AN1325

Amplifiers for Semiconductor Pressure Sensors

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INTRODUCTION

Amplifiers for interfacing Semiconductor Pressure Sensors to electronic systems have historically been based upon classic instrumentation amplifier designs. Instrumentation amplifiers have been widely used because they are well understood standard building blocks that also work reasonably well. For the specific job of interfacing Semiconductor Pressure Sensors to today's mostly digital systems, other circuits can do a better job. This application note presents an evolution of amplifier design that begins with a classic instrumentation amplifier and ends with a simpler circuit that is better suited to sensor interface.

INTERFACE AMPLIFIER REQUIREMENTS

Design requirements for interface amplifiers are determined by the sensor's output characteristics, and the zero to 5 V input range that is acceptable to microcomputer A/D converters. Since the sensor's full scale output is typically tens of millivolts, the most obvious requirement is gain. Gains from 100 to 250 are generally needed, depending upon bias voltage applied to the sensor and maximum pressure to be measured. A differential to single–ended conversion is also required in order to translate the sensor's differential output into a single ended analog signal. In addition, level shifting is necessary to convert the sensor's 1/2 B^+ common mode voltage to an appropriate DC level. For microcomputer A/D inputs, generally that level is from 0.3 – 1.0 V. Typical design targets are 0.5 V at zero pressure and enough gain to produce 4.5 V at full scale. The 0.5 V zero pressure offset allows for output saturation voltage in op amps operated with a single supply (V_{EE} = 0). At the other end, 4.5 V full scale keeps the output within an A/D converter's 5 V range with a comfortable margin for component tolerances. The resulting 0.5 to 4.5 V single–ended analog signal is also quite suitable for a variety of other applications such as bar graph pressure gauges and process monitors.

CLASSIC INSTRUMENTATION AMPLIFIER

A classic instrumentation amplifier is shown in Figure 1. This circuit provides the gain, level shifting and differential to single–ended conversion that are required for sensor interface. It does not, however, provide for single supply operation with a zero pressure offset voltage in the desired range.

