Application Report
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Using the XTR115 with the PGA309 to Generate 4mA to 20mA Output

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ABSTRACT

Sensor conditioning systems often require a 4mA to 20mA output, such as in the case of an instrumentation amplifier translating a pressure sensor output to a usable voltage level. The combination of the XTR115 and the PGA309 are ideally suited for such applications. This report discusses component selection to achieve 4mA to 20mA while setting the desired bandwidth. Grounding considerations are also reviewed.

1 Translating Nonlinear Variations to a Linear Output Voltage

A common requirement of sensor conditioning systems is that they have a 4mA to 20mA output. For example, instrumentation amplifiers are frequently used to translate a pressure sensor output to a usable voltage level. In many cases, it is desirable to translate the amplifier voltage output to the industry-standard 4mA to 20mA. The circuit in Figure 1 shows how the PGA309 voltage output can be translated to a 4mA to 20mA output. In this circuit, the PGA309 translates nonlinear variations in the pressure sensor bridge to a linear output voltage (0V to 5V). The PGA309 voltage output is translated into a current input for the XTR115 current loop transmitter. The XTR115 amplifies the input current and uses an offset to provide the desired 4mA to 20mA output.

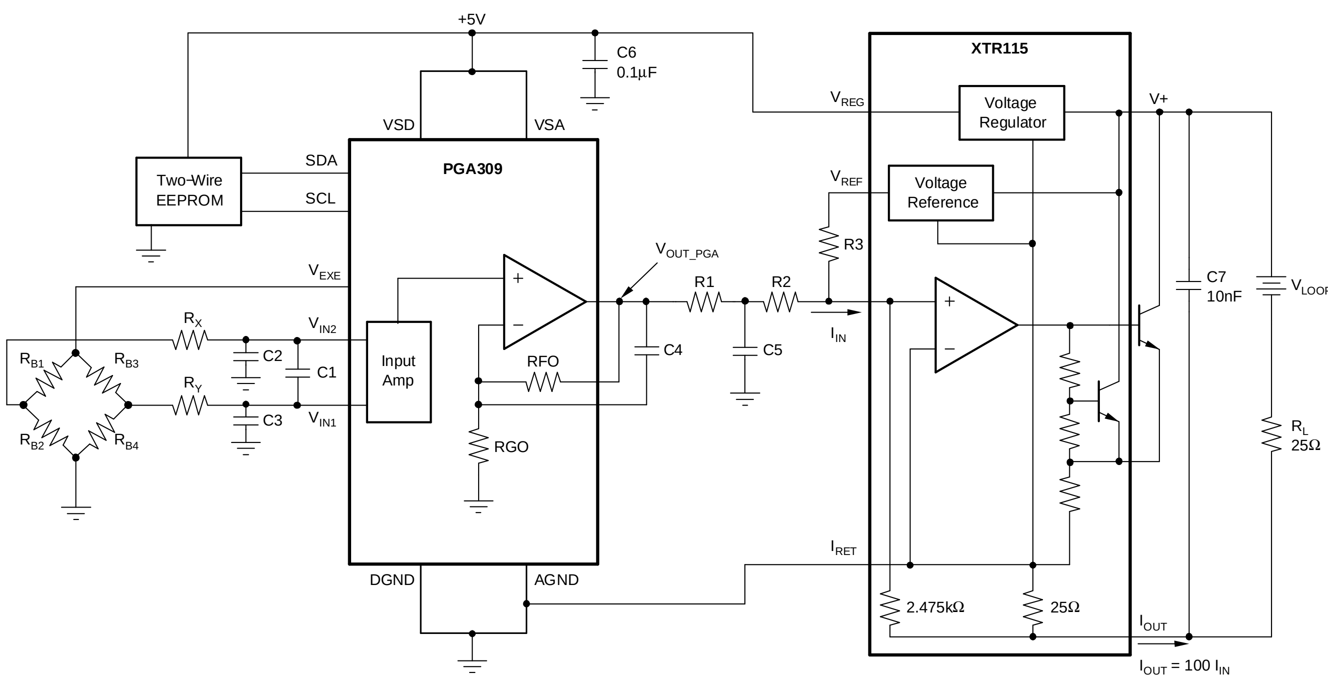

Figure 1. PGA309 and XTR115 Connections for a 4mA to 20mA Output

2 Component Selection to Achieve 4mA to 20mA

Resistors R1 and R2 translate the output voltage of the PGA309 to current [$I_{IN} = V_{OUT\_PGA}/(R1 + R2)$]. In fact, from a DC perspective, resistors R1 and R2 could be replaced with a single resistor. The topology shown in Figure 1, however, provides an additional first-order filter. Resistor R3 provides an output offset current for the XTR115; R3 may not be required, however, depending on the PGA309 output range. Example 1 illustrates a method for setting the output span to 4mA to 20mA when the PGA309 has a fixed output range. This method uses R3 to set the 4mA offset. Example 2 illustrates how to adjust the PGA309 output range to get the required 4mA to 20mA span without using R3.

2.1 Example 1: PGA309 with Fixed Output Range

Method to select components in order to achieve 4mA to 20mA span using R3 for offset:

Full-scale output of the PGA:

$$V_{OUT\_FS} = 4.5V$$

Zero output of the PGA:

$$V_{OUT\_Z} = 0.5V$$

Current gain of the XTR115:

$$A_I = \frac{I_{OUT}}{I_{IN}}$$

Resistance required for a 16mA span, given the PGA309 output swing:

$$R_1 + R_2 = \frac{V_{OUT\_FS} - V_{OUT\_Z}}{\frac{I_{OUT\_FS}}{A_I} - \frac{I_{OUT\_Z}}{A_I}} = \frac{V_{OUT\_FS} - V_{OUT\_Z}}{\frac{20mA}{100} - \frac{4mA}{100}} = \frac{4.5 - 0.5}{\left(\frac{16mA}{100}\right)} = 25.0k\Omega$$

Current with PGA309 output at minimum:

$$I_{V_{OUT\_Z}} = A_I\left(\frac{V_{OUT\_Z}}{R_1 + R_2}\right) = 100\left(\frac{0.5}{25.0k\Omega}\right) = 2mA$$

Offset required to set the XTR115 minimum current to 4mA:

$$I_{OFFSET} = 4mA - I_{V_{OUT\_Z}} = 4mA - 2mA = 2mA$$

R3 provides the offset current required to set the XTR115 minimum current to 4mA:

$$R_3 = \frac{V_{REF}}{\left(\frac{I_{OFFSET}}{A_I}\right)} = \frac{2.5V}{\left(\frac{2mA}{100}\right)} = 125k\Omega$$

2.2 Example 2: PGA309 Output Range without R3 Resistor

Method to select components in order to achieve 4mA to 20mA span by scaling the PGA309 output (R3 is not used):

Full-scale output of the PGA:

$$V_{OUT\_FS} = 4.5V$$

Zero output of the PGA:

$$V_{OUT\_Z} = \text{unknown}$$

Current gain of the XTR115:

$$A_I = \frac{I_{OUT}}{I_{IN}}$$

Resistance required to set full-scale output of the XTR115 to 20mA, given a maximum PGA309 output of 4.5V:

$$R_1 + R_2 = \frac{V_{OUT\_FS}}{\left(\frac{20mA}{A_I}\right)} = \frac{4.5}{\left(\frac{20mA}{100}\right)} = 22.5k\Omega$$

PGA309 minimum output required to set the XTR115 output to 4mA:

$$V_{OUT\_Z} = (R_1 + R_2)\left(\frac{4mA}{A_I}\right) = (22.5k\Omega)\left(\frac{4mA}{100}\right) = 0.9V$$

3 Component Selection to Set Desired Bandwidth

The circuit shown in Figure 1 has three low-pass filters. This section will provide guidelines for setting the low-pass cutoff frequency for each filter. For each filter in these examples, the cutoff frequency is selected to be 500Hz. To minimize noise, select the low-pass cutoff to provide the minimum bandwidth allowable by the given end application.

The first filter consists of C1, C2, and C3. C1 is used to filter the input common-mode noise for the PGA309. C2 and C3 filter input differential noise for the PGA309. The resistance of the bridge and the filter capacitors form first-order, low-pass filters. In order to avoid introducing a differential signal by mismatch errors in C2 and C3, the value of C1 needs to be at least 10 times that of C2.

