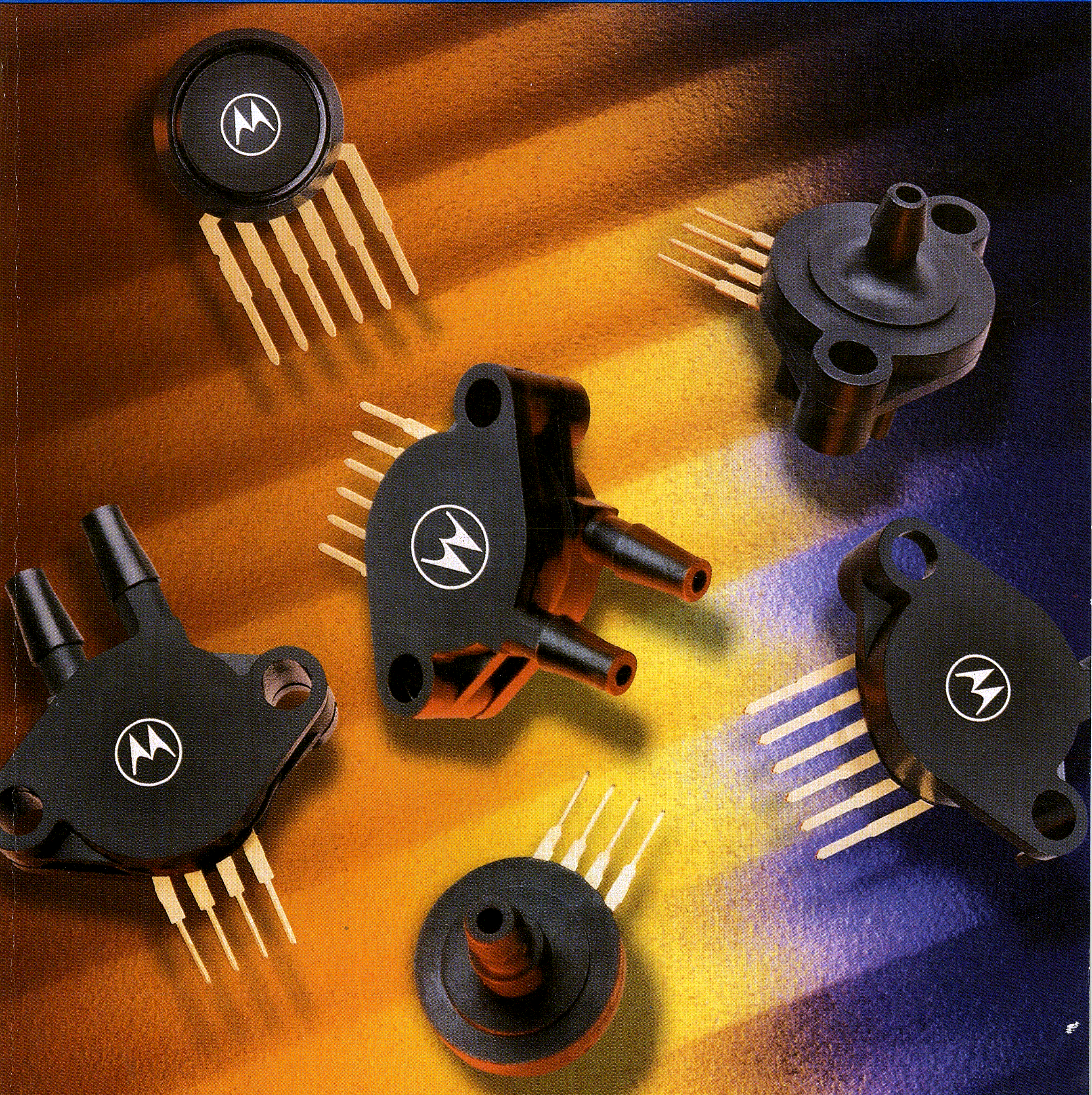
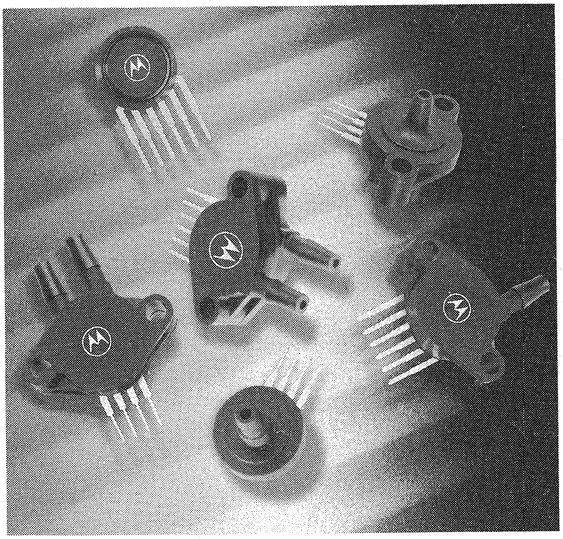
MOTOROLA

DL200/D
REV 1

Pressure Sensor

Device Data





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MOTOROLA

Pressure Sensor

Device Data

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MOTOROLA

Nineteen ninety-four promises to be another exciting year for Motorola's Pressure Sensor Operations as industry analysts continue to forecast aggressive global market growth. Piezoresistive transducers utilizing micromachining are emerging as the technology of choice for most applications.

Motorola's portfolio of advanced pressure sensors employs this technology. With extensive research and development in media compatibility and higher levels of silicon circuit integration, look for new products in 1994. This will further expand the applications for silicon pressure sensors into extended pressure ranges and harsh environments.

As always, product quality and reliability will be our foremost considerations as we launch new technologies for the marketplace. Motorola has been, and will continue to be, your most cost effective sensor solution.

Semiconductor Products Sector
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TABLE OF CONTENTS

SECTION ONE — Introduction

SECTION TWO — New Products

Chip Pak

Signal Conditioned

SECTION THREE — Data Sheets

Basic Uncompensated

Calibrated & Temperature Compensated

Signal Conditioned

High Impedance

Temperature Sensor

SECTION FOUR — Quality & Reliability

SECTION FIVE — Application Notes

(continued — next page)

Table of Contents (continued)

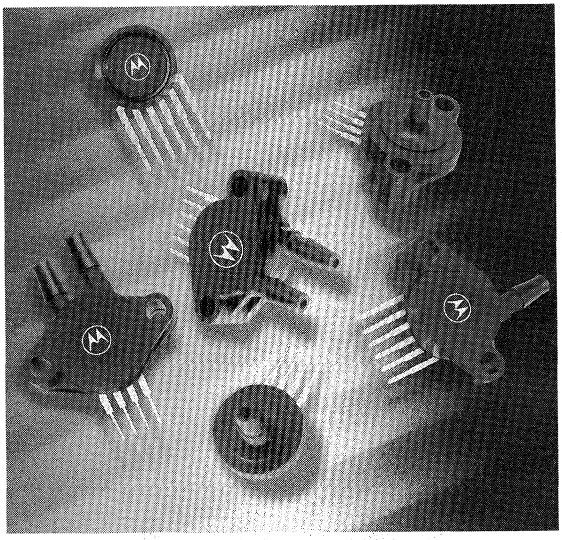
SECTION FIVE — Application Notes (continued)

SECTION SIX — Package Outline Dimensions

SECTION SEVEN — Appendices

SECTION EIGHT — Device Sample Kits

SECTION NINE — Distributors and Sales Offices



Section One

Introduction

General Product Information

Performance and price advantage all are part of the technology associated with the MPX transducer series. The unique design, coupled with computer controlled laser trimming and semiconductor batch processing techniques, makes these devices highly cost competitive.

PERFORMANCE

The performance of Motorola's MPX series of pressure sensors is based on its patented strain gauge design. Unlike the more conventional pressure sensors which utilize four closely matched resistors in a Wheatstone bridge configuration, the MPX series uses only a single piezoresistive element ion implanted on an etched silicon diaphragm to sense the stress induced on the diaphragm by an external pressure. The extremely linear output is an analog voltage that is proportional to pressure input and ratiometric with supply voltage. High sensitivity and excellent long-term repeatability make these units suitable for the most demanding applications.

ACCURACY

Computer controlled laser trimming of on-chip calibration and compensation resistors provide the most accurate pressure measurement over a wide temperature range. Temperature effect on span is typically ±0.5% of full scale over a temperature range from 0 to 85°C, while the effect on offset voltage over a similar temperature range is a maximum of only ±1 mV.

UNLIMITED VERSATILITY

Choice of Specifications:

MPX pressure sensors are available in pressure ranges to fit a wide variety of automotive, biomedical, consumer and industrial applications.

Choice of Measurement:

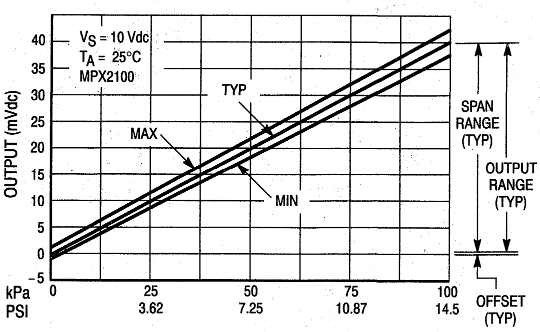
Devices are available for differential, absolute, or gauge pressure measurements.

Choice of Chip Complexity:

MPX pressure sensors are available as the basic sensing element, with temperature compensation and calibration, or with full signal conditioning circuitry included on the chip. Purchase of uncompensated units permits external compensation to any degree desired.

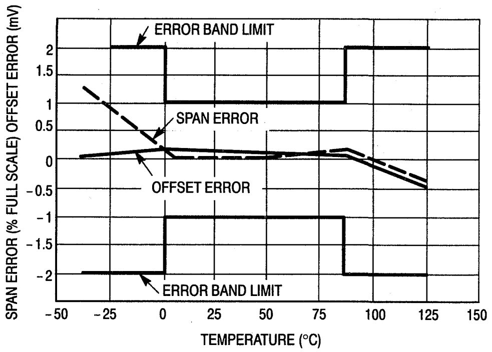
Choice of Packaging:

Buy it as a basic element for custom mounting, or in conjunction with one or two Motorola designed ports that provide printed circuit board mounting ease and barbed hose pressure connections. Alternate packaging material, which has been designed to meet biomedical compatibility requirements, is also available. Consult factory for information.