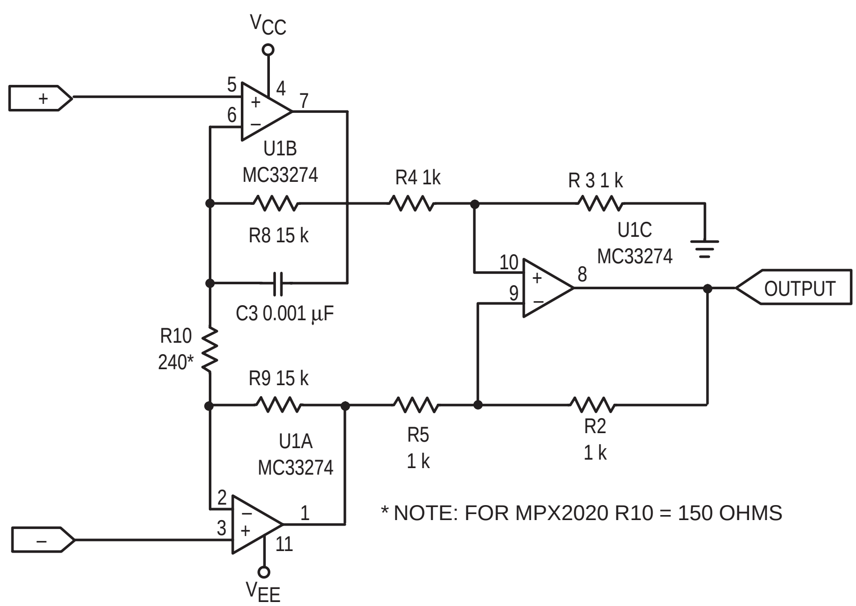
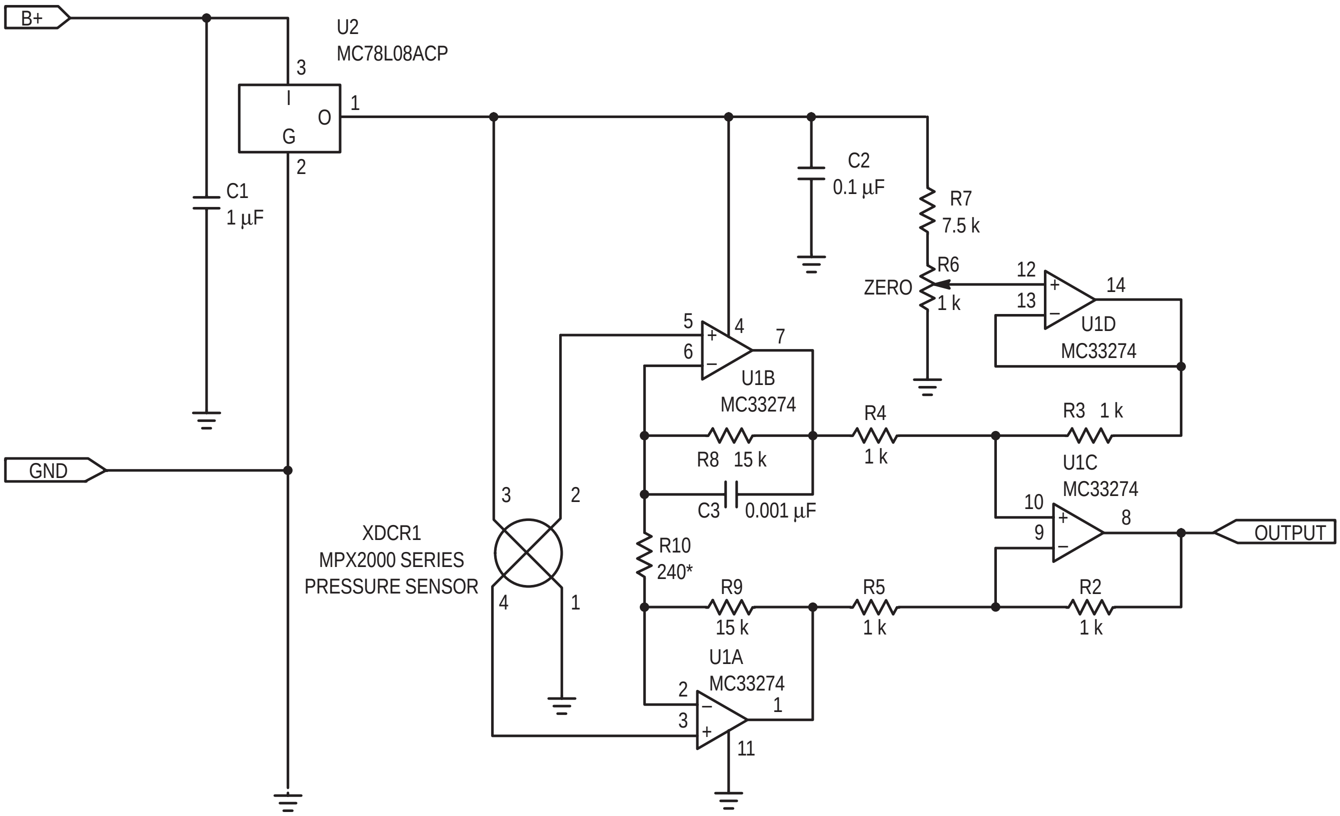


Figure 1. Classic Instrumentation Amplifier

REV 2



* NOTE: FOR MPX2010 R10 = 150 OHMS

Figure 2. Instrumentation Amplifier Interface

To provide the desired DC offset, a slight modification is made in Figure 2. R3 is connected to pin 14 of U1D, which supplies a buffered offset voltage that is derived from the wiper of R6. This voltage establishes a DC output for zero differential input. The translation is one to one. Whatever voltage appears at the wiper of R6 will, within component tolerances, appear as the zero pressure DC offset voltage at the output.

