Pressure transducer-to-ADC application

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Introduction

A major application of operational amplifiers (op amps) is converting and conditioning signals from transducers into signals that other devices such as analog-to-digital converters (ADCs) can use. Conversion and conditioning are usually necessary because the transducer and ADC ranges and offsets are rarely the same. Op amp circuits are also useful in signal filtering for compatibility with ADC circuits.

This article shows how to use a bridge-type transducer for measuring gas or liquid pressure, and for measuring strain in mechanical elements. A basic understanding of active and passive analog devices and their use is helpful to use this article to complete a design.

Transducer information

The sensor tested in this application is a pressure transducer SX01 produced by SenSym Inc. It is one of a set of solid-state pressure sensors with available full-scale ranges of 1 to 150 psi (7 kPa to 1 MPa). Three types of pressure measurement are available: gauge, differential, and absolute.

TRW, another supplier of such sensors, has an on-line product catalog with a link to data sheets at www.gesensing.com

The device evaluated here has a full-scale pressure of 1 psig (7 kPa). Its price is low relative to other devices in this range; however, the low price comes at the expense of no temperature compensation, a drawback that can be overcome by adding inexpensive, external compensation components. The SenSym data sheet defines three circuits for this purpose; the method chosen here uses an NPN bipolar transistor and two resistors.

Excitation source information

For a bridge transducer to work, it must be excited by a voltage source. Because the stability of the excitation voltage affects the accuracy of the measurement signal, a regulated voltage source is necessary. This application assumes the availability of a regulated 5-V supply.

Choice of ADC

For this design, the TLV2544 ADC was selected because it has an analog input range of 0 to 5 V (see Reference 1). Ideally, the span of the amplified sensor signal should fill this range. The voltage needed to power this device is a single 5-V supply.

Choice of op amp

The ADC's 0- to 5-V analog-input range and the use of a single 5-V power supply required a rail-to-rail output device. The op amp also needed to be able to handle the full input range of the transducer. For these reasons, the TLV2474 was chosen (see Reference 2).

Defining the circuit

The amplified pressure transducer signal is connected to an ADC. Since the ADC connects to a microprocessor or DSP, final calibrations can be done in software. Therefore, the 0- to 1-psi range should span the center of the ADC's range. For calculating gain, the output range of the amplifier is 1.25 to 3.75 V. Figure 1 is the schematic of the amplifier circuit for this application.

The output of the circuit is

$$V_{OUT} = V_{IN2}\left(\frac{2R_4 + R_3}{R_3}\right)\left(\frac{R_7}{R_5 + R_7}\right)\left(\frac{R_6 + R_2}{R_2}\right) - V_{IN1}\left(\frac{2R_1 + R_3}{R_3}\right)\left(\frac{R_6}{R_2}\right) + V_{REF}\left(\frac{R_5}{R_5 + R_7}\right)\left(\frac{R_6 + R_2}{R_2}\right). \quad (1)$$

When $R_7 = R_6$, $R_5 = R_2$, and $R_4 = R_1$, Equation 1 reduces to

$$V_{OUT} = (V_{IN2} - V_{IN1})\left(\frac{2R_1}{R_3} + 1\right)\left(\frac{R_6}{R_2}\right) + V_{REF}. \quad (2)$$

Solving for R_3 yields

$$R_3 = \frac{2R_1}{\dfrac{(V_{OUT} - V_{REF})R_2}{(V_{IN2} - V_{IN1})R_6} - 1}. \quad (3)$$

The sensitivity of the bridge is typically 4.0 mV/V/psi. The pressure is 1 psi and the excitation voltage is 5 V. Therefore, the differential output of the sensor (V_{IN2}–V_{IN1}) from 0 to 1 psi is 20 mV. Setting $R_1 = R_4 = R_6 = R_7 =$ 20.0 kΩ (1% value) and $R_2 = R_5 =$ 2.0 kΩ results in a full-scale output range of 2.5 V when R_3 = 3.478 kΩ.

A unique feature of this precision instrumentation amplifier is the ability to control the total gain of the amplifier with one resistor.

Calibration devices

The resistor that controls gain is R_1. A potentiometer has a larger temperature coefficient and is more likely to drift over time than a fixed resistor. Placing a fixed resistor in series with a potentiometer minimizes this problem. The values calculated in the following equations are based on about 10% gain adjustment.

