

High Precision, Low Cost Current Sources Using the AD8276 Difference Amplifier and the AD8603 Op Amp

CIRCUIT FUNCTION AND BENEFITS

Current sources are widely used in industrial, communication, and other equipment for sensor excitation and machine to machine communication. For example, the 4 mA to 20 mA loop is widely used in process control equipment.

Programmable current sources can be built using a digital-to-analog converter (DAC), op amp or difference amplifier, and matched resistors. Low value current sources can be integrated into low output current sources or amplifiers. For example, the AD8290 is an instrumentation amplifier with a single,

integrated current source, and the AD7794 is a high resolution, Σ - Δ , analog-to-digital converter (ADC) with two integrated current sources. For high currents, external MOSFETs or transistors are generally required.

Current sources using the low power AD8276 difference amplifier and the AD8603 op amp are affordable, flexible, and is small in size. Performance characteristics such as initial error, temperature drift, and power dissipation make the AD8276 and the AD8603 ideal candidates.

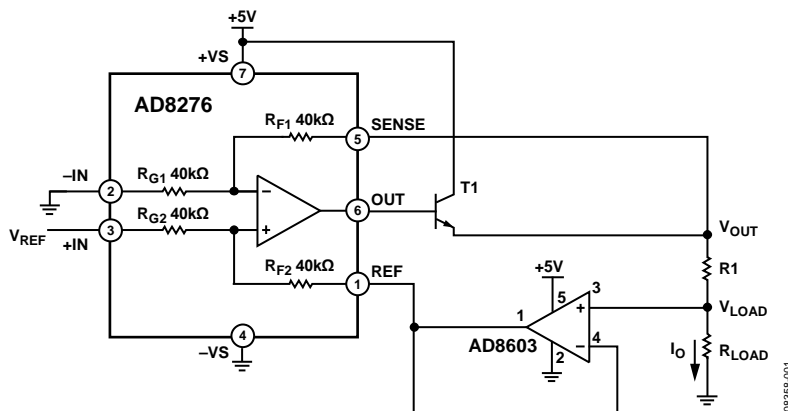


Figure 1. Current Source Using the AD8276 Difference Amplifier and the AD8603 Op Amp (Simplified Schematic)

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REVISION HISTORY

11/2017—Rev. A to Rev. B

Document Title Changed From CN0099 to AN-1530.....	Universal
Changes to Figure 1 and General Description	1
Changes to Circuit Description Section	3
Changes to Common Variations Section	4

8/2013—Rev. 0 to Rev. A

Changes to Circuit Description Section	2
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7/2009—Revision 0: Initial Version

CIRCUIT DESCRIPTION

Figure 1 shows the current source circuit. An input reference voltage, V_{REF} , is applied to the noninverting input of the [AD8276](#). This voltage controls the amount of output current, I_O . The inverting input of the [AD8276](#) is connected directly to ground. There are four laser trimmed, 40 k Ω resistors inside the [AD8276](#) that are connected to the input pins (+IN and -IN), the REF pin, and the SENSE pin. If a high current output is needed, use the output of the [AD8276](#) to drive a transistor.

If the resistors are matched, the input reference voltage, V_{REF} , appears across the R1 resistor, producing an output current, I_O , which is equal to $V_{REF} \div R1$.

The [AD8603](#) op amp is used in the feedback loop of the circuit and is chosen because of its low bias current (1 pA maximum) and offset voltage (less than 50 μ V). The low bias current makes it possible to interface to a high impedance load without introducing significant offset errors. The [AD8603](#) offset voltage drift specification (4.5 μ V/ $^{\circ}$ C maximum) allows operation over a wide temperature range, and the amplifier features low noise and rail-to-rail inputs and outputs.

The value of the output current, I_O , can be calculated by using the following equation:

$$I_O = \frac{V_{REF} \left(\frac{R_{F2}}{R_{G2}} + \frac{R_{F1}}{R_{G1}} \times \frac{R_{F2}}{R_{G2}} \right)}{R1 \left(1 + \frac{R_{F2}}{R_{G2}} \right) + R_{LOAD} \left(\frac{R_{F2}}{R_{G2}} - \frac{R_{F1}}{R_{G1}} \right)} \quad (1)$$

where R_{F1} and R_{F2} are feedback resistors, and R_{G1} and R_{G2} are gain resistors.

Because the [AD8276](#) has tight resistor matching, $R_{F1}/R_{G1} = R_{F2}/R_{G2} = 1$, and Equation 1 can be simplified as

$$I_O = \frac{V_{REF}}{R1} \quad (2)$$

Equation 1 shows that the primary errors of the circuit in Figure 1 are due to the internal resistor matching, the tolerance of R1, and the tolerance of the load resistance. The [AD8276](#) (Grade B) maximum gain error is 0.02%. The [AD8276](#) (Grade A) maximum gain error is 0.05%. The overall accuracy of 0.02% is possible with this circuit.

The accuracy of R1 is critical; therefore, it must have $\geq 0.1\%$ tolerance. Calibration removes this error.

The op amp input range, the difference amplifier output range, and the SENSE pin voltage range of the difference amplifier limit the amount of I_O available from the circuit.