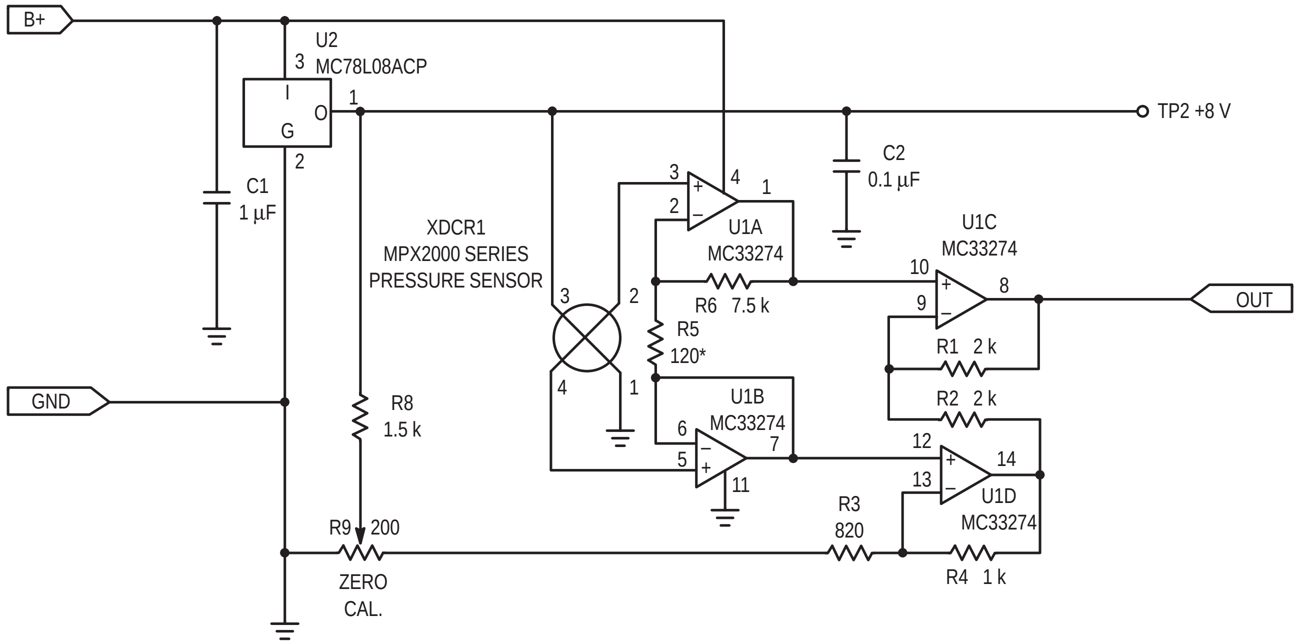
With R10 at 240 Ω gain is set for a nominal value of 125, providing a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to 0.75 V, results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs.

This circuit works reasonably well, but has several notable limitations when made with discrete components. First, it has a relatively large number of resistors that have to be well matched. Failure to match these resistors degrades common mode rejection and initial tolerance on zero pressure offset voltage. It also has two amplifiers in one gain loop, which makes stability more of an issue than it is in the following two alternatives. This circuit also has more of a limitation on zero pressure offset voltage than the other two. The minimum output voltage of U1D restricts the minimum zero pressure offset voltage that can be accommodated, given component tolerances. The result is a 0.75 V zero pressure offset voltage, compared to 0.5 V for each of the following two circuits.

SENSOR SPECIFIC AMPLIFIER

The limitations associated with classic instrumentation amplifiers suggest that alternate approaches to sensor interface design are worth looking at. One such approach is shown in Figure 3. It uses one quad op amp and several resistors to amplify and level shift the sensor's output.

