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Reference Circuits

Circuits from the Lab™ reference circuits are engineered and tested for quick and easy system integration to help solve today's analog, mixed-signal, and RF design challenges. For more information and/or support, visit www.analog.com/CN0295.

Devices Connected/Referenced	
AD8226	Wide Supply Range, Rail-to-Rail Output Instrumentation Amplifier
ADR02	Ultracompact, Precision 5.0 V Voltage Reference
ADA4091-4	Precision Micropower, OVP, RRIO Operational Amplifier

Flexible, 4 mA-to-20 mA Pressure Sensor Transmitter with Voltage or Current Drive

EVALUATION AND DESIGN SUPPORT

Circuit Evaluation Boards

CN0295 Evaluation Board (EVAL-CN0295-EB1Z)

Design and Integration Files

Schematics, Layout Files, Bill of Materials

CIRCUIT FUNCTION AND BENEFITS

The circuit shown in Figure 11 is a flexible current transmitter that converts the differential voltage output from a pressure sensor to a 4 mA-to-20 mA current output.

The circuit is optimized for a wide variety of bridge-based voltage or current driven pressure sensors, utilizes only five active devices, and has a total unadjusted error of less than 1%. The power supply voltage can range from 7 V to 36 V depending on the component and sensor driver configuration.

The input of the circuit is protected for ESD and voltages beyond the supply rail, making it ideal for industrial applications.

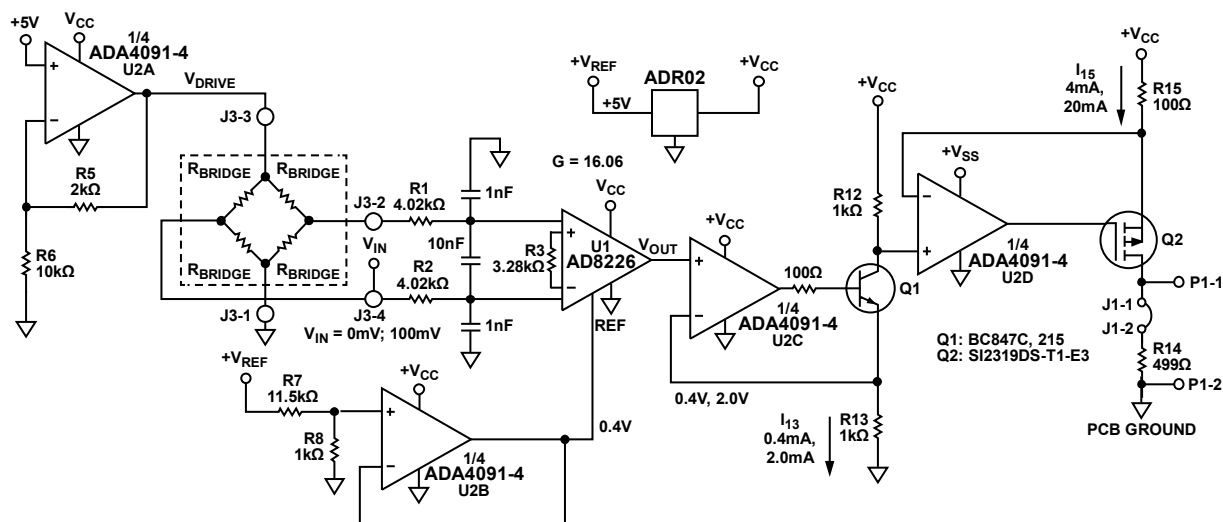


Figure 1. Pressure Sensor Signal Conditioning Circuit with 4 mA-to-20 mA Output (Shown in Sensor Voltage Drive Mode)
(Simplified Schematic; All Connections and Decoupling Not Shown)

Rev.0

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CIRCUIT DESCRIPTION

The design provides a complete solution for the 4 mA-to-20 mA transmitter for pressure sensor measurements. The circuit has three critical stages: the sensor excitation drive, the sensor output amplifier, and the voltage to current converter.