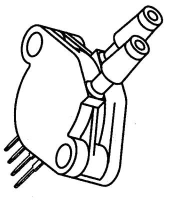
Linearity of output and less than ±1 mV variation in Offset over a temperature range from −40 to 125°C attest to the excellent performance of the compensated series of MPX pressure sensors.

Output versus Pressure Differential



Curves of span and offset errors indicate the accuracy resulting from on-chip compensation and laser trimming.

Temperature Error Band Limit and Typical Span and Offset Errors



DIFFERENTIAL PORT OPTION
CASE 352

Motorola MPX pressure sensors are available as basic elements, or with standard ports that facilitate mounting and media accessibility for differential, absolute or gauge pressure measurements.

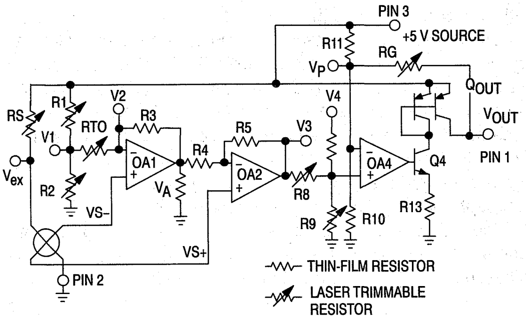
Packaging Flexibility

Integration

ON-CHIP SIGNAL CONDITIONING

To make the designer's job even easier, Motorola's integrated devices carry sensor technology one step further. Besides the on-chip temperature compensation and calibration offered currently on the MPX2000 series, amplifier signal conditioning has been integrated *on-chip* in the MPX5000 series to allow interface directly to any microcomputer with an on-board A/D converter.

The signal conditioning is accomplished by means of a four-stage amplification network, incorporating linear bipolar processing, thin-film metallization techniques, and interactive laser trimming to provide the state-of-the-art in sensor technology.



Fully Integrated Pressure Sensor

Introduction to Motorola Pressure Sensors

THE BASIC STRUCTURE

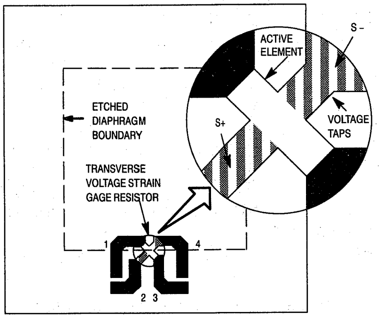
The Motorola pressure sensor is designed utilizing a monolithic silicon piezoresistor, which generates a changing output voltage with variations in applied pressure. The resistive element, which constitutes a strain gauge, is ion implanted on a thin silicon diaphragm.

Applying pressure to the diaphragm results in a resistance change in the strain gauge, which in turn causes a change in the output voltage in direct proportion to the applied pressure. The strain gauge is an integral part of the silicon diaphragm, hence there are no temperature effects due to differences in thermal expansion of the strain gauge and the diaphragm. The output parameters of the strain gauge itself are temperature dependent, however, requiring that the device be compensated if used over an extensive temperature range. Simple resistor networks can be used for narrow temperature ranges, i.e., 0°C to 85°C. For temperature ranges from −40°C to +125°C, more extensive compensation networks are necessary.

MOTOROLA'S PATENTED X-ducer™

Excitation current is passed longitudinally through the resistor (taps 1 and 3), and the pressure that stresses the diaphragm is applied at a right angle to the current flow. The stress establishes a transverse electric field in the resistor that is sensed as voltage at taps 2 and 4, which are located at the midpoint of the resistor. The single-element transverse voltage strain gauge can be viewed as the mechanical analog of a Hall effect device.

Using a single element eliminates the need to closely match the four stress and temperature sensitive resistors that form a Wheatstone bridge design. At the same time, it greatly simplifies the additional circuitry necessary to accomplish calibration and temperature compensation. The offset does not depend on matched resistors but instead on how well the transverse voltage taps are aligned. This alignment is accomplished in a single photolithographic step, making it easy to control, and is only a positive voltage, simplifying schemes to zero the offset.



PIN #
1. GROUND
2. $+V_{OUT}$
3. V_S
4. $-V_{OUT}$

Figure 1. Basic Uncompensated Sensor Element — Top View

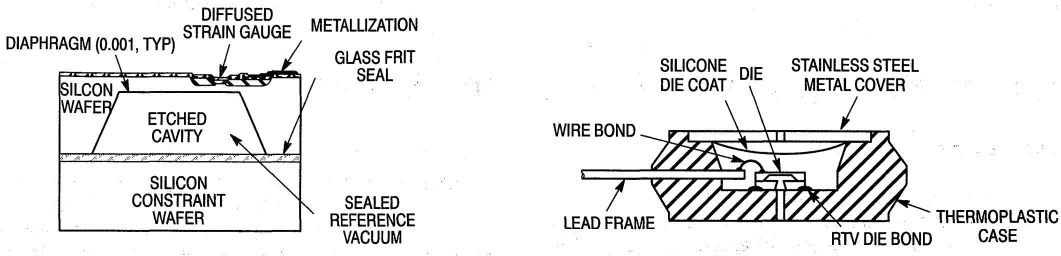
THE BASIC ELEMENTS

Motorola silicon pressure sensors are available in three different configurations that permit measurement of *absolute, differential* and *gauge* pressure. Absolute pressure, such as barometric pressure, is measured with respect to a built-in vacuum reference. A pressure differential, such as the pressure drop across a damper or filter in an air duct, is measured by applying pressure to opposite sides of the sensor simultaneously. Gauge pressure, as in blood pressure measurement, is a special case of differential pressure, where atmospheric pressure is used as a reference.

Figure 2 illustrates an absolute pressure sensing die (left) and a differential or gauge die in the chip carrier package. The difference in die structure between a differential pressure sensor and absolute pressure sensor is that the latter does not have a hole in the constraint wafer, and the chamber formed by the etched cavity and the solid constraint wafer contains the sealed-in reference vacuum.

The cross-section of the differential die in its chip carrier package shows a silicone gel which isolates the die surface and wire bonds from harsh environments while allowing a pressure signal to be transmitted to the silicon diaphragm.

The MPX series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.



ABSOLUTE SENSOR DIE

DIFFERENTIAL/GAUGE

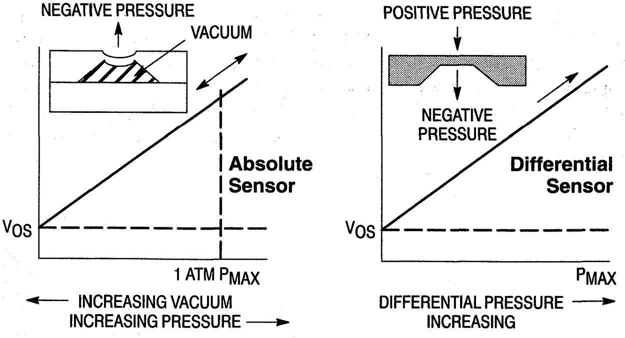
Figure 2. Cross-Sectional Diagrams (Not to Scale)

Operation

Motorola pressure sensors support three types of pressure measurements: Absolute Pressure, Differential Pressure and Gauge Pressure.

Absolute Pressure Sensors measure an external pressure relative to a zero-pressure reference (vacuum) sealed inside the reference chamber of the die during manufacture. This corresponds to a deflection of the diaphragm equal to approximately 15 PSI (one atmosphere), generating a quiescent full-scale output for the MPX100A (15 PSI) sensor, and a half-scale output for the MPX200A (30 PSI) device. Measurement of external pressure is accomplished by applying a relative negative pressure to the "Pressure" side of the sensor.

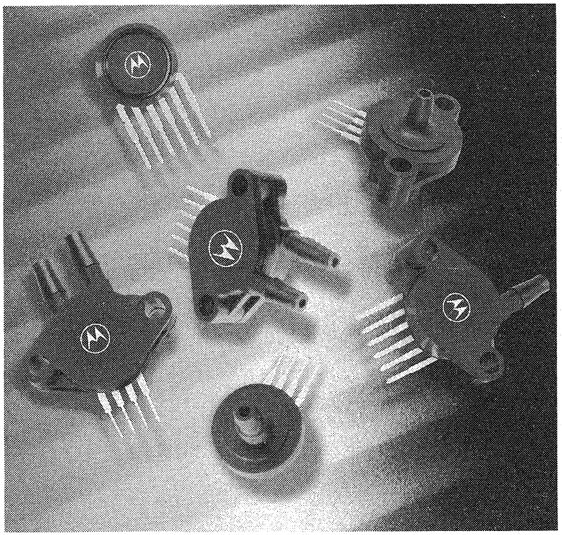
Differential Pressure Sensors measure the difference between pressures applied simultaneously to opposite sides of the diaphragm. A positive pressure applied to the "Pressure" side generates the same (positive) output as an equal negative pressure applied to the "Vacuum" side.



Motorola sensing elements can withstand pressure inputs as high as four times their rated capacity, although accuracy at pressures exceeding the rated pressure will be reduced. When excessive pressure is reduced, the previous linearity will immediately be restored.

Figure 3. Pressure Measurements

Gauge Pressure readings are a special case of differential measurements in which the pressure applied to the Pressure side is measured against the ambient atmospheric pressure applied to the Vacuum side through the vent hole in the chip of the differential pressure sensor elements.



Section Two

New Products

DATA CLASSIFICATION

Product Preview

This heading on a data sheet indicates that the device is in the formative stages or in design (under development). The disclaimer at the bottom of the first page reads: "This document contains information on a product under development. Motorola reserves the right to change or discontinue this product without notice."

Advance Information

This heading on a data sheet indicates that the device is in sampling, preproduction, or first production stages. The disclaimer at the bottom of the first page reads: "This document contains information on a new product. Specifications and information herein are subject to change without notice."