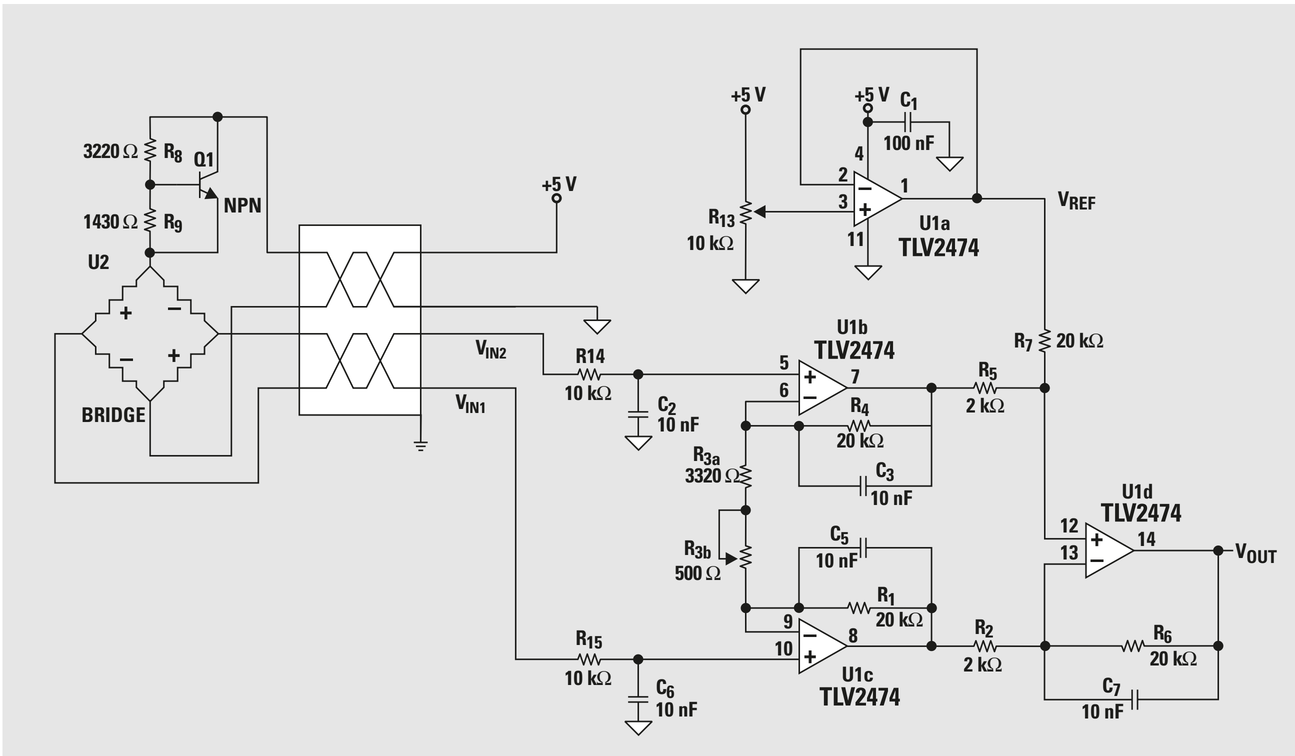
$$R_{3A} = R_1 - R_1(5\%) = 143\ \text{k}\Omega \text{ (1\% resistor)} \quad (4)$$

$$R_{3B} = R_3(10\%) = 50\ \text{k}\Omega \text{ (Cermet potentiometer)} \quad (5)$$

The potentiometer for adjusting offset, R_{13}, is not critical; but a 10-kΩ multiturn potentiometer uses 0.5 mA.

One of the goals of design is to reduce components without compromising function. If the offset voltage of the op amps is low enough, replacing potentiometers with fixed resistors is possible. Offset and gain calibration

Figure 8. Op amp circuit for the pressure transducer-to-ADC application



would then be done using software in a DSP or microprocessor. This is possible because the bottom and top 25% of the input range of the ADC are not presently used. In this condition, V_{REF} would be initially set by replacing R_{13} with a voltage divider. The offset drift of the op amps causes the output to move up or down into the unused areas. Variations on the resistors cause small gain errors, but these should be of less concern than the offset voltage. Instead of calibrating with potentiometers, using the offset and gain variables in calculations can generate a calibrated output.

Signal filtering

If the transducer is installed on the amplifier board, the input filter circuits and shielded wires are not needed.

Connecting a transducer to an input subjects the wiring to noise signals because of the surrounding electrical and magnetic environment. To prevent this noise from interfering with the measurement signals, some shielding is necessary. Using a twisted pair from the transducer to the conversion circuit and shielding this pair (grounding the shield at the instrument) reduces the noise.

Even when the transducer is connected through correctly shielded cabling, some noise is brought into the amplifier along with the measurement signal. Without an input filter, the op amp would act as an RF detector, converting high-frequency signals from other devices into signals with low-frequency components. Placing a resistor and capacitor on the input forms a low-pass filter and prevents radio-frequency signals from interfering with the measurement signal. The frequency response of this filter is

$$f_C = \frac{1}{2\pi RC}. \qquad (6)$$

Thus, if R_{14} and R_{15} are 10 kΩ, and C_2 and C_6 are 10 nF, then f_C is about 1600 Hz.

The next two stages have capacitors in parallel with the feedback resistors. The frequency response of these filters is also defined by Equation 6. Using 20 kΩ for the feedback resistor gives a cutoff frequency, f_C, of about 800 Hz.

References

For TI information related to this article, you can download an Acrobat Reader file at www-s.ti.com/sc/techlit/*litnumber* and replace *"litnumber"* with the **TI Lit. #** for the following document.

