Pressure Transducer to ADC Application

John Bishop *Advanced Analog Products/Op-Amp Applications*

ABSTRACT

A range of bridge-type transducers can measure numerous process variables. This report describes a pressure transducer, and a bridge transducer to measure strain in mechanical elements. It gives an example circuit from which to implement other applications.

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

Transducer Information

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

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

ADC Information

For this design, Systems Engineering selected the TLV2544 ADC, which has an analog input range of 0 – 5 V (see http://www.ti.com/sc/docs/products/analog/tlv2544.html for its data sheet). 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 – 5 V analog-input range, and the fact that the power available was a single 5-V supply required a rail-to-rail output device. The op amp must also be able to handle the full input range of the transducer. For these reasons, the TLV2474 was chosen; its data sheet is at http://www.ti.com/sc/docs/products/analog/tlv2474.html

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 – 1 psi range should span the center of the range of the ADC. For calculating gain, the output range of the amplifier is 0 – 2.5 V. Figure 1 is the schematic of the amplifier circuit for this application.

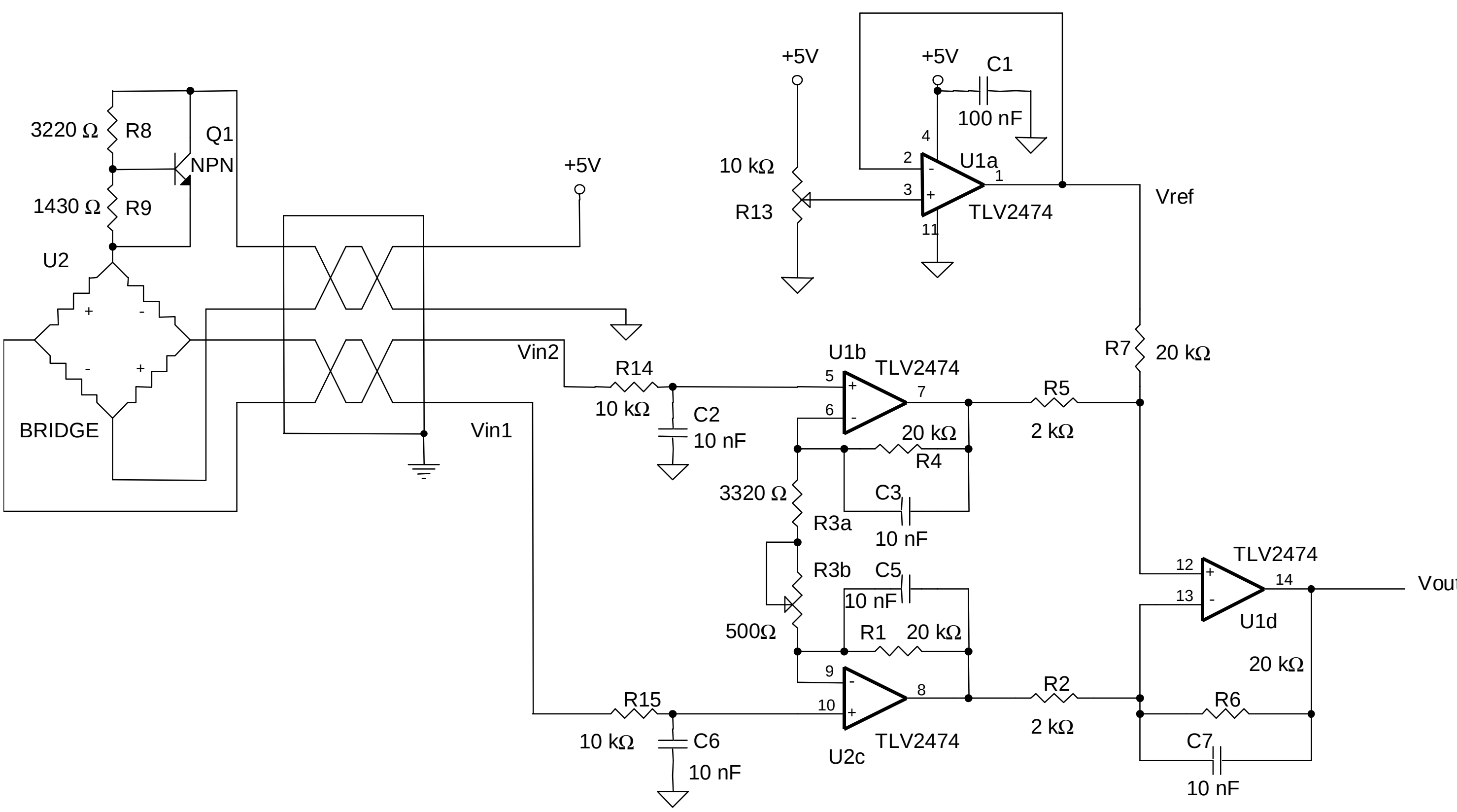


Figure 1. Op-Amp Circuit for the Pressure Transducer to ADC Application

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 gives:

$$R_3 = 2R_1 \Big/ \left[\frac{(V_{OUT} - V_{REF})R_2}{(V_{IN2} - V_{IN1})R_6} - 1\right] \quad (3)$$