Fully Released

A fully released data sheet contains neither a classification heading nor a disclaimer at the bottom of the first page. This document contains information on a product in full production. Guaranteed limits will not be changed without written notice to your local Motorola Semiconductor Sales Office.

MOTOROLA DEVICE CLASSIFICATIONS

In an effort to provide up-to-date information to the customer regarding the status of any given device, Motorola has classified all devices into three categories: Preferred devices, Current products and Not Recommended for New Design products.

A Preferred type is a device which is recommended as a first choice for future use. These devices are "preferred" by virtue of their performance, price, functionality, or combination of attributes which offer the overall "best" value to the customer. This category contains both advanced and mature devices which will remain available for the foreseeable future.

Preferred devices in the New Products Data Sheet sections are
identified as a "Motorola Preferred Device."

Device types identified as "current" may not be a first choice for **new** designs, but will continue to be available because of the popularity and/or standardization or volume usage in current production designs. These products can be acceptable for new designs but the preferred types are considered better alternatives for long term usage.

Any device that has not been identified as a "preferred device" is a "current" device.

Products designated as "Not Recommended for New Design" may become obsolete as dictated by poor market acceptance, or a technology or package that is reaching the end of its life cycle. Devices in this category have an uncertain future and do not represent a good selection for new device designs or long term usage.

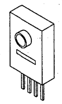
The Pressure Sensor Data Book does not contain any
"Not Recommended for New Design" devices.

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

Chip Pak Custom Low Cost, High Volume Pressure Sensor for Disposable, Back Side Pressure Applications

MPX2300D

PRESSURE SENSORS



CHIP PAK ELEMENT
CASE 423
Style 1

Motorola has developed a low cost, high volume, miniature pressure sensor package which is ideal as a sub-module component or a disposable unit. The unique concept of the Chip Pak allows great flexibility in system design while allowing an economic solution for the designer. This new chip carrier package uses Motorola's unique sensor die with its patented, piezoresistive implant technology, along with the added feature of on-chip, thin-film temperature compensation and calibration.

Features:

- Patented piezoresistive strain gauge implant, temperature compensation and calibration all integrated on a single, monolithic sensor die.
- Pressure Range Available: 0–300 mmHg
- Polysulfone (Mindell S-1000) Case Material (Medical, Class VI Approved)

Motorola is offering the Chip Pak option as a custom device only. Minimum volume requirement for this package is 50K units per year. The part number will have an "SPX" prefix, followed by a four digit number, unique to the specific customer. Individual devices are mounted in a metal frame strip which holds 24 units.

NOTE: The die and wire bonds are exposed on the front side of the Chip Pak (pressure is applied to the back side of the device). Frontside die and wire protection must be provided in the customer's housing. Use caution when removing devices from the metal frames and when handling during all processes.

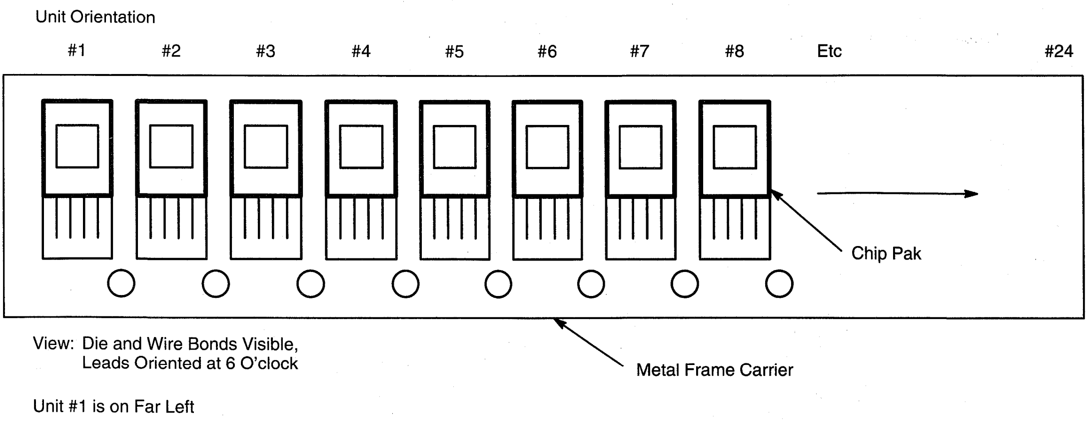


Figure 1. Motorola Chip Pak Strip MPX2300D

OPERATING CHARACTERISTICS (V_S = 6 Vdc, T_A = 25°C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	40	kPa
Supply Voltage(11)	V_S	—	6.0	10	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Zero Pressure Offset	V_{off}	–1.0	—	1.0	mV
Sensitivity	—	4.95	5.0	5.05	µV/V/mmHg
Linearity + Hysteresis	—	– 2.0	—	2.0	%FSS
Temperature Effect on Full Scale Span (+15°C to 40°C)	TCV_{FSS}	–1.5	—	1.5	µV/V/mmHg
Temperature Effect on Offset(4) (0 to +85°C)	TCV_{off}	—	± 0.3	—	mmHg/°C
Input Impedance	Z_{in}	1800	—	4500	Ω
Output Impedance	Z_{out}	270	—	330	Ω
Response Time(5) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band	—	0	—	85	°C
Stability(6)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight (Case 423)	—	—	170	—	mg
Warm-Up	—	—	15	—	Sec

NOTES:

1. Measured at 6 Vdc excitation for 40 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
2. Maximum deviation from end-point straight line fit at 0 and 40 kPa.
3. Slope of end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
4. Slope of end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
5. For a 0 to 40 kPa pressure step change.
6. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, –40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 40 kPa.
7. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential).
8. Recommended voltage supply: 6 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +10 V may induce additional error due to device self-heating.

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

Altimeter/Barometer Pressure Sensor, On-Chip Signal Conditioned, 0.2 V to 4.8 V Output, Temperature Compensated & Calibrated

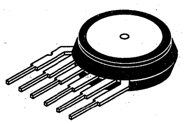
MPX4115 SERIES

15–115 kPa
X-ducer™
SILICON
PRESSURE SENSOR

The Motorola MPX4115 series Altimeter/Barometer Absolute Pressure (BAP) sensor is designed to sense absolute air pressure.

Motorola's BAP sensor integrates on-chip, Bi-Polar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Motorola BAP sensor a logical and economical choice.

- 1.5% Total Accuracy Over 0–85°C
- Easy-to-Use Chip Carrier Options
- Ideally suited for direct Microprocessor Interfacing
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over – 40 to +125°C
- Durable Epoxy Unibody Element



CASE 867
Style 1

MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage	V_{Smax}	5.35	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

Pin Number					
1	2	3	4	5	6
V_{out}	Ground	V_S	N/C	N/C	N/C

NOTE: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

The MPX4115 series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This patented, single element X-ducer combines advanced micromachining techniques, thin film metalization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure. A vacuum of approximately 40–60 µTorr is sealed behind the sensor diaphragm providing an accurate, reliable pressure reference. (See Figure 2.)

Figure 1 shows a schematic of the internal circuitry integrated on-chip to provide temperature compensation, offset and span calibration and signal conditioning.

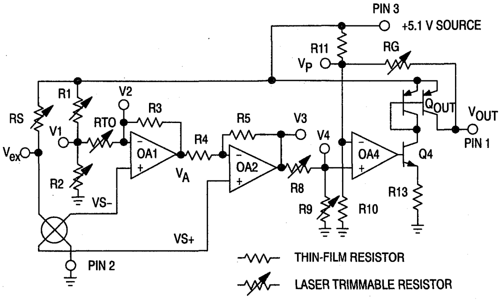


Figure 1. Fully Integrated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

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OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted)

Characteristic for MPX4115 Series	Symbol	Min	Typ	Max	Unit
Absolute Pressure Range	P_{OP}	15	—	115	kPa
Supply Voltage (5)	V_S	4.85	5.1	5.35	Vdc
Supply Current	I_o	—	8.0	15	mAdc
Full Scale Span	V_{FSS}	4.521	4.59	4.659	V
Sensitivity	ΔV/ΔP	—	45.9	—	mV/kPa
Accuracy (0−85°C) (6)	—	—	±0.2	1.5	%FSS
Response Time (10% to 90%) (2)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{ot}	—	0.1	—	mA
Stability (3)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up Time	—	—	15	—	ms
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a rated pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 15 to 115 kPa.
4. Using best fit straight line method: typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5.1 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

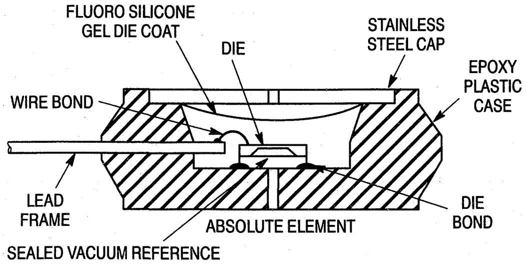


Figure 2. Cross Sectional Diagram (Not to Scale)

Figure 2 illustrates an absolute sensing configuration package in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPX4115 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term stability. Contact the factory for information regarding media compatibility in your application.

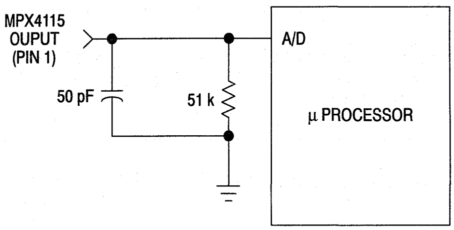


Figure 3. Typical Decoupling Filter for Sensor to Microprocessor Interface

Note: Stainless steel cap is not installed on device with port attach options.

