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4-20mA TO 0-20mA CONVERTER AND CURRENT SUMMING CURRENT-TO-CURRENT CONVERTERS

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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.

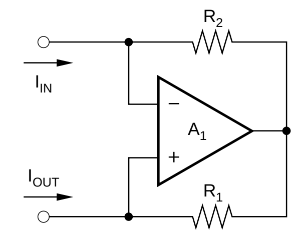
XTR110

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-soruce 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 XTR output must be converted to 0-20mA. This bulletin shows the suggested circuit and also discusses summing current-to-current converters in general.



$I_{OUT} = -I_{IN} \cdot R_2/R_1$

NOTE: The minus sign in the equation means that the I_{IN}, I_{OUT} currents flow as shown.

FIGURE 1. Basic Inverting Current-to-Current Converter.

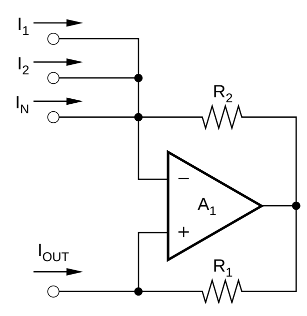
INVERTING CURRENT-TO-CURRENT CONVERTERS

Figure 1 shows the basic inverting current-to-current converter. The input current all flows through R_2 resulting in an $I_{IN} \cdot R_2$ voltage drop across R_2. The op amp forces the same voltage across R_1 so that there is no voltage difference at the op amp inputs. The I_{OUT} current is therefore:

For Figure 1:

$$I_{OUT} = -I_{IN} \cdot R_2/R_1$$

Notice that, like its cousin the inverting voltage amplifier,



$I_{OUT} = (-I_1 - I_2 - \cdots - I_N)\ R_2/R_1$

NOTE: The minus sign in the equation means that the I_{IN}, I_{OUT} currents flow as shown.

FIGURE 2. Equal-Gain Summing Inverting Current-to-Current Converter.

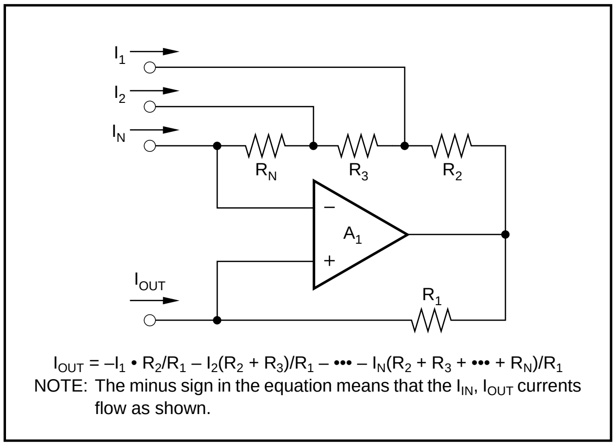


FIGURE 3. Arbitrary-Gain Summing Inverting Current-to-Current Converter.

the output current can be greater than or less than the input current. Of course, the output can also be equal to the input so the circuit can be used as a unity-gain current inverter with $R_1 = R_2$.

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 2.

For Figure 2:

$$I_{OUT} = (-I_1 - I_2 - \bullet\bullet\bullet - I_N)R_2/R_1$$

Any number of currents can be summed with arbitrary gain by using separate gain-setting resistors as shown in Figure 3.

For Figure 3:

$$I_{OUT} = -I_1 \bullet R_2/R_1 - I_2(R_2 + R_3)/R_1 - \bullet\bullet\bullet - I_N(R_2 + R_3 + \bullet\bullet\bullet + R_N)/R_1$$

NONINVERTING CURRENT-TO-CURRENT CONVERTERS

Figure 4 shows the circuit for the basic noninverting current-to-current converter. As before, all the input current flows through R_2 resulting in a $I_{IN} \bullet R_2$ voltage drop across R_2. In this circuit, the op amp is connected as a unity-gain buffer forcing the same voltage drop across R_1. The output current is the sum of the input current flowing through R_2 and the current flowing through R_1. The following relationships apply to the noninverting circuits.

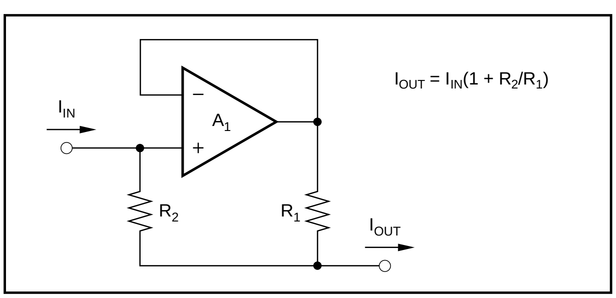


FIGURE 4. Basic Noninverting Current-to-Current Converter.

