Current loops have become the standard for signal transmission in the process control industry. Current loops are insensitive to noise and are immune to errors from line impedance. Burr-Brown offers a complete line of monolithic 4mA to 20mA current loop transmitters and receivers.

**XTR101**
General purpose two-wire 4-20mA current-loop transmitter. This transmitter has an instrumentation amplifier input and two 1mA current sources for transducer excitation and offsetting.

**XTR103**
Two-wire RTD 4-20mA current-loop transmitter. Similar to XTR101, but with internal linearization circuitry for direct interface to RTDs (Resistance Temperature Detectors). The XTR103 along with an RTD forms a precision temperature to 4-20mA current loop transmitter.

**XTR104**
Two-wire bridge 4-20mA current-loop transmitter. Similar to XTR101, but with shunt regulator and linearization circuitry for direct interface to resistor transducer bridges.

**XTR110**
Three-wire 4-20mA transmitter. The XTR110 converts a 0-5V or 0-10V high-level input into a 0-20mA or 4-20mA current-source output.

**RCV420**
Self-contained 4-20mA receiver. Conditions and offsets 4-20mA input signals to give a precision 0-5V output. Contains precision voltage reference, 75Ω precision sense resistor and ±40V common-mode input range difference amplifier.

The 4mA to 20mA current loop is the most often used standard. Since the minimum signal current is 4mA, the transducer and transmitter can be powered by the same two wires used for the current loop connection. This feature eliminates the need for a remote power supply. Also, open circuits are easy to detect since the signal goes to 0mA. Some systems, however, use a 0 to 20mA current loop standard instead. To interface to these systems, the 4-20mA output must be converted to 0-20mA. This bulletin shows the suggested circuit and also discusses summing current-to-current converters in general.

**INVERTING CURRENT-TO-CURRENT CONVERTERS**
Figure 1 shows the basic inverting current-to-current converter. The input current all flows through R₂ resulting in an I₁ • R₂ voltage drop across R₂. The op amp forces the same voltage across R₁ so that there is no voltage difference at the op amp inputs. The I_OUT current is therefore:

For Figure 1:

\[ I_{OUT} = -I_{IN} \cdot \frac{R_2}{R_1} \]

Notice that, like its cousin the inverting voltage amplifier,
apply to the noninverting circuits.

For Figure 4:

\[ I_{\text{OUT}} = I_{\text{IN}}(1 + R_2/R_1) \]

Notice that, like its cousin the noninverting voltage amplifier, the gain is always greater than 1.0 so that the output current must always be greater than the input current. As with the inverting summing current-to-current converter, so long as the gain is the same, any number of currents can be summed at the current-to-current converter input as shown in Figure 5.

For Figure 5:

\[ I_{\text{OUT}} = (I_1 + I_2 + \cdots + I_N)(1 + R_2/R_1) \]

Likewise, any number of currents can be summed with arbitrary gain by using separate gain-setting resistors as shown in Figure 6.

For Figure 6:

\[ I_{\text{OUT}} = I_1(1 + R_2/R_1) + I_2(R_1 + R_2 + R_3)/R_1 + \cdots + I_N(R_1 + R_2 + R_3 + \cdots + R_N)/R_1 \]
INVERTING AND NONINVERTING CURRENT-TO-CURRENT CONVERTERS

The inverting and noninverting circuits can be used simultaneously either with equal gains or arbitrary gains as shown in Figures 7 and 8:

For Figure 7:
\[ I_{OUT} = \left\{ (-I_{1A} - I_{2A} - \cdots - I_{NA})R_{2A}/R_{1B} \right\} + \left\{ (I_{1B} + I_{2B} + \cdots + I_{NB})(1 + R_{2B}/R_{1B}) \right\} \]

4-20mA to 0-20mA CONVERTER

There are two ways to make a 4-20mA to 0-20mA converter using current summing circuits and a REF200 100µA current source for offsetting. Since the polarity of the 0-20mA output current must be the same as the 4-20mA input signal, the noninverting circuit is used in the main signal path. The REF200 100µA current source can be connected in either polarity so either inverting or noninverting summing can be used to offset the signal for 0mA out with 4mA in.

4-20mA to 0-20mA CONVERTER USING BOTH INVERTING AND NONINVERTING CURRENT-TO-CURRENT CONVERTER CIRCUITS

One implementation of the 4-20mA to 0-20mA converter is shown in Figure 9. From the Figure 4 and Figure 1 equations:

For Figure 9:
\[ I_{OUT} = I_1(1 + R_2/R_1) - I_2 \cdot R_2/R_1 \]

Where:
- \( I_1 \) = 4-20mA input current
- \( I_2 \) = 100µA REF200 offsetting current

Two equations can be written: one for \( I_{OUT} = 0mA \) with \( I_{IN} = 4mA \) and one for \( I_{OUT} = 20mA \) with \( I_{IN} = 20mA \). Since there are three unknowns (\( R_1 \), \( R_2 \), and \( R_3 \)) and only two equations, one resistor value must be selected first. A value of 100Ω was selected as an arbitrary but adequate value for \( R_2 \). With \( R_2 = 100Ω \), the maximum voltage drop across it is 2V at 20mA. A smaller value for \( R_2 \) will reduce the voltage burden and power dissipation in the circuit, but since the signal-to-noise ratio is reduced, it will be more sensitive to op amp errors.