Figure 3 shows a typical decoupling circuit for interfacing the output of the integrated map sensor to the A/D input of a microprocessor.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 4 shows the output characteristics of the MPX4115 at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

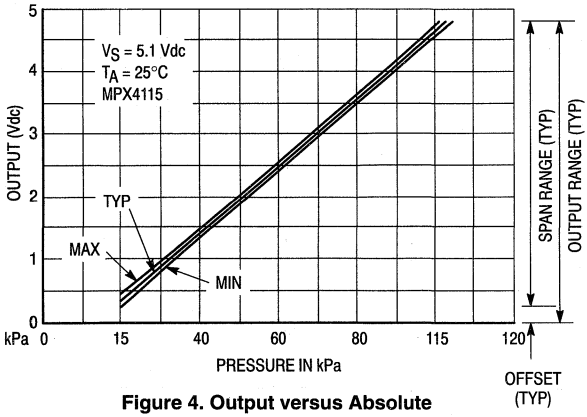


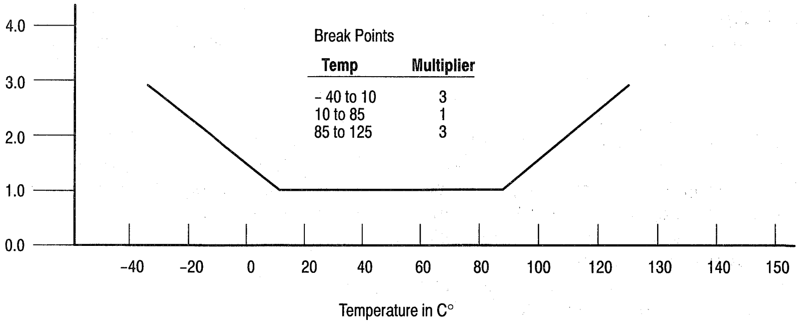
Figure 4. Output versus Absolute Pressure Differential

Transfer Function

Nominal Transfer Value: $V_{out} = V_S\,(P \times 0.009 - 0.095)$
$\pm$ (Pressure Error x Temp. Mult. x $0.009 \times V_S$)
$V_S = 5.1\ \text{V} \pm 5\%$ P (kPa)

Temperature Error Multiplier

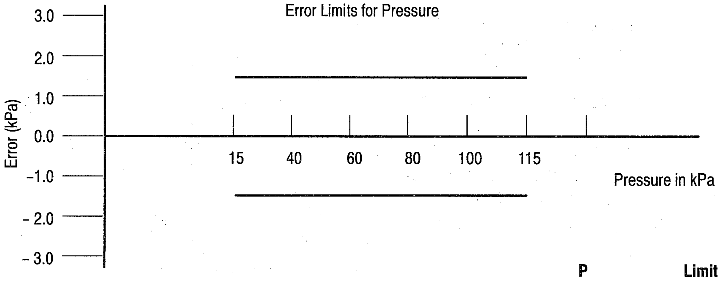
MPX4115 Series



Break Points

Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band



P	Limit (kPa)
15	+/- 1.5
40	+/- 1.5
94	+/- 1.5
115	+/- 1.5

ORDERING INFORMATION

The MPX4115 series BAP Silicon Pressure sensors are available in the Basic Element package, or with pressure port fittings that provide mounting ease and barbed hose connections.

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element Only	Case 867	MPX4115A	MPX4115A
Ported Elements	Absolute, Ported	Case 867B	MPX4115AP	MPX4115AP
	Absolute, Stove Pipe Port	Case 867E	MPX4115AS	MPX4115A
	Absolute, Axial Port	Case 867F	MPX4115ASX	MPX4115A

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, 0.2 V to 4.9 V Output, Temperature Compensated & Calibrated

MPX4250 SERIES

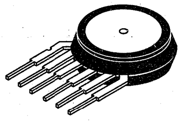
Motorola Preferred Devices

20–250 kPa
X-ducer™
SILICON
PRESSURE SENSOR

The Motorola MPX4250 series Turbo boost, Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

Motorola's MAP sensor integrates on-chip, Bi-Polar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Motorola MAP sensor a logical and economical choice for the automotive system designer.

- 1.5% Total Accuracy Over 0–85°C
- Specifically designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally suited for direct Microprocessor Interfacing
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over −40 to +125°C
- Offers Large Reduction in Weight and Volume Compared to Existing Hybrid Modules
- Durable Epoxy Unibody Element



CASE 867
Style 1

MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage	V_{Smax}	5.35	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

Pin Number					
1	2	3	4	5	6
V_{out}	Ground	V_S	N/C	N/C	N/C

NOTE: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

The MPX4250 series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This patented, single element X-ducer combines advanced micromachining techniques, thin film metalization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure. A vacuum of approximately 40−60 µTorr is sealed behind the sensor diaphragm providing an accurate, reliable pressure reference. (See Figure 2.)

Figure 1 shows a schematic of the internal circuitry integrated on-chip to provide temperature compensation, offset and span calibration and signal conditioning.

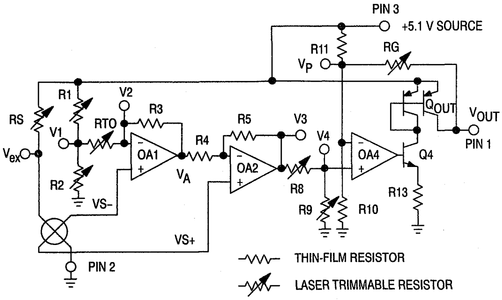


Figure 1. Fully Integrated Pressure Sensor Schematic

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted)

Characteristic for MPX4250 Series	Symbol	Min	Typ	Max	Unit
Absolute Pressure Range	P_{OP}	20	—	250	kPa
Supply Voltage	V_S	4.85	5.1	5.35	Vdc
Supply Current	I_o	—	8.0	15	mAdc
Full Scale Span	V_{FSS}	4.622	4.692	4.762	V
Sensitivity	$\Delta V/\Delta P$	—	20	—	mV/kPa
Linearity (4)	—	—	±0.2	—	%FSS
Accuracy (0–85°C) (6)	—	—	±0.2	1.5	%FSS
Response Time (2) (10% to 90%)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{o+}	—	0.1	—	mA
Stability (3)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up Time	—	—	15	—	ms
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a rated pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 20 to 250 kPa.
4. Using best fit straight line method: typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5.1 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

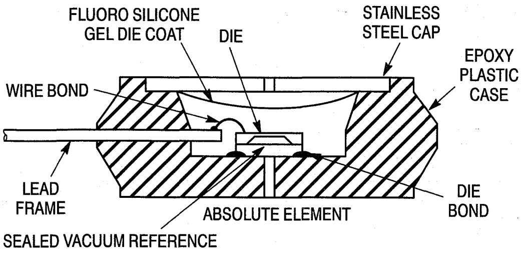


Figure 2. Cross Sectional Diagram (Not to Scale)

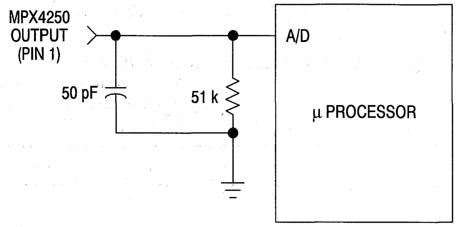


Figure 3. Typical Decoupling Filter for Sensor to Microprocessor Interface

Figure 2 illustrates an absolute sensing configuration package in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPX4250 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term stability. Contact the factory for information regarding media compatibility in your application.

Note: Stainless steel cap is not installed on device with port attach options.

Figure 3 shows a typical decoupling circuit for interfacing the output of the integrated map sensor to the A/D input of a microprocessor.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 4 shows the output characteristics of the MPX4250 at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

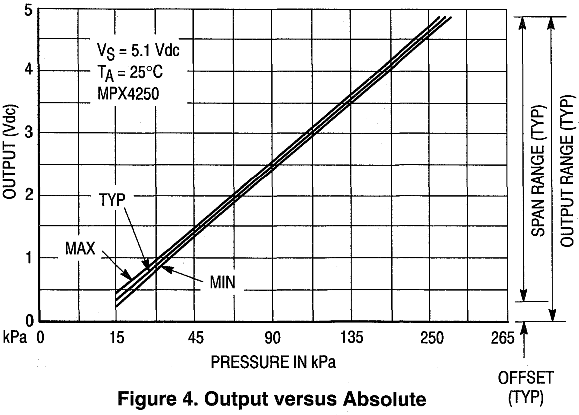


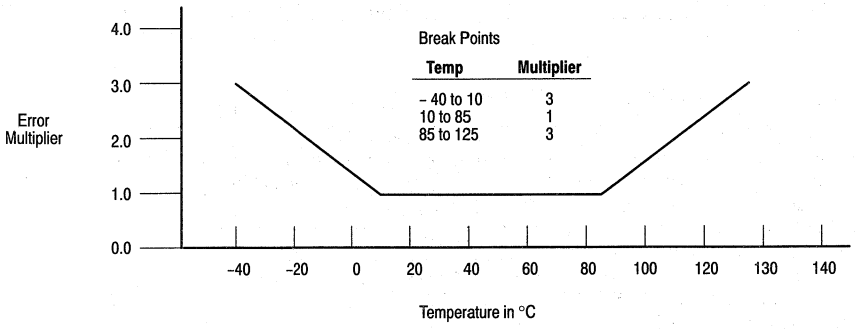
Figure 4. Output versus Absolute Pressure Differential

Transfer Function

Nominal Transfer Value: $V_{out} = V_S\ (P \times 0.004 - 0.04)$
$+/- (\text{Pressure Error} \times \text{Temp. Mult.} \times 0.004 \times V_S)$
$V_S = 5.1\ V \pm 5\%\ P\ kPa$