The total current required by the circuit (neglecting the bridge drive current and the output current) is 5.23 mA (maximum) as shown in Table 1.

Table 1. Maximum circuit currents at 25°C

Component	Current (mA)
ADR02	0.80
ADA4091-4	1.00
AD8226	0.43
R5, R6 at 6 V	0.60
R7, R8 at 5 V	0.40
R13 at 2 V	2.00
Total	5.23

Excitation: Voltage Drive Configuration

Depending on the pressure sensor selected, either a voltage or current drive is required. The circuit uses one-fourth of the ADA4091-4 (U2A) with different configurations chosen by switching S1 to support either option. Figure 2 shows the

configuration for the voltage drive with S1 in the position closest to the identifying marking (see complete circuit layouts and schematics in the CN0295 design support package: <http://www.analog.com/CN0295-DesignSupport>). The voltage drive is normally configured for a bridge drive voltage of 6 V by the gain of the stage, $1 + R5/R6$. Other drive voltages can be obtained by changing the resistor ratio appropriately:

$$V_{DRIVE} = 5 \text{ V} \left(1 + \frac{R5}{R6} \right)$$

Note that the power supply voltage V_{CC} should be at least 0.2 V greater than the bridge drive voltage to allow sufficient headroom for U2A, the ADA4091-4:

$$V_{CC} \geq V_{DRIVE} + 0.2 \text{ V}$$

For the values shown in Figure 2, $R5 = 2 \text{ k}\Omega$, $R6 = 10 \text{ k}\Omega$, $I_{DRIVE} = 2 \text{ mA}$, $V_{DRIVE} = 6 \text{ V}$, and $V_{CC} \geq 6.2 \text{ V}$.

The ADA4091-4 op amp is chosen for the circuit because of its low current consumption (250 μA /amplifier), low offset voltage (250 μV), and rail-to-rail inputs and outputs.

The ADR02 is chosen for the 5 V reference because of its accuracy (A-Grade: 0.1%, B-Grade: 0.06%) and low quiescent current (0.8 mA).

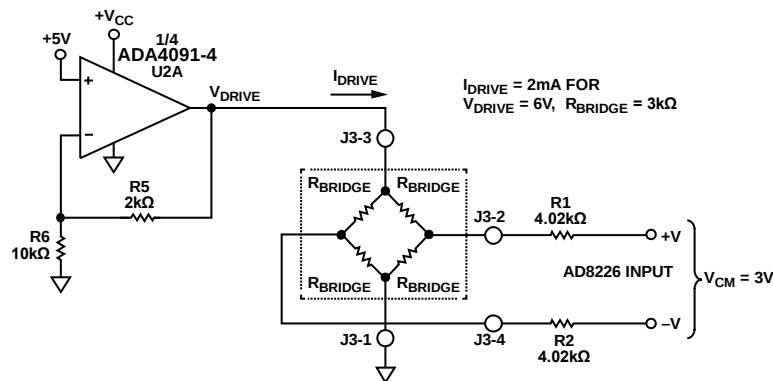


Figure 2. Sensor Voltage Drive Configuration (Simplified Schematic: All Connections and Decoupling Not Shown)

Excitation: Current Drive Configuration

The circuit can be switched to the current drive configuration shown in Figure 3 by moving S1 to the position that is furthest away from the identifying marking.