To solve for \( R_1 \):

Notice that the current gain is:
\[ (20mA - 0mA)/(20mA - 4mA) = (20mA)/(16mA) \]
\[ = 1.25mA/mA \]

Rewriting the Figure 4 equation in terms of gain:
\[ \text{GAIN} = I_{OUT}/I_{IN} \]
\[ \text{GAIN} = 1 + R_2/R_1 \]

Solving the gain equation for \( R_1 \):
\[ R_1 = R_2(\text{GAIN} - 1) \]

Substituting \( R_2 = 100Ω \):
\[ R_1 = 100Ω/(1.25 - 1) \]
\[ R_1 = 400Ω \]

Then, solving the Figure 9 equation for \( R_3 \):
\[ R_3 = I_1(R_1 + R_2)/I_2 \]

Substituting \( I_1 = 4mA \), \( I_2 = 100µA \):
\[ R_3 = 40(R_1 + R_2) \]

Substituting \( R_1 = 100Ω \), \( R_2 = 400Ω \):
\[ R_3 = 20.0kΩ \]
NOTE: This circuit has poor compliance with positive power-supply rail.

FIGURE 9. 4-20mA to 0-20mA Current-to-Current Converter Using Inverting and Noninverting Summing Circuits.

4-20mA TO 0-20mA CONVERTER USING ONLY NONINVERTING CURRENT-TO-CURRENT CONVERTER CIRCUIT

The other possible circuit is shown in Figure 10. From the Figure 6 equations:

For Figure 10:

\[ I_{OUT} = I_1(1 + R_2/R_1) + I_2(R_1 + R_2 + R_3)/R_1 \]

Where, as before:

\[ I_1 = 4-20mA \text{ input current} \]
\[ I_2 = 100\mu A \text{ REF200 offsetting current} \]

The relationships for \( R_1 \) and \( R_2 \) are the same as for the Figure 9 circuit: with \( R_2 = 100\Omega \), \( R_1 = 400\Omega \).

Solving the Figure 10 equation for \( R_3 \):

\[ R_3 = (I_1 - I_2)(R_1 + R_2)/I_2 \]

Substituting \( I_1 = 4mA \), \( I_2 = 100\mu A \):

\[ R_3 = 39(R_1 + R_2) \]

Substituting \( R_1 = 100\Omega \), \( R_2 = 400\Omega \):

\[ R_3 = 19.5k\Omega \]

WHICH 4-20mA TO 0-20mA CONVERTER IS BETTER?

The only significant functional difference between the Figure 9 and Figure 10 converter circuits is the output voltage compliance range. Output range of the current-to-current converter circuit is limited by the op amp input and output ranges and by the minimum compliance range of the REF200 current source. Voltages for the two circuits at the 0mA and 20mA output current extremes are shown in Table I.

Both circuits have an op amp \( V_{OUT} \) of approximately \(-1.6V\) at one extreme. This limits the compliance to the negative power-supply rail to \( SL + 1.6V \) where \( SL \) is the op amp output negative swing limit. For example, if an op amp can swing to \(-12V\) (\( V_S = \pm 15V \)), its swing limit is \( SL = 3V \). The closest the circuit can swing to the negative rail is \( 3V + 1.6V = 4.6V \) or \( V_{OUT} = -10.4V \) (\( V_S = \pm 15V \)).

The Figure 10 circuit has an advantage for compliance to the positive power-supply rail. The Figure 9 circuit has a worst-case \( V_{IN} = 2V \). Also, the REF200 (with a min compliance of \( 2.5V \)) is connected between the input and \( +V_S \). This limits the compliance to the positive power-supply rail to \( 2V + 2.5V = 4.5V \).

The Figure 10 circuit has a worst-case \( V_{IN} = 0.04V \). Also, the REF200 is connected between the input and \(-V_S \). This allows the Figure 10 circuit to swing to the positive power-supply rail within the limits of the op amp input compliance. Op amps are available with input compliance to \(+V_S \). Compliance of the Figure 10 circuit (using the OPA177) is:

\[ +13V (+14V \text{ typ}), -10.9V (-11.4V \text{ typ}) \text{ with } V_S = \pm 15V. \]

TABLE I. Op Amp Input/Output Voltages for Figures 9 and 10 Circuits.

<table>
<thead>
<tr>
<th>OUTPUT CURRENT</th>
<th>FIGURE 9 CIRCUIT</th>
<th>FIGURE 10 CIRCUIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0mA</td>
<td>0.4</td>
<td>–1.6</td>
</tr>
<tr>
<td>20mA</td>
<td>2.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

NOTE: With the 0-20mA output connection node held at 0V.

NOTE: This circuit has excellent compliance with positive power-supply rail.

FIGURE 10. 4-20mA to 0-20mA Current-to-Current Converter Using Only Noninverting Summing Circuits.

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