Temperature Error Multiplier

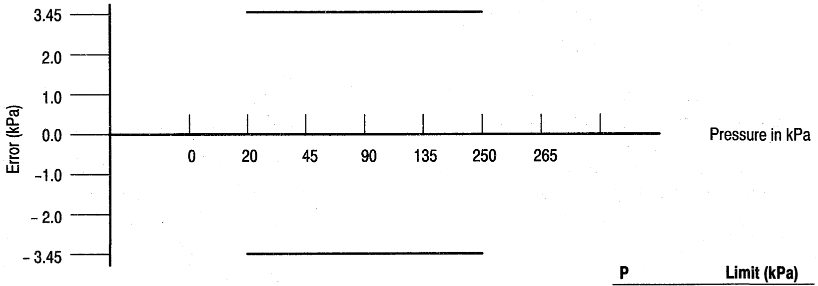
MPX4250 Series



Break Points

Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band



P	Limit (kPa)
20	+/- 3.45
90	+/- 3.45
135	+/- 3.45
250	+/- 3.45

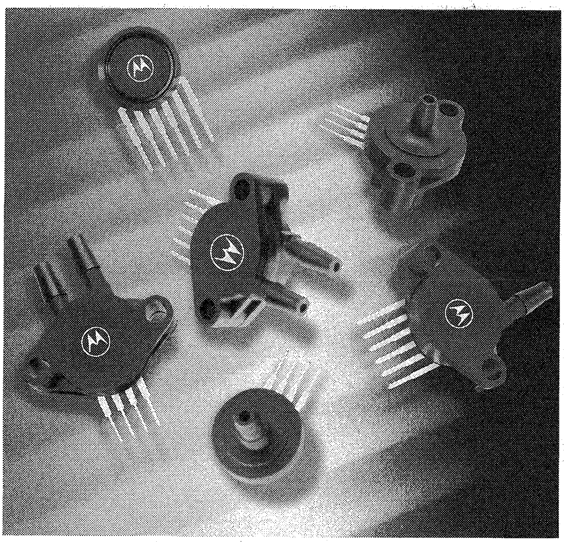
ORDERING INFORMATION

The MPX4250A series Turbo MAP silicon pressure sensors are available in the basic element package, or with pressure port fittings that provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element	867	MPX4250A	MPX4250A
Ported Elements	Absolute, Ported	867B	MPX4250AP	MPX4250AP
	Absolute, Stove Pipe Port	867E	MPX4250AS	MPX4250A
	Absolute, Axial Port	867F	MPX4250ASX	MPX4250A

CONVERSION TABLE FOR COMMON UNITS OF PRESSURE

	kiloPascals	mm Hg	millibars	inches H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038
1 mm Hg	0.133322	1.00000	1.33322	0.535257	0.0193368
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038
1 inch H_2O	0.249081	1.86826	2.49081	1.00000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038
1 cm H_2O	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223



Section Three

Data Sheets

Basic Uncompensated

Calibrated & Temperature Compensated

Signal Conditioned

High Impedance

Temperature Sensor

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

0 to 1.5 PSI Uncompensated, Silicon Pressure Sensors

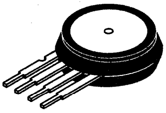
MPX10
MPX12
SERIES

0–1.5 PSI
X-ducer™
SILICON
PRESSURE SENSORS

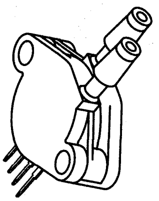
The MPX10 and MPX12 series device is a silicon piezoresistive pressure sensors providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

It is designed for applications in air movement control, environmental control systems, fluid level measurement, leak detection, medical instruments, industrial controls, etc.

- Low Cost
- Patented Silicon Shear Stress Strain Gauge Design
- ±1.0% (Max) Full Scale Linearity
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options



BASIC CHIP CARRIER ELEMENT CASE 344 Style 1



DIFFERENTIAL PORT OPTION CASE 352 Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	100	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	–50 to +150	°C
Operating Temperature	T_A	–40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX10 sensor circuit.

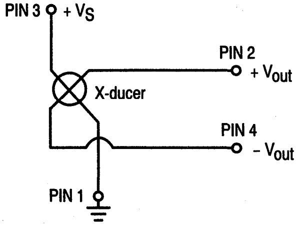


Figure 1. Uncompensated Pressure Sensor Schematic

REV 2 1/94

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Differential Pressure Range(1), Figure 2	P_{OP}	0	—	10	kPa
Supply Voltage	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 2 MPX10 MPX12	V_{FSS}	20 45	35 55	50 70	mV
Zero Pressure Offset, Figure 2	V_{off}	0	20	35	mV
Sensitivity MPX10 MPX12	V/P	— —	3.5 5.5	— —	mV/kPa
Linearity(3), Figure 3 MPX10 MPX12	—	–1.0 0	— —	1.0 5.0	%FS
Pressure Hysteresis(4) (0 to 10 kPa)	—	–0.1	—	0.1	%FS
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	± 0.5	—	%FS
Temperature Coefficient of Full Scale Span(6)	TCV_{FSS}	–0.22	–0.19	–0.16	%/°C
Temperature Coefficient of Offset(7)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(8)	TCR	0.21	0.24	0.27	%/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(9) (10% to 90%)	t_R	—	1.0	—	ms
Stability(10)	—	—	±0.5	—	%FS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element, Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 3.0 Vdc excitation for 10 kPa pressure differential, V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 10 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at –40°C and +125°C, relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at –40°C and +125°C, relative to resistance at +25°C.
8. Slope of end-point straight line fit to input resistance at –40°C and +125°C, relative to resistance at +25°C.
9. For a 0 to 10 kPa pressure step change.
10. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, –40°C to +125°C.
    b. 1.5 million pressure cycles, 0 to 10 kPa.
11. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential).

TEMPERATURE COMPENSATION

Figure 2 shows the output characteristics of the MPX10 series at 25°C.

The X-ducer piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components or on-chip by using MPX2010 Series.

Several approaches to external temperature compensation over both –40 to +125°C and 0 to +80°C ranges are presented in Motorola Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

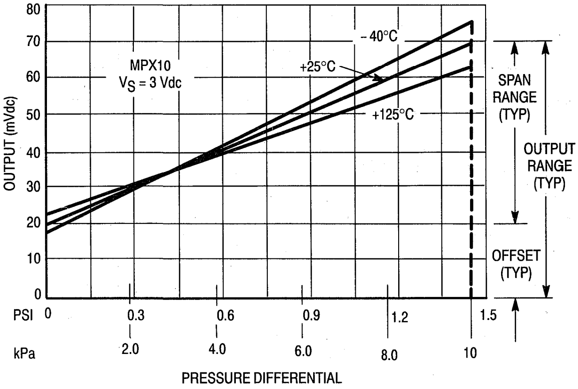


Figure 2. Output versus Pressure Differential

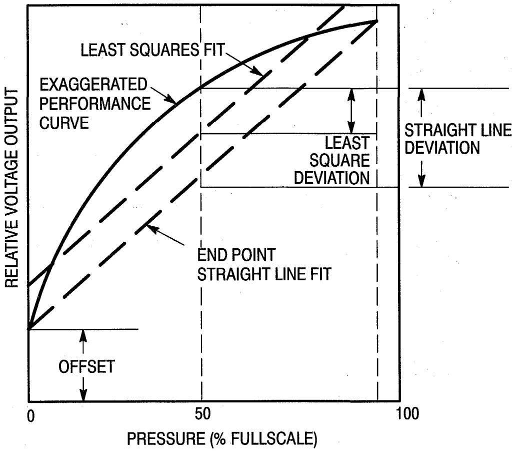


Figure 3. Linearity Specification Comparison

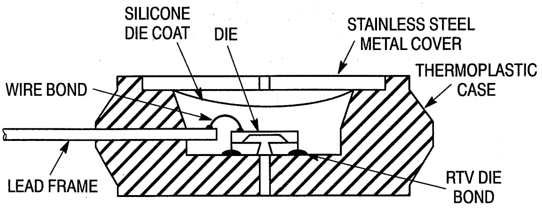


Figure 4. Cross Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX10 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX10D	MPX12D	344	Stainless Steel Cap
MPX10DP	MPX12DP	352	Side with Part Marking
MPX10GP	MPX12GP	350-03	Side with Port Attached
MPX10GVP	MPX12GVP	350-04	Stainless Steel Cap
MPX10GS	MPX12GS	371-06	Side with Port Attached
MPX10GVS	MPX12GVS	371-05	Stainless Steel Cap
MPX10GSX	MPX12GSX	371C	Side with Port Attached
MPX10GVSX	MPX12GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION

MPX10 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

			MPX Series	
Device Type	Options	Case Type	Order Number	Device Marking
Basic Element	Differential	Case 344	MPX10D MPX12D	MPX10D MPX12D
Ported Elements	Differential	Case 352	MPX10DP MPX12DP	MPX10DP MPX12DP
	Gauge	Case 350-03	MPX10GP MPX12GP	MPX10GP MPX12GP
	Gauge Vacuum	Case 350-04	MPX10GVP MPX12GVP	MPX10GVP MPX12GVP
	Gauge Stove Pipe	Case 371-06	MPX10GS MPX12GS	MPX10D MPX12D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX10GVS MPX12GVS	MPX10D MPX12D
	Gauge Axial	Case 371C	MPX10GSX MPX12GSX	MPX10D MPX12D
	Gauge Vacuum Axial	Case 371D	MPX10GVSX MPX12GVSX	MPX10D MPX12D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

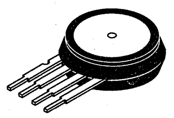
0 to 7.3 PSI Uncompensated, Silicon Pressure Sensors

MPX50
SERIES

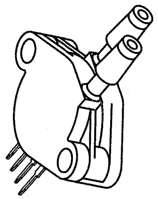
0–7.3 PSI
X-ducer™
SILICON
PRESSURE SENSORS

The MPX50 silicon piezoresistive pressure sensor provides a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

- Low Cost
- 0 to 50 kPa (0 to 7.3 PSI) Differential Pressure Range
- ±1.0% (Max) Full Scale Linearity
- Patented Silicon Shear Stress Strain Gauge Design
- Ratiometric to Supply Voltage
- Easy to Use Chip Carrier Package Options



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	**2**	**3**	**4**
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	200	kPa
Burst Pressure	P_{burst}	500	kPa
Supply Voltage	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX50 sensor circuit.