For Figure 4:

$$I_{OUT} = I_{IN}(1 + R_2/R_1)$$

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:

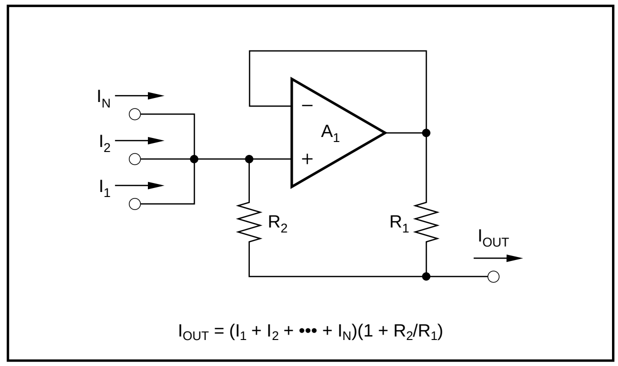


FIGURE 5. Equal-Gain Summing Noninverting Current-to-Current Converter.

$$I_{OUT} = (I_1 + I_2 + \bullet\bullet\bullet + I_N)(1 + R_2/R_1)$$

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:

$$I_{OUT} = I_1(1 + R_2/R_1) + I_2(R_1 + R_2 + R_3)/R_1 + \bullet\bullet\bullet + I_N(R_1 + R_2 + R_3 + \bullet\bullet\bullet + R_N)/R_1$$

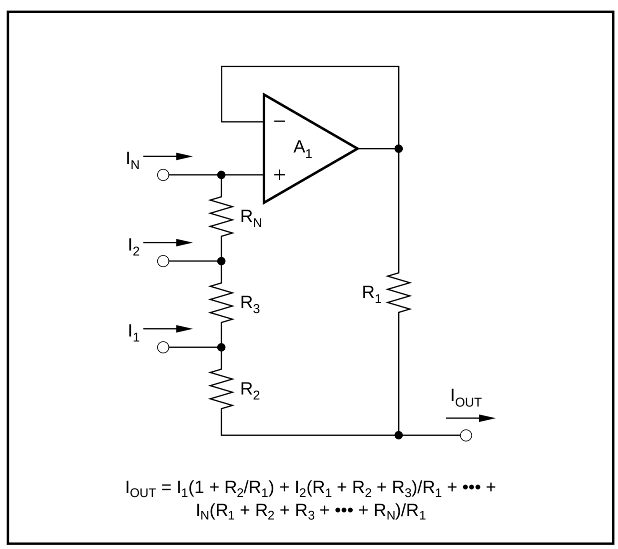


FIGURE 6. Arbitrary-Gain Summing Noninverting Current-to-Current Converter.

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:

$$I_{OUT} = \{(-I_{1A} - I_{2A} - \bullet\bullet\bullet - I_{NA})R_{2A}/R_{1B}\} + \{(I_{1B} + I_{2B} + \bullet\bullet\bullet + I_{NB})(1 + R_{2B}/R_{1B})\}$$

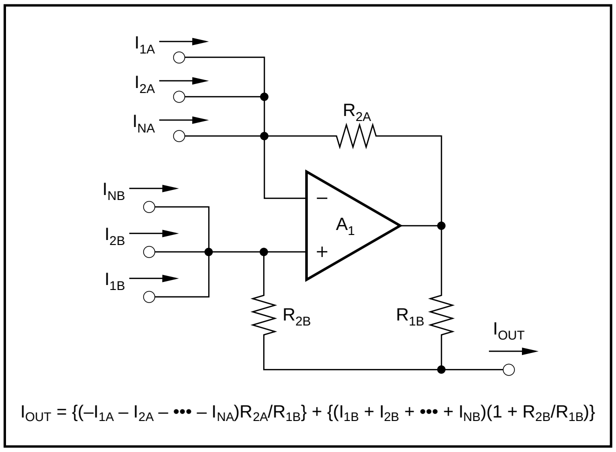


FIGURE 7. Equal-Gain Summing Inverting and Noninverting Current-to-Current Converter.