The sensitivity of the bridge is typically 4.0 mV/V/psi. The pressure range 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 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 reduces this. The values calculated in the following equations are based on about 10% gain adjustment:

$R_{3A} = R_1 - R_1$ (5%) = 143 kΩ (1% resistor) (4)

$R_{3B} = R_3$ (10%) = 50 kΩ (Cermet potentiometer) (5)

The potentiometer for adjusting offset, R13 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 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 R13 with a voltage divider. The offset drift of the op amps cause 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:

$$F_C = \frac{1}{2\pi RC} \tag{5}$$

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 (5). Using 20 kΩ for the feedback resistor gives a cutoff frequency, F_C, of about 800 Hz.

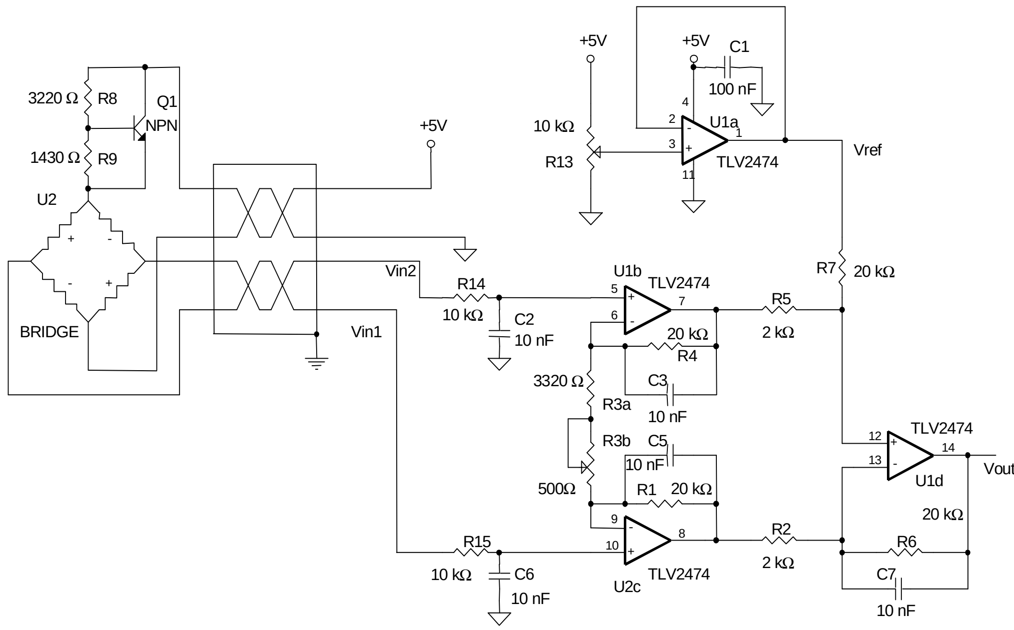
Bibliography

For more information, you can access the following reports as .pdf files at http://www.ti.com/ by searching for the literature numbers indicated.

1. *Understanding Basic Analog—Ideal Op Amps*, Texas Instruments Literature Number SLAA068.
2. *Single Supply Operational Amplifier Design Techniques,* Texas Instruments Literature Number SLOA030.
3. *Active Low Pass Filter Design*, Texas Instruments Literature Number SLOA049.
4. *Use Of Rail-To-Rail Operational Amplifiers*, Texas Instruments Literature Number SLOA039 (Revision A).
5. *Sensor to ADC-Analog Interface Design,* Texas Instruments Literature Number SLYT015 (page 22)
6. *Mixed-Signal: Amplifiers: Operational Amplifiers* (This is a complete op amp application index). http://www.ti.com/sc/docs/apps/analog/operational_amplifiers.html
7. *Signal Conditioning Wheatstone Resistive Bridge Sensors,* Texas Instruments Literature Number SLOA034.

Appendix A. Calculations

The following spreadsheet output indicates values and equations used in this application note.



Given:						
OUTPUTmin=	0.0	psi		OUTPUTmin=	0	V
INPUTmax=	1.0	psi		OUTPUTmax=	2.5	V
Sensitivity	0.004	mV/V/psi				
Exitation Voltage	5	V				
Full Scale Span	0.02	V		R_8=	3.22k	Ohms
Nominal Gain	125			R_9=	1.43k	Ohms

R1 = R4 = R7 = R6=	20000	Ohms
R5 = R2 =	2000	Ohms
Vin=	0.02	V
vout=	2.5	V
R3=	3478	Ohms

		1% value	
R3A=	3304	3320	Ohms
		Pot. Value	
R3B=	348	500	Ohms

C_4=C_6=	0.01	uF		C_3=C_5=C_7=	0.01	uF
R_{14}=R_{15}=	10000	Ohms		R_1=R_4=R_6=	20000	Ohms
F_C=	1592	Hz		F_C=	796	Hz

Note: Values in solid boxes are entered values while values in dashed boxes are calculated.

Mailing Address:

Texas Instruments
Post Office Box 655303
Dallas, Texas 75265