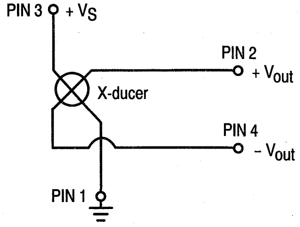


Figure 1. Uncompensated Pressure Sensor Schematic

REV 2 1/94

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1), Figure 2	P_{OP}	0	—	50	kPa
Supply Voltage	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 2	V_{FSS}	45	60	90	mV
Zero Pressure Offset, Figure 2	V_{off}	0	20	35	mV
Sensitivity	V/P	—	1.2	—	mV/kPa
Linearity(3)	—	–0.1	—	0.1	%FSS
Pressure Hysteresis(4) (0 to 50 kPa)	—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (– 40°C to +125°C)	—	—	± 0.5	—	%FSS
Temperature Coefficient of Full Scale Span(6)	TCV_{FSS}	–0.22	–0.19	–0.16	%/°C
Temperature Coefficient of Offset(7)	TCV_{off}	—	± 15	—	µV/°C
Temperature Coefficient of Resistance(8)	TCR	0.21	0.24	0.27	%/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(9) (10% to 90%)	t_R	—	1.0	—	ms
Stability(10)	—	—	± 0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 3.0 Vdc excitation for 50 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 50 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range – 40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at – 40°C and +125°C, relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at – 40°C and +125°C, relative to +25°C.
8. Slope of end-point straight line fit to input resistance at – 40°C and +125°C, relative to +25°C.
9. For a 0 to 50 kPa pressure step change.
10. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, – 40°C to +125°C.
    b. 1.5 million pressure cycles, 0 to 50 kPa.
11. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential).

TEMPERATURE COMPENSATION

Figure 2 shows the output characteristics of the MPX50 series at 25°C.

The X-ducer piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components or on-chip by using MPX2050 series.

Several approaches to external temperature compensation over both −40 to +125°C and 0 to +80°C ranges are presented in Motorola Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (see Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

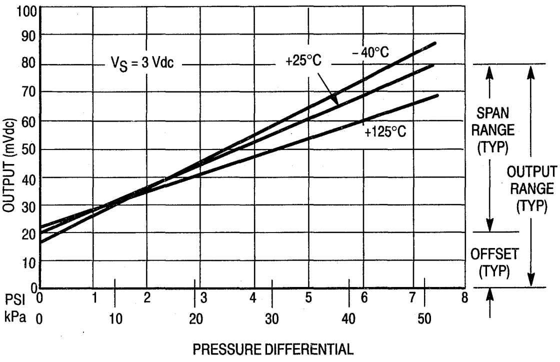


Figure 2. Output versus Pressure Differential

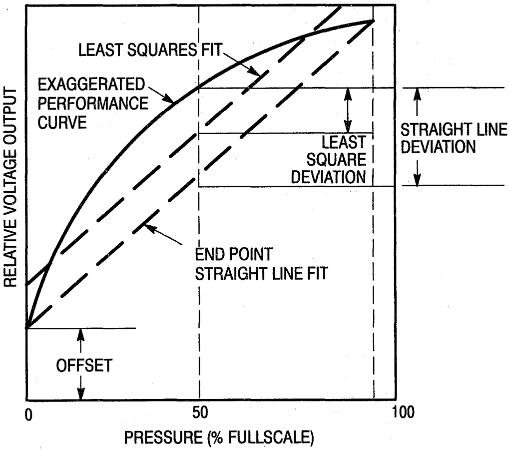


Figure 3. Linearity Specification Comparison

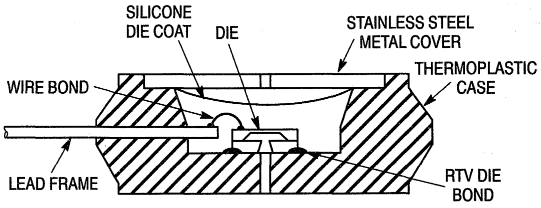


Figure 4. Cross Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX50 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number	Case Type	Pressure Side Identifier
MPX50D	344	Stainless Steel Cap
MPX50DP	352	Side with Part Marking
MPX50GP	350-03	Side with Port Attached
MPX50GVP	350-04	Stainless Steel Cap
MPX50GS	371-06	Side with Port Attached
MPX50GVS	371-05	Stainless Steel Cap
MPX50GSX	371C	Side with Port Attached
MPX50GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION

MPX50 series pressure sensors are available in differential and gauge configurations. Devices are available with basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

			MPX Series	
Device Type	**Options**	**Case Type**	**Order Number**	**Device Marking**
Basic Element	Differential	Case 344	MPX50D	MPX50D
Ported Elements	Differential	Case 352	MPX50DP	MPX50DP
	Gauge	Case 350-03	MPX50GP	MPX50GP
	Gauge Vacuum	Case 350-04	MPX50GVP	MPX50GVP
	Gauge Stovepipe	Case 371-06	MPX50GS	MPX50D
	Gauge Vacuum Stovepipe	Case 371-05	MPX50GVS	MPX50D
	Gauge Axial	Case 371C	MPX50GSX	MPX50D
	Gauge Vacuum Axial	Case 371D	MPX50GVSX	MPX50D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

0 to 14.5 PSI Uncompensated, Silicon Pressure Sensors

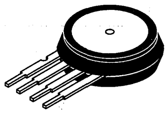
MPX100 SERIES

0–14.5 PSI
X-ducer™
SILICON
PRESSURE SENSORS

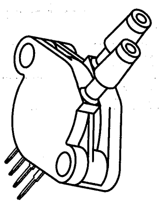
The MPX100 series device is a silicon piezoresistive pressure sensor providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

It is designed for applications in the pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers and altimeters.

- Low Cost
- Patented, Silicon Shear Stress Strain Gauge Design
- ±0.25% (Max) Full Scale Linearity
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	**2**	**3**	**4**
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	200	kPa
Burst Pressure	P_{burst}	2000	kPa
Supply Voltage	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	–50 to +150	°C
Operating Temperature	T_A	–40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure side. Vacuum down to the reference can be measured with the indicated accuracy. The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 illustrates the simple schematic diagram of the MPX100 sensor circuit.

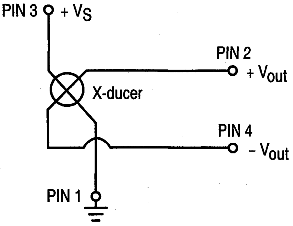


Figure 1. Uncompensated Pressure Sensor Schematic

REV 2 1/94

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1), Figure 3	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 3	V_{FSS}	45	60	90	mV
Zero Pressure Offset, Figure 3	V_{off}	0	20	35	mV
Sensitivity	V/P	—	0.6	—	mV/kPa
Linearity(3) Figure 2	—	–0.25	—	0.25	%FSS
Pressure Hysteresis(4) (0 to 100 kPa)	—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	%FSS
Temperature Coefficient of Full Scale Span(6), Figure 3	TCV_{FSS}	–0.22	–0.19	–0.16	%/°C
Temperature Coefficient of Offset(7)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(8)	TC_R	0.24	—	0.3	%/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(9) (10% to 90%)	t_R	—	1.0	—	ms
Stability(10)	—	–0.5	—	0.5	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 3.0 Vdc excitation for 100 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 100 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at –40°C and +125°C, relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at –40°C to +125°C, relative to +25°C.
8. Slope of end-point straight line fit to input resistance at –40°C and +125°C, relative to resistance at +25°C.
9. For a 0 to 100 kPa pressure step change.
10. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, –40°C to +125°C.
    b. 1.5 million pressure cycles, 0 to 100 kPa.
11. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off} + \text{sensitivity} \times P$ over the operating pressure range (see Figure 2). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worse case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

TEMPERATURE COMPENSATION

Figure 3 shows the output characteristics of the MPX100 series at 25°C.

The X-ducer piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components or on-chip by using MPX2100 series.

Several approaches to external temperature compensation over both −40 to +125°C and 0 to +80°C ranges are presented in Motorola Applications Note AN840.

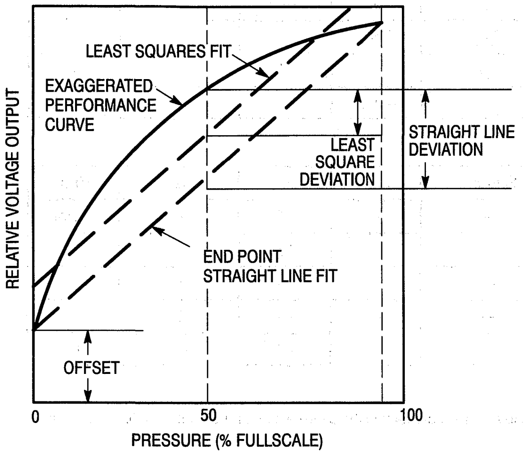


Figure 2. Linearity Specification Comparison

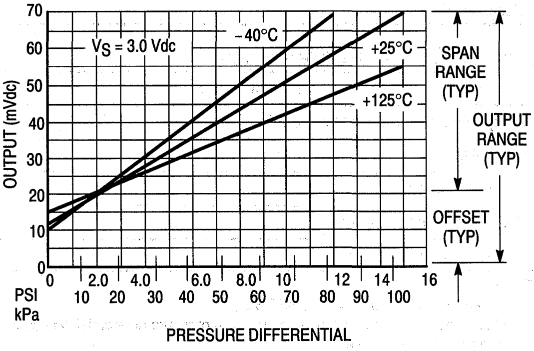


Figure 3. Output versus Pressure Differential

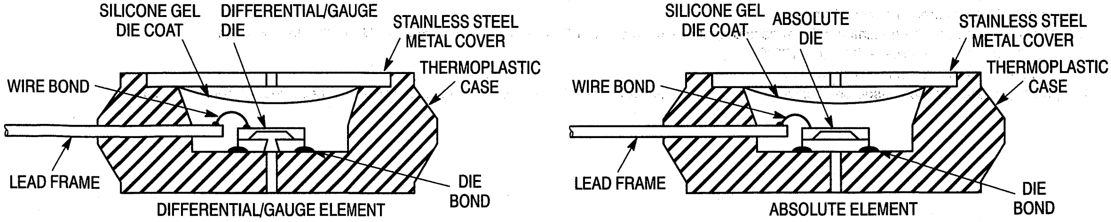


Figure 4. Cross-Sectional Diagrams (Not to Scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel helps protect the die surface and wire bond from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX100 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX100A	MPX100D	344	Stainless Steel Cap
MPX100DP		352	Side with Part Marking
MPX100AP	MPX100GP	350-03	Side with Port Attached
MPX100GVP		350-04	Stainless Steel Cap
MPX100AS	MPX100GS	371-06	Side with Port Attached
MPX100GVS		371-05	Stainless Steel Cap
MPX100ASX	MPX100GSX	371C	Side with Port Attached
MPX100GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX100 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	Device Marking
Basic Element	Absolute, Differential	Case 344	MPX100A MPX100D	MPX100A MPX100D
Ported Elements	Differential	Case 352	MPX100DP	MPX100DP
	Absolute, Gauge	Case 350-03	MPX100AP MPX100GP	MPX100AP MPX100GP
	Gauge Vacuum	Case 350-04	MPX100GVP	MPX100GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX100AS MPX100GS	MPX100A MPX100D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX100GVS	MPX100D
	Absolute, Gauge Axial	Case 371C	MPX100ASX MPX100GSX	MPX100A MPX100D
	Gauge Vacuum Axial	Case 371D	MPX100GVSX	MPX100D