Document Title	**TI Lit. #**
1. "TLV2544, TLV2548 2.7-V to 5.5-V, 12-bit, 200-kSPS, 4-/8-channel, Low-power Serial Analog-to-Digital Converters with Autopower-down," Data Sheet	slas198
2. "TLV2470, TLV2471, TLV2472, TLV2473, TLV2474, TLV2475, TLV247xA Family of 600-µA/Ch 2.8-MHz Rail-to-Rail Input/Output High-Drive Operational Amplifiers with Shutdown," Data Sheet	slos232

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Document Title	TI Lit. #
3. “Understanding Basic Analog-Ideal Op Amps,” Application Report	.slaa068
4. “Single Supply Op Amp Design Techniques,” Application Report	.sloa030
5. “Active Low-Pass Filter Design,” Application Report	.sloa049
6. “Application of Rail-to-Rail Operational Amplifiers,” Application Report	.sloa039
7. Ron Mancini, “Sensor to ADC—Analog Interface Design,” *Analog Applications Journal* (May 2000), p. 22	.slyt173
8. “Signal Conditioning Wheatstone Resistive Bridge Sensors,” Application Report	.sloa034

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Appendix A. Calculations

The following values and equations were used in this article. Values in **bold** are calculated. All entered values are non-bold.

Given:

$Input_{MIN}$ = 0.0 psi ⇒ $Output_{MIN}$ = 1.25 V
$Input_{MAX}$ = 1.0 psi ⇒ $Output_{MAX}$ = 3.75 V
Sensitivity = 0.004 mV/V/psi
Excitation voltage = 5 V
Full-scale span = 0.02 V
Nominal Gain = 125

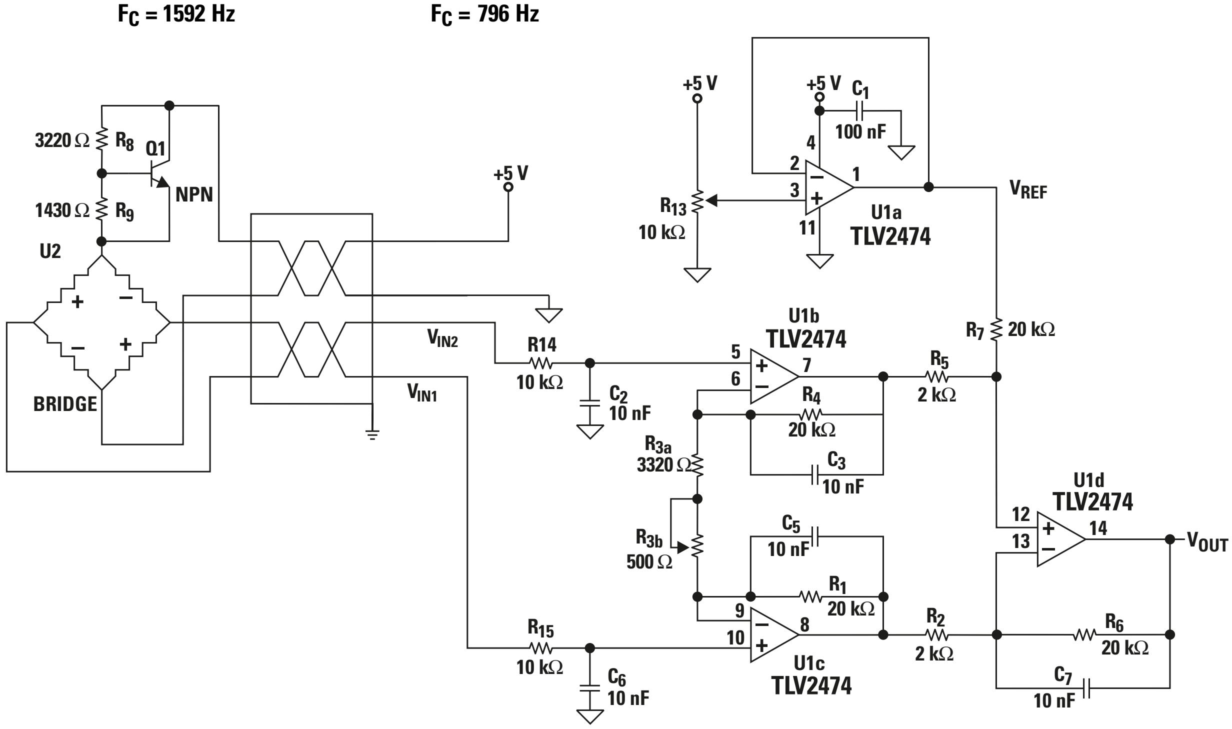
R_8 = 3.22 kΩ
R_9 = 1.43 kΩ

$R_1 = R_4 = R_7 = R_6$ = 20 kΩ
$R_5 = R_2$ = 2 kΩ
V_{IN} = 0.02 V
V_{OUT} = 2.5 V
R_3 = 3478 Ω

R_{3A} = 3304 Ω ⇒ 1% value **3320 Ω**
R_{3B} = 348 Ω ⇒ Pot. value **500 Ω**

$C_4 = C_6$ = 0.01 µF
$R_{14} = R_{15}$ = 10 kΩ
F_C = 1592 Hz

$C_3 = C_5 = C_7$ = 0.01 µF
$R_1 = R_4 = R_6$ = 10 kΩ
F_C = 796 Hz



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