Two instrumentation amps make accurate voltage-to-current source

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Many designs require precise voltage-controlled current sources, especially in the presence of variable loads. Common approaches, which use a few op amps and a handful of passive components, have inherent errors due to nonideal component characteristics, such as finite open-loop gain, common-mode rejection, bias current, and offset voltage. Designs using operational amplifiers may require precision resistors to set gain and additional capacitors for stability. In addition, some circuit designs provide currents that are not directly proportional to the input voltage. The voltage-to-current converter in Figure 1, for example, relies on the fact that the collector current is approximately equal to the emitter current and provides current in only one direction.

With two instrumentation amplifiers and two transistors, you can build a 0.01%-accurate voltage-controlled current source (Figure 2). This current source features a ±10V input-voltage swing that is directly proportional to the output current. It maintains high accuracy, even while delivering as much as 90 mA of output current. The AD620 low-power, low-drift instrumentation amplifiers from Analog Devices provide circuit control and error correction but are not part of the output circuit. Thus, you can substitute higher-power transistors for Q1 and Q2 to achieve higher output currents. You can configure the instrumentation amplifiers for any gain of one to 10,000 to accommodate input signals lower than 1 mV. Simply connect a resistor across the inputs of both IC1 and IC2 to achieve the desired gain.

The first instrumentation amplifier, IC1, controls the base voltage of the push-pull output stage. The resistors and diodes provide bias to Q1 and Q2 to eliminate crossover distortion. IC2 provides error correction and accounts for deltas in the base-to-emitter voltage. The error voltage, which you measure differentially from the D1/D2 junction to the output voltage, feeds into the reference pin of IC1, summing it with the input voltage. The result is an output current that is directly proportional to the input voltage. This circuit achieves a 0.01% typical dc accuracy across a ±10V input span and 1.5% typical ac accuracy at 1 kHz with an output voltage of ±5V p-p.

The equations for calculating the output current are:

\[
V_{\text{OUT}_{\text{IC1}}} = \left( V_{\text{IC1}}^{+} - V_{\text{IC1}}^{-} \right)^{A_{1\text{IC1}}} + V_{\text{REF}_{\text{IC1}}},
\]

\[
V_{\text{REF}_{\text{IC1}}} = V_{\text{OUT}_{\text{IC2}}} = \left( V_{\text{IC2}}^{+} - V_{\text{IC2}}^{-} \right)^{A_{1\text{IC2}}} + V_{\text{REF}_{\text{IC2}}},
\]

\[
V_{\text{OUT}} = V_{\text{OUT}_{\text{IC1}}} = \left( V_{\text{IC1}}^{+} - V_{\text{IC1}}^{-} \right)^{A_{1\text{IC1}}} + \left( V_{\text{IC2}}^{+} - V_{\text{IC2}}^{-} \right)^{A_{1\text{IC2}}} + V_{\text{REF}_{\text{IC2}}},
\]
where

\[ V_{IC1}^+ = V_{IN}, \quad V_{IC1}^- = 0; \quad A_{IC1} = A_{IC2} = 1; \quad V_{REF_{IC2}} = 0. \]

Therefore,

\[ V_{OUT} = V_{IC1}^+ + (V_{IC2}^+ - V_{IC2}^-), \]

or

\[ I_{OUT} = \frac{V_{IN}}{R_L}. \]

This circuit provides a wide output range, as well as output current that is directly proportional to the input voltage and high linearity and precision (Figure 3).