0 to 29 PSI Uncompensated, Silicon Pressure Sensors

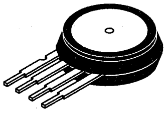
MPX200 SERIES

0–29 PSI
X-ducer™
SILICON
PRESSURE SENSORS

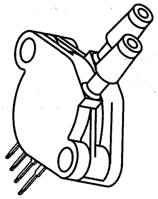
The MPX200 series device is a silicon piezoresistive pressure sensors provide a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

It is designed for applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

- Low Cost
- Patented Silicon Shear Stress Strain Gauge
- ±0.25% (max) Full Scale Linearity
- Full Scale Span 60 mV (Typ)
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	**2**	**3**	**4**
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	2000	kPa
Supply Voltage	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	–50 to +150	°C
Operating Temperature	T_A	–40 to +125	°C

VOLTAGE OUTPUT versus APPLIED PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built-in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure side. Vacuum down to the reference can be measured with the indicated accuracy.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX200 sensor circuit.

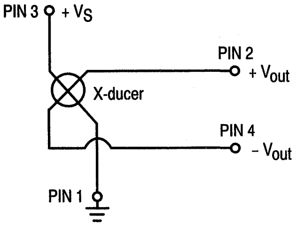


Figure 1. Uncompensated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

REV 4 1/94

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1), Figure 3	P_{OP}	0	—	200	kPa
Supply Voltage	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 3	V_{FSS}	45	60	90	mV
Zero Pressure Offset, Figure 3	V_{off}	0	20	35	mV
Sensitivity	V/P	—	0.3	—	mV/kPa
Linearity(3) Figure 2	—	−0.25	—	0.25	%FSS
Pressure Hysteresis(4) (0 to 200 kPa)	—	−0.1	—	0.1	%FSS
Temperature Hysteresis(5) (−40°C to +125°C)	—	—	±0.5	—	%FSS
Temperature Coefficient of Full Scale Span(6), Figure 3	TCV_{FSS}	−0.22	−0.19	−0.16	%/°C
Temperature Coefficient of Offset(7)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(8)	TC_R	0.21	—	0.27	%/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(9) (10% to 90%)	t_R	—	1.0	—	ms
Stability(10)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 3.0 Vdc excitation for 200 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 200 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range −40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at −40°C and +125°C, relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at −40°C and +125°C, relative to +25°C.
8. Slope of end-point straight line fit to input resistance at −40°C and +125°C, relative to resistance at +25°C.
9. For a 0 to 200 kPa pressure step change.
10. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, −40°C to +125°C.
    b. 1.5 million pressure cycles, 0 to 200 kPa.
11. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range (see Figure 2). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worse case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

TEMPERATURE COMPENSATION

Figure 3 shows the output characteristics of the MPX200 series at 25°C. The output is directly proportional to the pressure and is essentially a straight line.

The X-ducer piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components or on-chip by using MPX2200 series.

Several approaches to external temperature compensation over both −40 to +125°C and 0 to +80°C ranges are presented in Motorola Applications Note AN840.

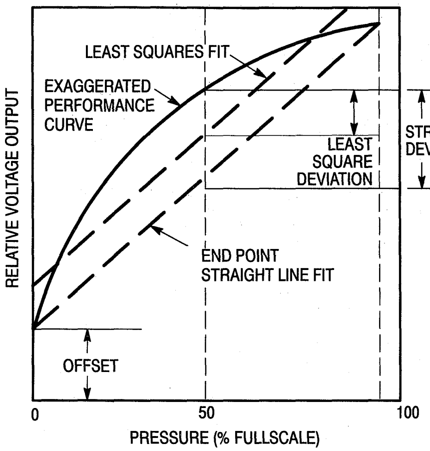


Figure 2. Linearity Specification Comparison

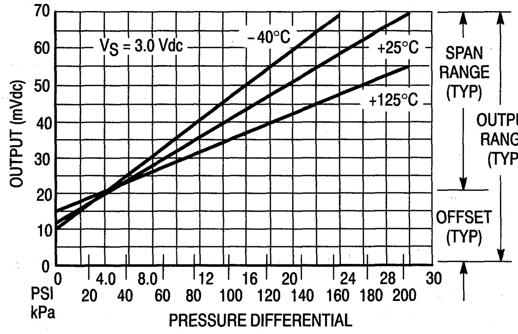


Figure 3. Output versus Pressure Differential

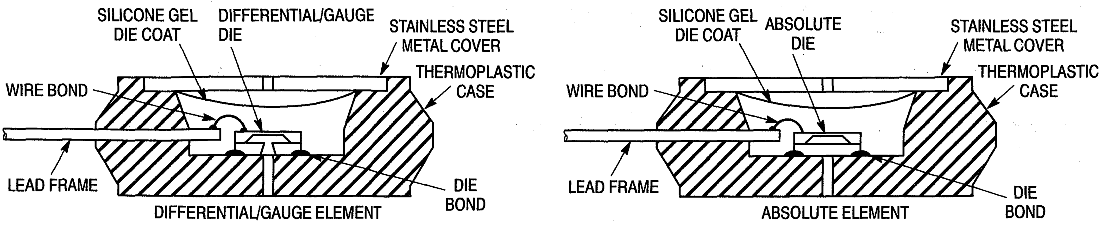


Figure 4. Cross-Sectional Diagrams (not to scale)

Figure 4 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bond from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPX200 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on device with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX200A	MPX200D	344	Stainless Steel Cap
MPX200DP		352	Side with Part Marking
MPX200AP	MPX200GP	350-03	Side with Port Attached
MPX200GVP		350-04	Stainless Steel Cap
MPX200AS	MPX200GS	371-06	Side with Port Attached
MPX200GVS		371-05	Stainless Steel Cap
MPX200ASX	MPX200GSX	371C	Side with Port Attached
MPX200GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX200 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

			MPX Series	
Device Type	Options	Case Type	Order Number	Device Marking
Basic Element	Absolute, Differential	Case 344	MPX200A MPX200D	MPX200A MPX200D
Ported Elements	Differential	Case 352	MPX200DP	MPX200DP
	Absolute, Gauge	Case 350-03	MPX200AP MPX200GP	MPX200AP MPX200GP
	Gauge Vacuum	Case 350-04	MPX200GVP	MPX200GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX200AS MPX200GS	MPX200A MPX200D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX200GVS	MPX200D
	Absolute, Gauge Axial	Case 371C	MPX200ASX MPX200GSX	MPX200A MPX200D
	Gauge Vacuum Axial	Case 371D	MPX200GVSX	MPX200D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

0 to 100 PSI Uncompensated, Silicon Pressure Sensors

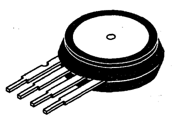
MPX700
SERIES

0–100 PSI
X-ducer™
SILICON
PRESSURE SENSORS

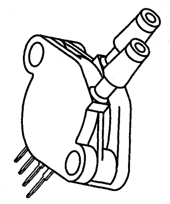
The MPX700 series device is a silicon piezoresistive pressure sensor providing a very accurate and linear voltage output — directly proportional to the applied pressure. This standard, low cost, uncompensated sensor permits manufacturers to design and add their own external temperature compensating and signal conditioning networks. Compensation techniques are simplified because of the predictability of Motorola's single element strain gauge design.

It is designed for applications in environmental control systems, pneumatic control systems, appliances, automotive performance controls, medical instrumentation and industrial controls.

- Low Cost
- Patented, Silicon Shear Stress Strain Gauge Design
- Linearity to ± 0.5% (Max) Full Scale Linearity
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	2100	kPa
Burst Pressure	P_{burst}	7000	kPa
Supply Voltage	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX700 sensor circuit.

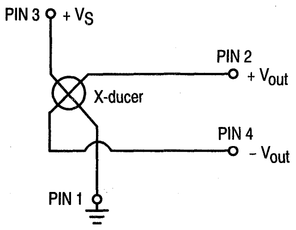


Figure 1. Uncompensated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

REV 2 1/94

OPERATING CHARACTERISTICS (V_S = 3.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1), Figure 2	P_{OP}	0	—	700	kPa
Supply Voltage	V_S	—	3.0	6.0	Vdc
Supply Current	I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 2	V_{FSS}	45	60	90	mV
Zero Pressure Offset, Figure 2	V_{off}	0	20	35	mV
Sensitivity	ΔV/ΔP	—	86	—	µV/kPa
Linearity(3), Figure 3	—	–0.5	—	0.5	%FSS
Pressure Hysteresis(4) (0 to 700 kPa)	—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	± 0.5	—	%FSS
Temperature Coefficient of Full Scale Span(6)	TCV_{FSS}	– 0.21	– 0.18	– 0.15	%/°C
Temperature Coefficient of Offset(7)	TCV_{off}	—	±15	—	µV/°C
Temperature Coefficient of Resistance(8)	TCR	0.34	0.37	0.4	%/°C
Input Impedance	Z_{in}	400	—	550	Ω
Output Impedance	Z_{out}	750	—	1875	Ω
Response Time(9) (10% to 90%)	t_R	—	1.0	—	ms
Stability(10)	—	—	± 0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element, Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 3.0 Vdc excitation for 700 kPa differential pressure. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 700 kPa. Using “best fit straight line” Method: Maximum linearity is ±0.25% FSS.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at –40°C and +125°C, relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at –40°C and +125°C, relative to +25°C.
8. Slope of end-point straight line fit to input resistance at –40°C and +125°C, relative to resistance at +25°C.
9. For a 0 to 700 kPa pressure step change.
10. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, – 40°C to + 125°C.
    b. 1.5 million pressure cycles, 0 to 700 kPa.
11. Operating characteristics based on positive pressure relative to the vacuum side (gauge/differential).

