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Low-Pressure Sensing Using MPX2010 Series Pressure Sensors

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INTRODUCTION

This application note presents a design for a low pressure evaluation board using the Freescale Semiconductor, Inc. MPX2010 series pressure sensors. By providing large gain amplification and allowing for package flexibility, this board is intended to serve as a design-in tool for customers seeking to quickly evaluate this family of pressure sensors.

The MPX2010 family of pressure sensors appeals to customers needing to measure small gauge, vacuum, or differential pressures at a low cost. However, different applications present design-in challenges for these sensors. For very low pressure sensing, large signal amplification is required, with gains substantially larger than what is provided in Freescale's current integrated pressure sensor portfolio. In terms of packaging, customers often need more mechanical flexibility such as smaller size, dual porting or both. In many cases, customers often lack the engineering resources, time or expertise to evaluate the sensor. The low-pressure evaluation board, shown in Figure 1, facilitates the design-in process by providing large signal gain and by providing for different package designs in a relatively small footprint.

CIRCUIT DESCRIPTION

For adequate and stable signal gain and output flexibility, a two-stage differential op-amp circuit with analog or switch output is utilized, as shown in Figure 2. The four op-amps are packaged in a single 14 pin quad package. There are several features to note about the circuitry.

The first gain stage is accomplished by feeding both pressure sensor outputs (VS- & VS+) into the non-inverting inputs of operational amplifiers. These op-amps are used in the standard non-inverting feedback configuration. With the condition that Resistors R2=R3, and R1=R4 (as closely as possible), this configuration results in a gain of G1= R4/R3+1.

The default gain is 101, but there are provisions for easily changing this value. The signal V (op-amp Pin 7) is then calculated as:

$$V_1 = G1*(VS+ - VS-) + Voffset. \quad ....Equation\ (1)$$

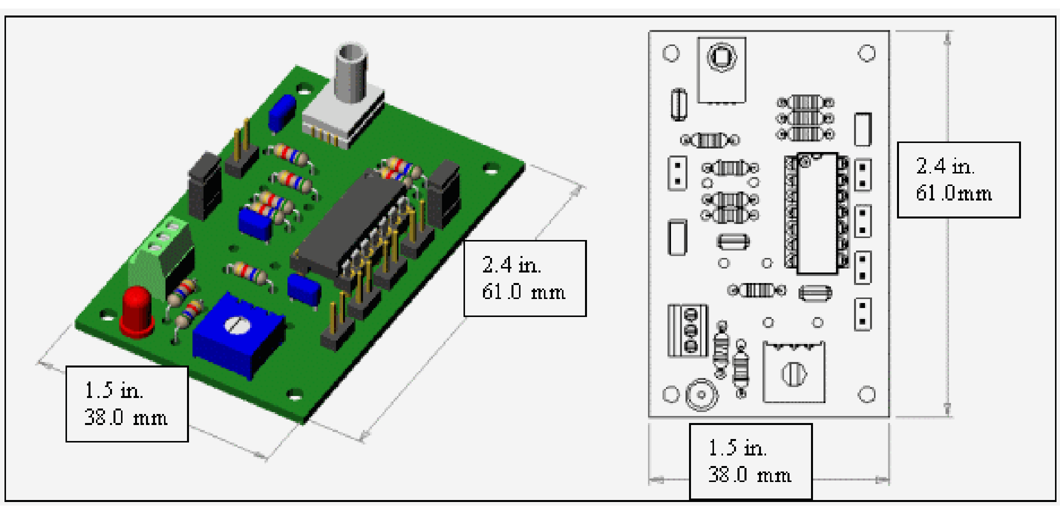

Figure 1. Low Pressure Evaluation Board

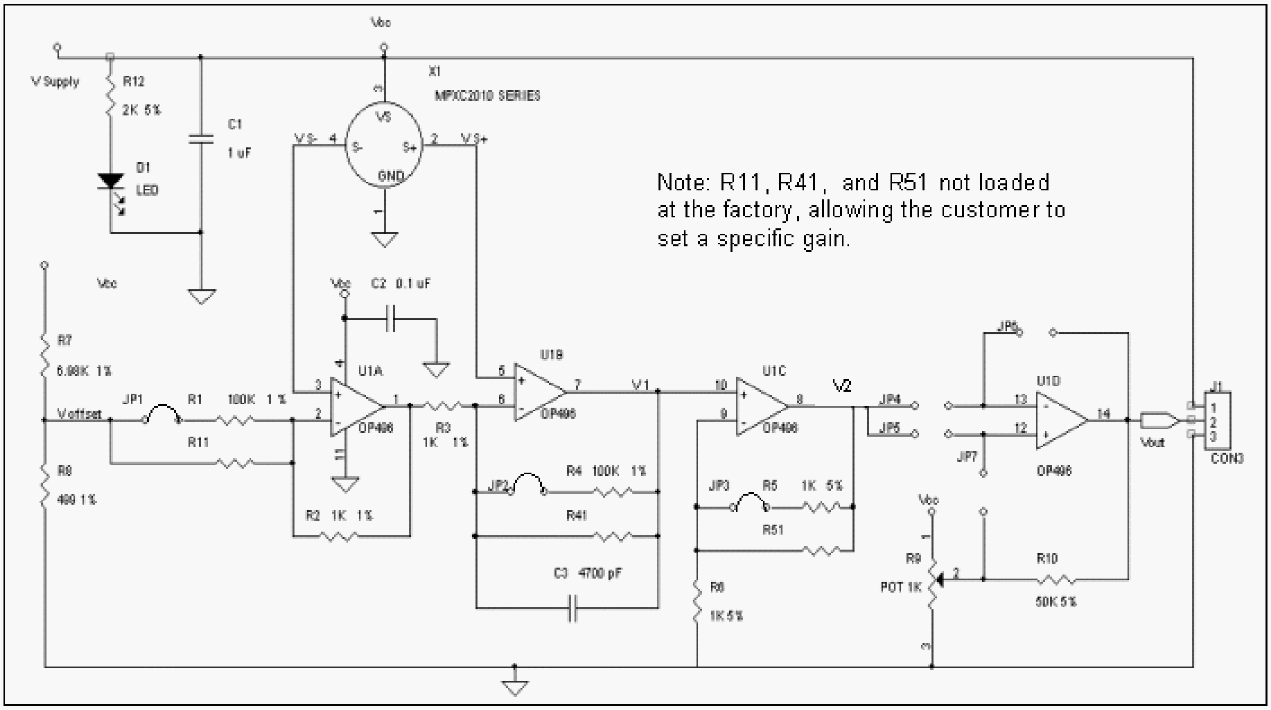

Figure 2. Circuit Schematic

Voffset is the reference voltage for the first op-amp and is pre-set with a voltage divider from the supply voltage. This value is set to be 6.7 percent of the supply voltage. It is important to keep this value relatively small simply because it too is amplified by the second gain stage. It is also desirable to have resistors R7 and R8 sufficiently large to reduce power consumption.

The second gain stage takes the signal from the first gain stage, V, and feeds it into the non-inverting input of a single op-amp. This op-amp is also configured with standard non-inverting feedback, resulting in a gain of G2=R5/R6+1. The default value is set to 2, but can easily be changed.

The signal produced at the output of the second stage amplifier, V (op-amp pin 8) is the fully amplified signal. This is calculated as

$V_2 = G2^* V_1$. . . . .Equation (2)

From this point, there are two possible output types available. One is a simple follower circuit, as shown in Figure 3, in which the circuit output, Vout (op-amp pin 14), is essentially a buffered V signal. This analog output option is available for applications in which the real time nature of the pressure signal needs to be measured. This option is selected by connecting jumpers J5 and J6. J4 and J7 are not connected for analog output.