In the current drive mode, the circuit is configured for $R_4 = 2.5\text{ k}\Omega$, and $I_{\text{DRIVE}} = 2\text{ mA}$. Lower or higher values of I_{DRIVE} can be obtained by using the following equation to select the value of R_4 :

$$R_4 = \frac{5\text{ V}}{I_{\text{DRIVE}}}$$

The resulting drive voltage V_{DRIVE} is calculated from:

$$V_{\text{DRIVE}} = 5\text{ V} + I_{\text{DRIVE}} \times R_{\text{BRIDGE}}$$

A headroom of 0.2 V is required for the V_{CC} supply, therefore:

$$V_{\text{CC}} \geq V_{\text{DRIVE}} + 0.2\text{ V}$$

For the values shown in Figure 3, $R_{\text{BRIDGE}} = 3\text{ k}\Omega$, $I_{\text{DRIVE}} = 2\text{ mA}$, $V_{\text{DRIVE}} = 11\text{ V}$, and $V_{\text{CC}} \geq 11.2\text{ V}$.

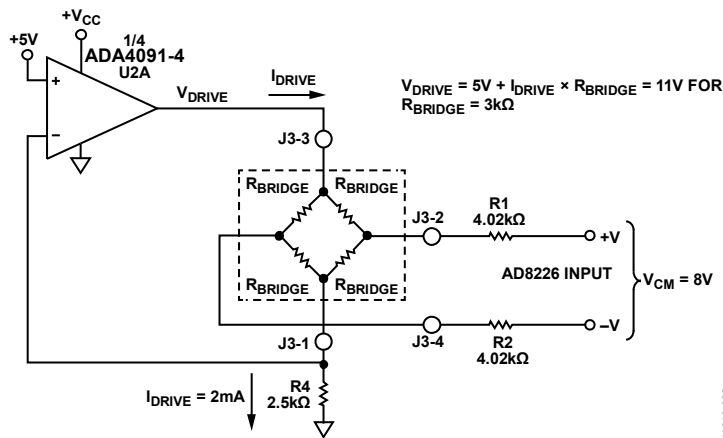


Figure 3. Sensor Current Drive Configuration (Simplified Schematic: All Connections and Decoupling Not Shown)

Bridge Output Instrumentation Amplifier and Offset Circuit

The output of the bridge is filtered by a common-mode filter (4.02 kΩ, 1 nF) with a bandwidth of 39.6 kHz and a differential-mode filter (8.04 kΩ, 10 nF) with a bandwidth of 1.98 kHz.

The [AD8226](#) is an ideal choice for the in-amp because of its low gain error (0.1%, B-grade), low offset (58 μV at G = 16, B-grade; 112 μV at G = 16, A-grade), excellent gain nonlinearity (75 ppm = 0.0075%), and rail-to-rail inputs and output.

The [AD8226](#) instrumentation amplifier amplifies the 100 mV FS signal by a factor of 16 to 1.6 V using a gain setting resistor R3 = 3.28 kΩ. The relationship between the gain, G, and R3 is given by

$$R3 = \frac{49.4 \text{ k}\Omega}{G - 1}$$

For G = 16, R3 = 3.2933 kΩ. The nearest standard 0.05% value of 3.28 kΩ is chosen for R3, yielding a gain of G = 16.06, which introduces an overall gain error of +0.4%.

For a 0 V bridge output, the output loop current should be 4 mA. This is achieved by simply applying a +0.4 V offset to the REF input of the [AD8226](#) in amp as shown in Figure 1. The +0.4 V is derived from the [ADR02](#) 5 V reference using divider resistors R7/R8 and buffering the voltage with U2B.

The [ADR02](#) 5 V reference is used to set the drive voltage or current to the bridge and to set the 4 mA zero offset. It has an initial accuracy of 0.06% (B-grade) and 10 μV p-p voltage noise. In addition, it operates on supply voltages up to 36 V and consumes less than 1 mA, making it an ideal choice for low power applications.

Voltage to Current Conversion

The 0 V to 100 mV input to the [AD8226](#) generates an output swing at V_{OUT} of 0.4 V to 2.0 V. The buffer, U2C, applies this voltage across R13 that produces a corresponding current I₁₃ of 0.4 mA to 2.0 mA. Transistor Q1 then mirrors the I₁₃ current to R12, and the resulting voltage is applied to R15, thereby developing the final loop current of 4 mA to 20 mA. Transistor Q1 should have a high gain of at least 300 to minimize the linearity error due to its base current.