Most of the amplification is done in U1A, which is configured as a differential amplifier. It is isolated from the sensor's minus output by U1B. The purpose of U1B is to prevent feedback current that flows through R5 and R6 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero V. For example, assume that the common mode voltage is 4.0 V. The zero pressure output voltage at pin 1 of U1A is then 4.0 V, since any other voltage would be coupled back to pin 2 via R6 and create a non zero bias across U1A's differential inputs. This 4.0 V zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage by U1C and U1D. To see how the level translation works, assume that the wiper of R9 is at ground. With 4.0 V at pin 12, pin 13 is also at 4.0 V. This leaves 4.0 V across (R3+R9), which total essentially 1 kΩ. Since no current flows into pin 13, the same current flows through R4, producing approximately 4.0 V across R4, as well. Adding the voltages (4.0 + 4.0) yields 8.0 V at pin 14. Similarly 4.0 V at pin 10 implies 4.0 V at pin 9, and the drop across R2 is 8.0 V – 4.0 = 4.0 V. Again 4.0 V across R2 implies an equal drop



* NOTE: FOR MPX2010 R5 = 75 OHMS

Figure 3. Sensor Specific Amplifier

across R1, and the voltage at pin 8 is 4.0 V – 4.0 V = 0 V. In practice, the output of U1C will not go all the way to ground, and the voltage injected by R8 at the wiper of R9 is approximately translated into a DC offset.

Gain is approximately equal to R6/R5(R1/R2+1), which predicts 125 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 127. Cascading the gains of U1A and U1C using standard op amp gain equations does not give an exact result, because the sensor's negative going differential signal at pin 4 subtracts from the DC level that is amplified by U1C. Setting offset to 0.5 V results in an analog zero to full scale range of 0.5 to 4.5 V. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = (R3+R9)/R4.

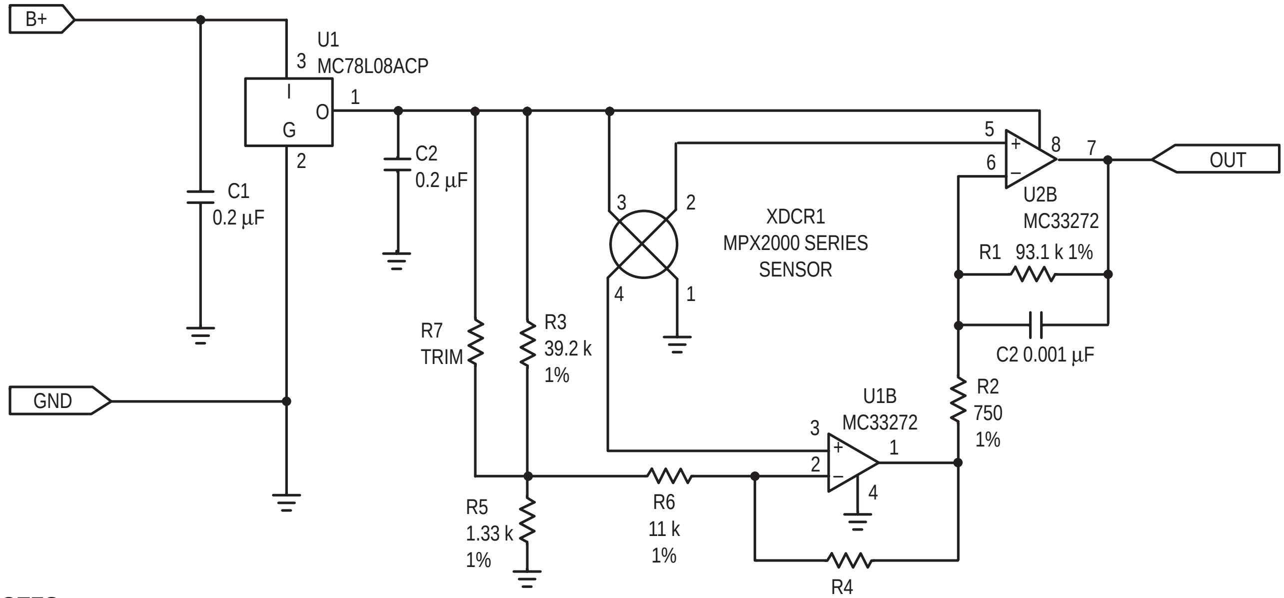
This approach to interface amplifier design is an improvement over the classic instrument amplifier in that it uses fewer resistors, is inherently more stable, and provides a zero pressure output voltage that can be targeted at .5 V. It has the same tolerance problem from matching discrete resistors that is associated with classic instrument amplifiers.