Note that in some cases, the resistance of the bridge may be low enough to require capacitance values that are larger than 1µF. This undesirable situation can be avoided by using resistors R_X and R_Y. Example 3 and Example 4 illustrate two methods for selecting these component values.

3.1 Example 3: Component Selection for Input Filter, with $R_X = R_Y = 0\Omega$

Let:

$$f_{3dB} = 500Hz$$

If:

$$R_{B1} = R_{B2} = R_{B3} = R_{B4} = 2k\Omega$$

Then the resistance seen by each input of the PGA309 is the parallel combination of two of these elements.

$$R_{BDG} = R_{B1} \parallel R_{B2} = 2k\Omega \parallel 2k\Omega = 1k\Omega$$

$$C_1 = \frac{1}{2\pi R_{BDG} f_{3dB}} = \frac{1}{2\pi(1k\Omega)(500Hz)} = 0.31\mu F \quad \text{use } 0.33\mu F$$

$$C_2 = C_3 = \frac{C_1}{10} = 0.031\mu F \quad \text{use } 0.033\mu F$$

3.2 Example 4: Component Selection for Input Filter, with Non-Zero R_X and R_Y

Let:

$$f_{3dB} = 500Hz$$

If:

$$R_{B1} = R_{B2} = R_{B3} = R_{B4} = 100\Omega$$

Then the resistance seen by each input of the PGA309 is the parallel combination of two of these elements.

$$R_{BDG2} = R_{BDG} + R_X = 50\Omega + 1k\Omega = 1.05k\Omega$$

$$C_1 = \frac{1}{2\pi R_{BDG2} f_{3dB}} = \frac{1}{2\pi(1.05k\Omega)(500Hz)} = 0.30\mu F \quad \text{use } 0.33\mu F$$

$$C_2 = C_3 = \frac{C_1}{10} = 0.030\mu F \quad \text{use } 0.033\mu F$$

3.3 Example 5: Component Selection for PGA309 Filter

For a gain of two and a low-pass cutoff frequency of 500kHz:

$$C_4 = \frac{1}{2\pi R_{FO} f_{3dB}} = \frac{1}{2\pi(18k\Omega)(500Hz)} = 0.018\mu F$$

The PGA309 output can be used as a first-order filter. This filter consists of C4 and RFO. In order to select components for this filter, we need to know the gain setting that will be used in the PGA309 output amplifier. The feedback resistance values from Table 1 are used in the formula to compute C4.

Table 1. Resistance Values for PGA309 Output Amplifier Feedback Network

GAIN	RFO (TYPICAL)
x2	18kΩ
x2.4	21kΩ
x3	24kΩ
x3.6	26kΩ
x4.5	28kΩ
x6	30kΩ
x9	32kΩ

3.4 Example 6: Component Selection Filter Between the XTR115 and the PGA309

A final first-order filter consists of C5, R1, and R2. R2 is used to isolate C5 from the XTR115 input amplifier; a minimum value of R2 = 10kΩ should be used to insure the XTR115 stability. The value of R1 is defined by the XTR115 current scaling requirements. See Example 1 and Example 2 for the current scaling requirements.

From Example 1:

$$R_1 + R_2 = 25k\Omega$$

$$R_1 = 25k\Omega - R_2 = 25k\Omega - 10k\Omega = 15k\Omega$$

$$C_5 = \frac{1}{2\pi R_1 f_{3dB}} = \frac{1}{2\pi(15k\Omega)(500Hz)} = 0.021\mu F$$

4 Grounding Considerations

A common concern regarding this circuit is that the loop supply ground on the XTR115 (or the ground on the equipment that communicates digitally with the PGA309) can create ground contention. Figure 2 shows a typical system that includes a PC and a PC interface board to facilitate PGA309 programming. It is critical that the V_{LOOP} supply must be isolated from the PGA309 supply in order to avoid ground contention, as seen in Figure 2. It is also important that the PGA309, PC Interface Board, and the computer share a common ground. It is recommended that V_{PC}, the supply connected to the PC interface board, be a floating supply to eliminate ground loop errors or contention.