The second output choice, a switch output as shown in Figure 4, is accomplished by setting jumpers J4 and J7, and leaving J5 and J6 unconnected. This is appropriate for applications in which a switching function is desired. In this case, the fourth op-amp is configured as a comparator, which will invert V_2, high or low, depending on whether V_2 is larger or smaller than the preset reference signal, set by trim-pot R9. This signal can be used to simulate a real world threshold.

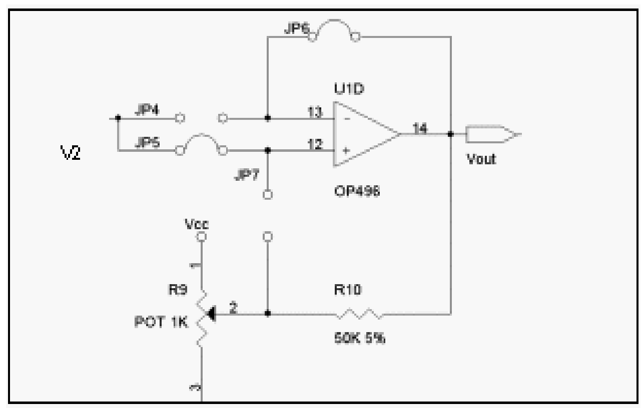

Figure 3. Analog Output Jumper Settings

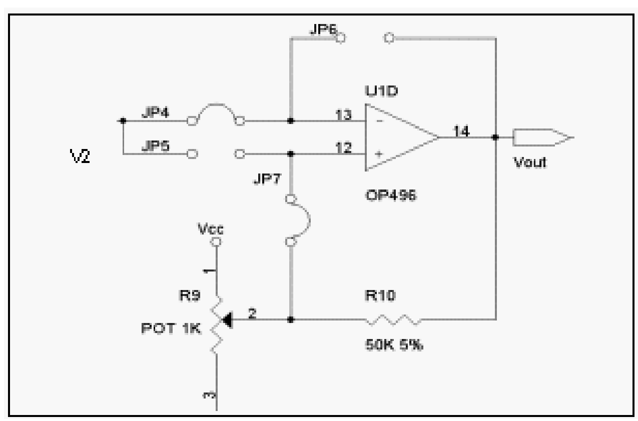

Figure 4. Switch Output Jumper Settings

Table 1 shows the jumper settings for both analog and switches outputs.

Table 1. Output Jumper Settings

Output	JP4	JP5	JP6	JP7
Analog	Out	In	In	Out
Switch	In	Out	Out	In

For the switch output option, it is desirable to apply some hysteresis on the output signal to make it relatively immune to potential noise that may be present in the voltage signal as it reaches and passes the threshold value. This is accomplished with feedback resistor R10. From basic op-amp theory, it can be shown that the amount of hysteresis is computed as follows:

V_H = Vout *[1-(10 / (R10 + R pot-eff))]

Where:

- VH is the output voltage attenuation, due to hysteresis, in volts
- Vout is the output voltage (railed hi or low)
- R10 is the feedback resistor, = 50K
- Rpot-eff is the effective potentiometer resistance

V_H may vary depending on the particular value of the potentiometer.