The output transistor Q2 is a 40 V P-channel MOSFET power transistor capable of dissipating 0.75 W at 25°C. The worst-case power dissipation in the circuit is for an output current of 20 mA into a loop load resistance of 0 Ω with a V_{CC} supply of 36 V. Under these conditions the power dissipation of Q2 is 0.68 W. However, the power in Q2 can be significantly reduced by properly selecting V_{CC} so that it is at least 3 V greater than the maximum loop load voltage. This ensures sufficient headroom due to the voltage dropped across the sense resistor R15.

Voltage Supply Requirement

In order for the circuit to operate properly, the supply voltage, V_{CC}, must be greater than 7 V in order to provide sufficient headroom for the [ADR02](#) voltage reference.

The minimum V_{CC} supply voltage is also dependent on the configuration of the drive circuit for the bridge. In the voltage drive mode with V_{DRIVE} = 6 V, the supply voltage V_{CC} must be greater than 6.2 V in order to maintain sufficient headroom for U2A (see Figure 2).

In the current drive mode, the supply voltage V_{CC} must be greater than 11.2 V in order to maintain sufficient headroom for U2A (see Figure 3).

The V_{CC} supply voltage is limited to 36 V maximum.

Error Analysis for Active Components

The maximum and rss errors due to the active components in the system for A- and B-grade levels of the [AD8226](#) and the [ADR02](#) are shown in Tables 2 and 3. Note that the [ADA4091-2](#) op amp is only available in one grade level.

Table 2. Errors Due to Active Components (A-Grade)

Error Component	Error	Error Value	Error %FSR
AD8226-A	Offset	112 μV	0.11%
ADR02-A	Offset	0.10%	0.02%
ADA4091-4 (U2B)	Offset	250 μV	0.02%
ADA4091-4 (U2C)	Offset	250 μV	0.02%
ADA4091-4 (U2D)	Offset	250 μV	0.02%
AD8226-A	Gain	0.15%	0.15%
RSS Offset			0.12%
RSS Gain			0.15%
RSS FS Error			0.27%
Max Offset			0.19%
Max Gain			0.15%
Max FS Error			0.34%

Table 3. Errors Due to Active Components (B-Grade)

Error Component	Error	Error Value	Error %FSR
AD8226-B	Offset	58 μV	0.06%
ADR02-B	Offset	0.06%	0.01%
ADA4091-4 (U2B)	Offset	250 μV	0.02%
ADA4091-4 (U2C)	Offset	250 μV	0.02%
ADA4091-4 (U2D)	Offset	250 μV	0.02%
AD8226-B	Gain	0.10%	0.10%
RSS Offset			0.07%
RSS Gain			0.10%
RSS FS Error			0.17%
Max Offset			0.13%
Max Gain			0.10%
Max FS Error			0.23%

LEARN MORE

CN-0295 Design Support Package:

<http://www.analog.com/CN0295-DesignSupport>

MT-035 Tutorial, *Op Amp Inputs, Outputs, Single-Supply, and Rail-to-Rail Issues*. Analog Devices.

MT-051 Tutorial, *Current Feedback Op Amp Noise Considerations*

MT-065 Tutorial, *In-Amp Noise*

MT-066 Tutorial, *In-Amp Bridge Circuit Error Budget Analysis*

MT-087 Tutorial, *Voltage References*

MT-031 Tutorial, *Grounding Data Converters and Solving the Mystery of AGND and DGND*. Analog Devices.

MT-101 Tutorial, *Decoupling Techniques*. Analog Devices.

Voltage Reference Wizard Design Tool.

Data Sheets and Evaluation Boards

[AD8226 Data Sheet](#)

[ADA4091-4 Data Sheet](#)

[ADR02 Data Sheet](#)

REVISION HISTORY

5/13—Revision 0: Initial Version

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