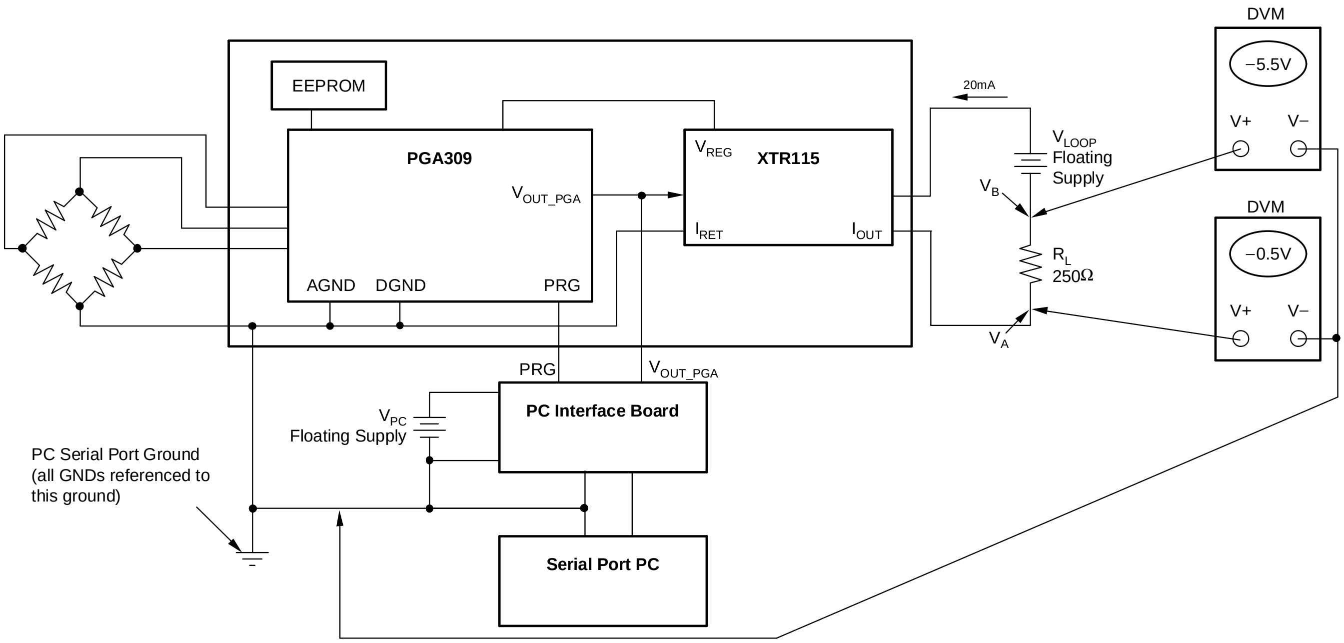

Figure 2. Power Supply and Grounding Connections for PGA309 and XTR115

Doing a nodal analysis on the XTR115 circuit provides insight regarding why the floating supply is required for V_{LOOP}. The negative end of the V_{LOOP} supply (V_B in Figure 2) must be at V_B = - $R_L(I_{OUT})$ – (2.475kΩ)I_{IN} with respect to ground (I_{RET} for the XTR115). For the circuit shown, then, the voltage V_B will vary between –5.5V to –1.1V with respect to ground for a 4mA to 20mA output signal (see DVM1 in Figure 2). It is also interesting to note that the voltage on the I_{OUT} pin of the XTR115 (V_A in Figure 2) varies according to the following equation:

V_A= – (2.475kΩ)I_{IN}.

So, for the circuit shown, V_A will vary between –0.1V and –0.5V (see DVM2 in Figure 2).

Furthermore, some care must be taken in the measurement of the output voltage across R_L. As seen in Figure 2, the device or instrument used to measure these voltages needs to be able to measure –5.5V with respect to **PC Serial Port Ground**. Specifically, the differential voltage (V_B, V_A) varies from (–1.1, –0.1) to (–5.5, –0.5) with respect to **PC Serial Port Ground**. Therefore, a floating DVM or an analog-to-digital converter that is capable of measuring signals below ground is required.

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