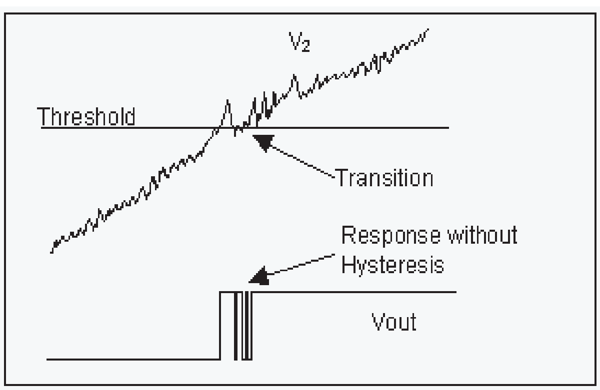

Figure 5. Output Transition without Hysteresis

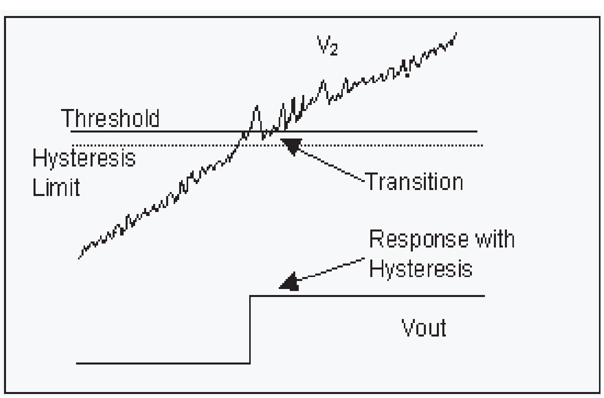

Figure 6. Output Transition with Hysteresis

To take an example, suppose that the supply voltage, Vs is 5 volts, and the threshold is set to 60 percent of Vs, or 3 volts. This corresponds to one leg of the 1K potentiometer set to 0.4K while the other is set to 0.6K. Thus the effective pot resistance is 0.4K // 0.6K = 0.24K.

Therefore,

V_H = 5V* [1- (50K/(50K + 0.24K))] = 24 mV.

Under these conditions, V signals passing through the threshold will not cause Vout to oscillate between Vs and Ground as long as noise and signal variations in V are less than 24mV during the transition. Figure 5 illustrates the benefit of having a hysteresis feedback resistor.

GAIN CUSTOMIZATION

The low-pressure evaluation board comes with default gains for both G1 and G2. G1 is factory set at 101, while G2 is set to 1. Jumpers JP1, JP2 and JP3 physically connect the resistors that produce these default gains. Three resistor sockets (R11, R41 and R51) are provided in parallel with R1, R4 and R5, respectively. By removing jumpers JP1, JP2 and JP3, and soldering different resistor values in the appropriate sockets, different gain values can be achieved. The limit on the largest overall gain that can be used is determined by op-amp saturation. Thus if gain values are chosen such that the output would be larger than the supply voltage, then the op-amp would saturate, and the pressure would not be accurately reflected. Table 2 outlines the jumper settings for customizing the gain.

Table 2. Resistor and Jumper Settings for Gain Customization

Gain		Resistors			Jumpers			Remarks
G1	*G2*	*R11*	*R41*	*R51*	*JP1*	*JP2*	*JP3*	
101	2	no load	no load	no load	In	In	In	Default
User Set	2	load	load	no load	Out	Out	In	R11=R41
101	User Set	no load	no load	load	In	In	Out	
User Set	User Set	load	load	load	Out	Out	Out	R11=R41

DESIGN CONSIDERATIONS

Since the evaluation board is primarily intended for low-pressure gage and differential applications, large gain values can be utilized for pressures less than 1.0 kPa. For example if G1 is set to 101, and G2 set to 6, then the total gain is 606.

Inherent in the MPX2010 family of pressure sensors is a zero-pressure offset voltage, which can be up to 1 mV. This offset is amplified by the circuit and appears as a DC offset at Vout with no pressure applied. The op-amp also has a voltage offset specification, though for the recommended op-amp this value is small and does not contribute significantly to the Vout offset.

For example, if the evaluation board is being used under the following conditions:

Vs = 3V

G1 = 101

G2 = 6

MPX2010 zero pressure offset = 0.3mV

At this supply voltage, VOFFSET can be calculated to be 6.7% x 3V = 0.2V. The voltage V, due simply to the zero pressure sensor offset voltage of 0.3mV, can be calculated from equation (1):

V_1 = 0.3mV * 101 + 0.2V = 0.23V

The voltage after the second gain stage comes from equation (2),

V_2 = 6 x 0.23V = 1.38 V.

