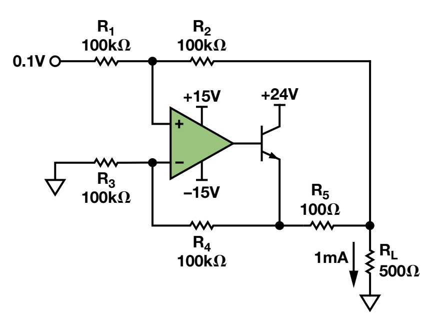

Figure 3. Example circuit for I_{OUT} = 1 mA.

Table 1. Worst Case Output Current Error (%) vs. Resistor Tolerance (%)

Resistor Tolerance/ Resistors Varied	5	1	0.5	0.1	0.05	0.01	0
$R_1/R_2/R_3/R_4$	110.11	10.98	5.07	1.18	0.69	0.30	0.20
R_5	5.05	1.19	0.70	0.30	0.25	0.21	0.20
R_L	0.21	0.20	0.20	0.20	0.20	0.20	0.20

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, and 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. Multisim can be used to simulate how these specifications influence the accuracy. An integrated difference amplifier—with its low offset voltage, offset voltage drift, gain error, and gain drift—can cost effectively implement accurate, stable current sources.

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