For Figure 8:

$$I_{OUT} = \{-I_{1A} \bullet R_{2A}/R_{1B} - I_{2A}(R_{2A} + R_{3A})/R_{1B} - \bullet\bullet\bullet - I_{NA}(R_{2A} + R_{3A} + \bullet\bullet\bullet + R_{NA})/R_{1B}\} + \{I_{1B}(1 + R_{2B}/R_{1B}) + I_{2B}(R_{1B} + R_{2B} + R_{3B})/R_{1B} + \bullet\bullet\bullet + I_{NB}(R_{1B} + R_{2B} + R_{3B} + \bullet\bullet\bullet + R_{NB})/R_{1B}\}$$

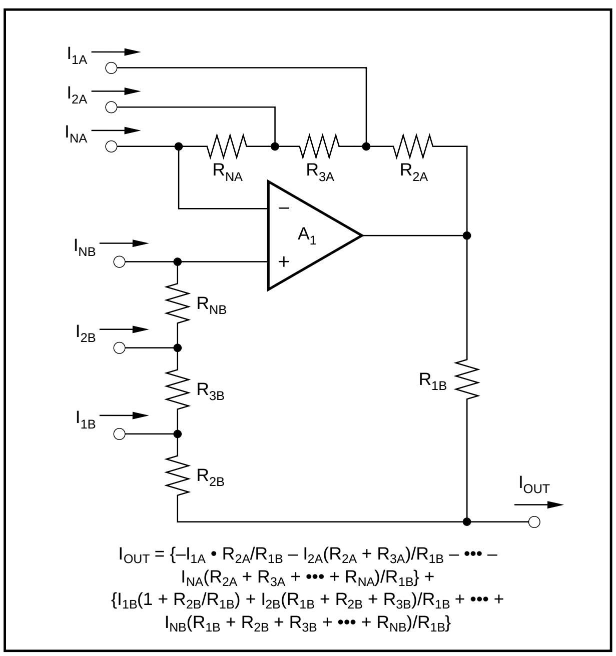


FIGURE 8. Arbitrary-Gain Summing Inverting and Noninverting Current-to-Current Converter.

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:

$$I_{OUT} = I_1(1 + R_2/R_1) - I_2 \bullet R_3/R_1$$

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:

$$GAIN = I_{OUT}/I_{IN}$$
$$GAIN = 1 + R_2/R_1$$

Solving the gain equation for R_1:

$$R_1 = R_2/(GAIN - 1)$$

Substituting R_2 = 100Ω:

$$R_1 = 100\Omega/(1.25 - 1)$$
$$R_1 = 400\Omega$$

Then, solving the Figure 9 equation for R_3:

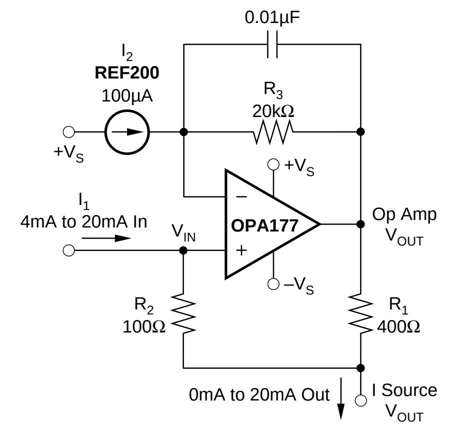
$$R_3 = I_1(R_1 + R_2)/I_2$$

Substituting I_1 = 4mA, I_2 = 100µA:

$$R_3 = 40(R_1 + R_2)$$

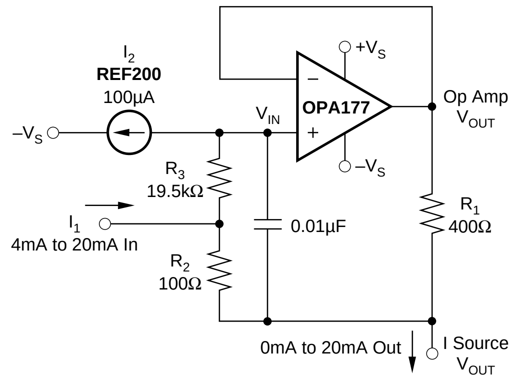
Substituting R_1 = 100Ω, R_2 = 400Ω:

$$R_3 = 20.0k\Omega$$



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.



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.

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 input current
I_2 = 100µA 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 = 100µA:

$$R_3 = 39(R_1 + R_2)$$

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.

OUTPUT CURRENT	FIGURE 9 CIRCUIT		FIGURE 10 CIRCUIT	
	OP AMP V_{IN}	OP AMP V_{OUT}	OP AMP V_{IN}	OP AMP V_{OUT}
0mA	0.4	–1.6	–1.56	–1.56
20mA	2.0	0.0	0.04	0.04

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

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

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 = ±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 = ±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 typ), –10.9V (–11.4V typ) with V_S = ±15V.