Therefore, before any pressure is applied to the sensor, a 1.38V DC signal will appear at V. Since the supply voltage is 3V, the available signal for actual pressure is 1.62 V. With a total gain of G1 x G2 = 606, the largest raw pressure signal that can be accurately measured would be 1.62V/606 = 2.67 mV. For the MPX2010 family operating at Vs = 3V, this corresponds to roughly 3.5 kPa.

The board lends itself well to system integration via an A/D converter and microprocessor. For particular applications, general knowledge of the expected pressure signal can aid in choosing the proper customized gain. This will avoid op-amp saturation and will also ensure that the full-scale output signal is suitable for A/D conversion. To take another example, suppose that a particular application has the following constraints:

Supply Voltage, Vs = 5.0 V,

(thus VOFFSET = 6.7% x 5 = 0.335 V)

Sensor zero-pressure offset voltage, V_{ZP} = 0.3mV

Expected Pressure range = 0-2 kPa,

(corresponds to $\Delta V_{SENSOR\text{-}MAX}$ = 2.5mV @ 5V)

Desired maximum output range, ΔV_{2MAX} = 2V

(assume VMIN = 2V, V_{2MAX} = 4V for reasonable A/D resolution)

By manipulating equations (1) and (2) it can be shown that,

$\Delta V_{2MAX} = G_T \times \Delta V_{SENSOR\text{-}MAX}$

where GT is the total gain, equal to G1G2.

Thus GT = 2V/2.5mV = 800

To find G1 and G2, evaluate V_{2MIN} at the zero pressure condition.

$V_{2MIN} = G2\ V_{1MIN}$,

But $V_{1MIN} = G1\ V_{ZP} + V_{OFFSET}$

Thus $V_{2MIN} = G_T\ V_{ZP} + G2\ V_{OFFSET}$

Solving for G2, $G2 = (V_{2MIN} - G_T\ V_{ZP})/\ V_{OFFSET}$

numerically, G2 = (2V - (800x.0003V))/.335V

G2 = 5.2, and G1 = GT /G2 = 152

BOARD LAYOUT & CONTENT

The low-pressure evaluation board has been designed using standard components. The only item that requires careful selection is the operation amplifier IC. Because the selected gain may be relatively high as in the previous example, it is essential that this device have a low offset voltage. A device with a typical voltage offset of 35 mV has been selected. Even with a gain of 1500, this will result in a 52mV offset. Table 3 is a parts list for the board layout shown in Figure 1.

Table 3. Parts List

Ref.	Qty.	Description	Value	Vendor	Part No.
X1	1	Pressure Sensor	10 Kpa	Freescale	MPX2010 MPXC201 1
C1	1	Vcc Cap	1 uF	Generic	
C2	1	Op-Amp Cap	0.1 uF	Generic	
C3	1	2nd stage cap	4700 pF	Generic	
D1	1	LED		Generic	
for U1	1	Op-Amp socket		Generic	
U1	1	Op-Amp		Analog Devices	OP496GP
R1, R4	2	1/4 W Resistor	100K	Generic	
R2,R3, R5,R6	4	1/4 W Resistor	1K	Generic	
R7	1	1/4 W Resistor	6.8K	Generic	
R8	1	1/4 W Resistor	510	Generic	
R9	1	Potentiometer	1K	Bourns	3386P-102
R10	1	1/4 W Resistor	51K	Generic	
R11	1	1/4 W Resistor	custom	Generic	
R12	1	1/4 W Resistor	2K	Generic	
R41	1	1/4 W Resistor	custom	Generic	
R51	1	1/4 W Resistor	custom	Generic	
JP1 - JP7	7	Jumper		Generic	
J1	1	3 Pos Connector		Phoenix	MKDS1

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