SENSOR MINI AMP

Further improvements can be made with the circuit that is shown in Figure 4. It uses one dual op amp and several resistors to amplify and level shift the sensor's output. To see how this amplifier works, let's simplify it by grounding the output of voltage divider R3, R5 and assuming that the divider impedance is added to R6, such that R6 = 12.4 k. If the common mode voltage at pins 2 and 4 of the sensor is 4.0 V, then pin 2 of U2A and pin 6 of U2B are also at 4.0 V. This puts 4.0 V across R6, producing 323 µA. Assuming that the current in R4 is equal to the current in R6, 323 µA • 100 Ω produces a 32 mV drop across R4 which adds to the 4.0 V at pin 2. The output voltage at pin 1 of U2A is, therefore, 4.032 V. This puts 4.032 – 4.0 V across R2, producing 43 µA. The same current flowing through R1 again produces a voltage drop of 4.0 V, which sets the output at zero. Substituting a divider output greater than zero into this calculation reveals that the zero pressure output voltage is equal to the output voltage of divider R3, R5. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R1/R2 = R6/R4, where R6 includes the divider impedance.

Gain can be determined by assuming a differential output at the sensor and going through the same calculation. To do this assume 100 mV of differential output, which puts pin 2 of U2A at 3.95 V, and pin 6 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 uA. This current flowing through R4 produces 31.9 mV, placing pin 1 of U2A at 3950 mV + 31.9 mV = 3982 mV. The voltage across R2 is then 4050 mV – 3982 mV = 68 mV, which produces a current of 91 µA that flows into R1. The output voltage is then 4.05 V + (91 µA • 93.1 k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4 V span for 32 mV of full scale sensor output. Setting divider R3, R5 at 0.5 V results in a 0.5 V to 4.5 V output that is comparable to the other two circuits.

This circuit performs the same function as the other two with significantly fewer components and lower cost. In most cases it is the optimum choice for a low cost interface amplifier.



NOTES:
R7 IS NOMINALLY 39.2 k AND SELECTED FOR ZERO PRESSURE V_{OUT} = 0.5 V
FOR MPX2010 SENSORS R1 = 150 k AND R4 = 61.9 OHMS

Figure 4. Sensor Mini Amp

PERFORMANCE

Performance differences between the three topologies are minor. Accuracy is much more dependent upon the quality of the resistors and amplifiers that are used and less dependent on which of the three circuits are chosen. For example, input offset voltage error is essentially the same for all three circuits. To a first order approximation, it is equal to total gain times the difference in offset between the two amplifiers that are directly tied to the sensor. Errors due to resistor tolerances are somewhat dependent upon circuit topology. However, they are much more dependent upon the choice of resistors. Choosing 1% resistors rather than 5% resistors has a much larger impact on performance than the minor differences that result from circuit topology. Assuming a zero pressure offset adjustment, any of these circuits with an MPX2000 series sensor, 1% resistors and an MC33274 amplifier results in a ± 5% pressure to voltage translation from 0 to 50° C. Software calibration can significantly improve these numbers and eliminate the need for analog trim.

CONCLUSION

Although the classic instrumentation amplifier is the best known and most frequently used sensor interface amplifier, it is generally not the optimal choice for inexpensive circuits made from discrete components. The circuit that is shown in Figure 4 performs the same interface function with significantly fewer components, less board space and at a lower cost. It is generally the preferred interface topology for MPX2000 series semiconductor pressure sensors.

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