Based the circuit configuration shown in Figure 1, the following conditions must be met:

1. $V_{LOAD} = I_O \times R_{LOAD}$ must be within the [AD8603](#) op amp input range.
2. $V_{OUT} = I_O \times (R_{LOAD} + R1)$ must be within the [AD8276](#) SENSE pin voltage range: $2 \times -V_S - 0.2$ V to $2 \times +V_S - 3$ V. $\pm V_S$ refers to the supply voltage.
3. $I_O \times (R_{LOAD} + R1) + V_{BE}$ must be within the [AD8276](#) output voltage range: $-V_S + 0.2$ V to $+V_S - 0.2$ V. V_{BE} refers to the voltage across the base and emitter of the T1 transistor.

The [AD8276](#) rail-to-rail output feature and the ability to operate on a 2.0 V to 36 V power supply allow a wide range of output current.

The [AD8276B](#) offset voltage drift of 2 μ V/ $^{\circ}$ C maximum and gain drift of 1 ppm/ $^{\circ}$ C maximum yield low temperature drift and wide temperature operation. The specifications for the [AD8276A](#) are 5 μ V/ $^{\circ}$ C and 5 ppm/ $^{\circ}$ C, respectively.

Both the [AD8276](#) 8-lead mini small outline package (MSOP) and the [AD8603](#) 5-lead thin small outline transistor (TSOT) are in small packages, minimizing the board area required by the circuit.

The external current source transistor, T1, must have a voltage collector to the base of the T1 transistor (V_{CB}) breakdown voltage higher than the [AD8276](#) supply voltage. The transistor maximum collector current must be higher than the expected output current with suitable headroom, and the transistor power dissipation limits must be observed. Low cost transistors, such as the 2N3904, 2N4401, 2N3391, and MPSA06 are recommended.

The [AD8276](#) can drive output currents of 15 mA or less without the need for the external transistor or metal-oxide semiconductor field-effect transistor (MOSFET).

Testing results under room temperature based on the [AD8276A](#), [AD8603](#), and 2N3904 are shown in Figure 2. R1 is 50 Ω with 0.1% tolerance. The actual output complies with the calculated results. Figure 2 shows that the measured results are indistinguishable from the ideal results because they are within 0.5% of each other with the average of less than 0.1% limited by the tolerance of R1.

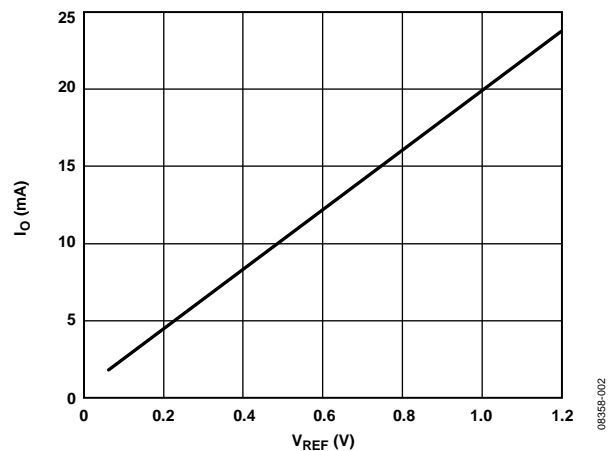


Figure 2. Test Results for Current Source Using the [AD8276A](#), [AD8603](#), and 2N3904 ($R1 = 50 \Omega$, $R_{LOAD} = 100 \Omega$, $V_S = 5$ V, Ambient Temperature (T_A) = 25 $^{\circ}$ C)

Employ proper layout, grounding, and decoupling techniques. See [MT-031](#), *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND"* and [MT-101](#), *Decoupling Techniques* for more details.

COMMON VARIATIONS

If higher power supplies are needed for higher value output current, use the [OP1177](#), [AD8661](#), or [AD8663](#). The important specifications are power supply range, bias current, offset voltage, input voltage range, and temperature drift.

If a fixed current source is required, V_{REF} can be supplied from the [ADR360](#), [ADR361](#), [ADR363](#), [ADR364](#), [ADR365](#), or [ADR366](#) family of devices.

If a dual-current source is needed, use the [AD8607](#) or [AD8277](#).

If programmable current sources are needed, use a precision 14-bit or 16-bit DAC to generate the reference voltage, V_{REF} . The [AD5560](#), [AD5060](#) (single), and [AD5663R](#) (dual) are suitable for this application.

REFERENCES

Kitchin, Charles and Lew Counts. *A Designer's Guide to Instrumentation Amplifiers (3rd Edition)*. Analog Devices, Inc.

[MT-031](#) Tutorial, *Grounding Data Converters and Solving the Mystery of "AGND" and "DGND."* Analog Devices.

[MT-035](#) Tutorial, *Op Amp Inputs, Outputs, Single-Supply, and Rail-to-Rail Issues*. Analog Devices.

[MT-061](#) Tutorial, *Instrumentation Amplifier Basics*. Analog Devices.

[MT-068](#) Tutorial, *Difference and Current Sense Amplifiers*, Analog Devices.

[MT-101](#) Tutorial, *Decoupling Techniques*. Analog Devices.