TEMPERATURE COMPENSATION

Figure 2 shows the output characteristics of the MPX700 series at 25°C.

The X-ducer piezoresistive pressure sensor element is a semiconductor device which gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependent, requiring that the device be temperature compensated if it is to be used over an extensive temperature range.

Temperature compensation and offset calibration can be achieved rather simply with additional resistive components.

Several approaches to external temperature compensation over both −40 to +125°C and 0 to +80°C ranges are presented in Motorola Applications Note AN840.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off} + \text{sensitivity} \times P$ over the operating pressure range (Figure 3). There are two basic methods for calculating nonlinearity: (1) end point straight line fit or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

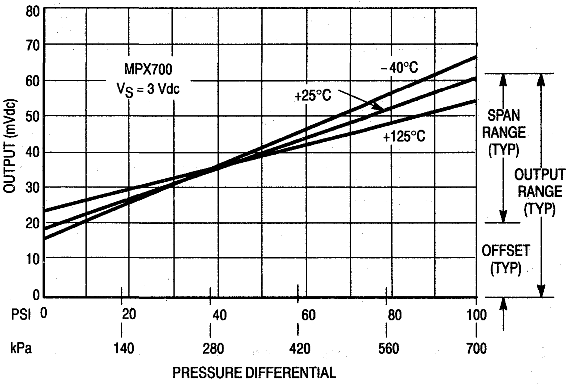


Figure 2. Output versus Pressure Differential

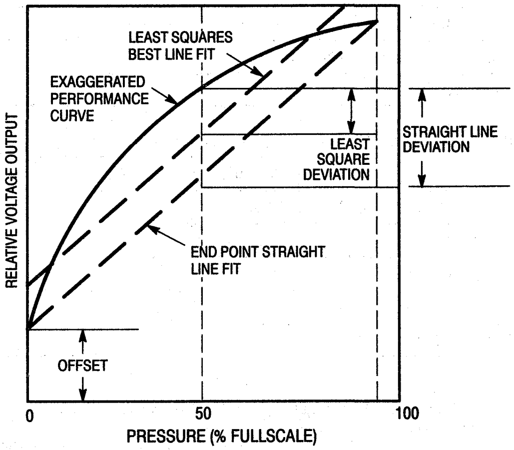


Figure 3. Linearity Specification Comparison

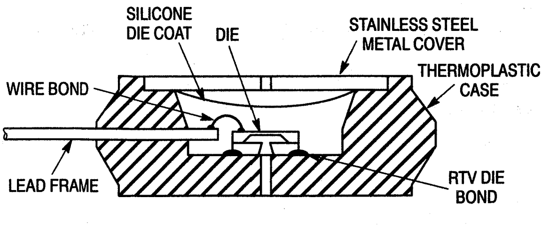


Figure 4. Cross Sectional Diagram (not to scale)

Figure 4 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX700 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table on the below:

Part Number	Case Type	Pressure Side Identifier
MPX700D	344	Stainless Steel Cap
MPX700DP	352	Side with Part Marking
MPX700GP	350-03	Side with Port Attached
MPX700GVP	350-04	Stainless Steel Cap
MPX700GS	371-06	Side with Port Attached
MPX700GVS	371-05	Stainless Steel Cap
MPX700GSX	371C	Side with Port Attached
MPX700GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION

MPX700 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	Case 344	MPX700D	MPX700D
Ported Elements	Differential	Case 352	MPX700DP	MPX700DP
	Gauge	Case 350-03	MPX700GP	MPX700GP
	Gauge Vacuum	Case 350-04	MPX700GVP	MPX700GVP
	Gauge Stovepipe	Case 371-06	MPX700GS	MPX700D
	Gauge Vacuum Stovepipe	Case 371-05	MPX700GVS	MPX700D
	Gauge Axial	Case 371C	MPX700GSX	MPX700D
	Gauge Vacuum Axial	Case 371D	MPX700GVSX	MPX700D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX2010
MPX2012
SERIES

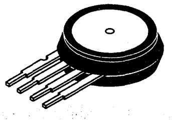
Motorola Preferred Devices

0 to 1.5 PSI On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

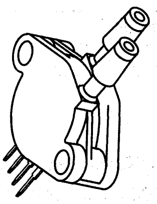
0–1.5 PSI
X-ducer™
SILICON
PRESSURE SENSORS

The MPX2010 and MPX2012 series silicon piezoresistive pressure sensors provide a very accurate and linear voltage output — directly proportional to the applied pressure. These sensors house a single monolithic silicon die with the strain gauge and thin-film resistor network integrated on each chip. The sensor is laser trimmed for precise span, offset calibration and temperature compensation. They are designed for use in applications such as respiratory diagnostics, air movement control, level indicators, controllers and pressure switching.

- Temperature Compensated over 0°C to +85°C
- Full Scale Span Calibrated to 25 mV (typical)
- Unique Silicon Shear Stress Strain Gauge
- ±1.0% (Max) Full Scale Linearity
- Easy to use Chip Carrier Package Options
- Ratiometric to Supply Voltage



BASIC CHIP CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	75	kPa
Burst Pressure	P_{burst}	100	kPa
Supply Voltage (Note 11)	V_{Smax}	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX2010 sensor circuit.

X-ducer is a trademark of Motorola Inc.

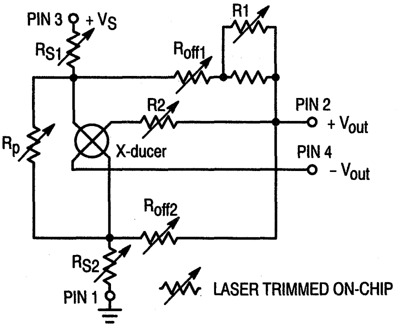


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 3 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	10	kPa
Supply Voltage(11)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 2		V_{FSS}	24	25	26	mV
Zero Pressure Offset, Figure 2	MPX2010 MPX2012	V_{off}	–1.0 –1.5	— —	1.0 1.5	mV
Sensitivity		ΔV/ΔP	—	2.5	—	mV/kPa
Linearity(3,11)		—	–1.0	±0.15	1.0	%FSS
Pressure Hysteresis(4) (0 to 10 kPa)		—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6), Figure 3		TCV_{FSS}	–1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 3		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	1300	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(8) (10% to 90%)		t_R	—	1.0	—	ms
Temperature Error Band, Figure 3		—	0	—	85	°C
Stability(9)		—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 10 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 10 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 10 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, –40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 10 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential).
11. Recommended voltage supply: 10 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +16 V may induce additional error due to device self-heating.

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 2 shows the output characteristics of the MPX2010 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are very small and are shown under Operating Characteristics and in Figure 3.

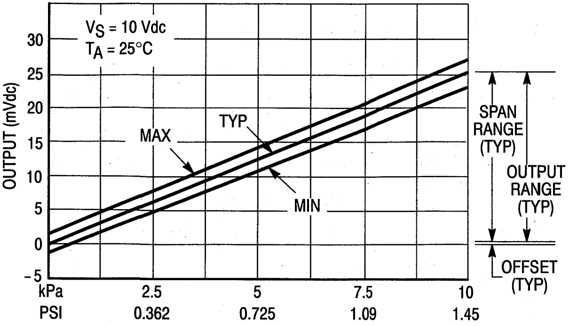


Figure 2. Output versus Pressure Differential

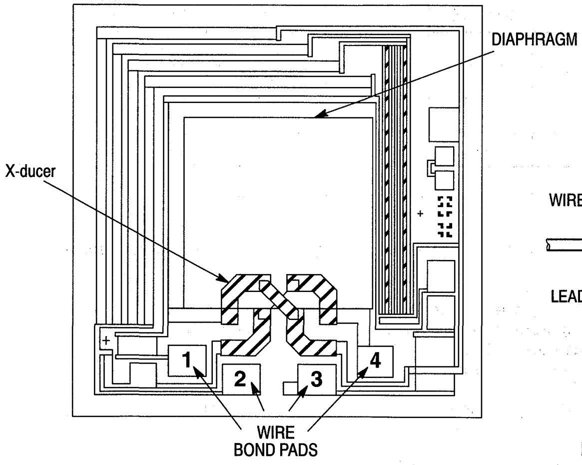


Figure 4. Monolithic Pressure Sensor Chip (Top View)

Monolithic pressure sensor chip, showing diaphragm, X-ducer, thin-film resistor circuitry and pin out. Devices available in basic chip carrier or as ported elements only. See standard options available on the following page.

This performance over temperature is achieved by having both the shear stress strain gauge and the thin-film resistor circuitry on the same silicon diaphragm as shown in Figure 4. Each chip is dynamically laser trimmed for precise span and offset calibration and temperature compensation.

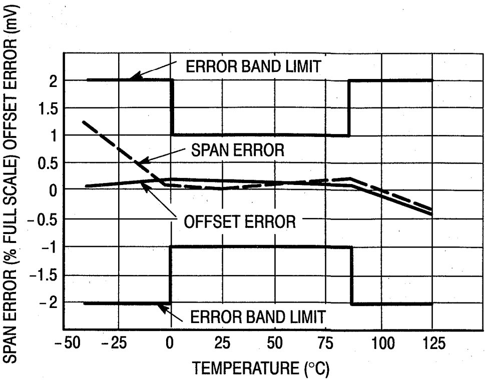


Figure 3. Temperature Error Band Limit and Typical Span and Offset Errors

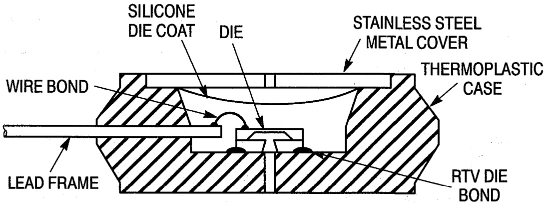


Figure 5. Cross Sectional (not to scale)

Figure 5 illustrates the differential/gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2010 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX2010D	MPX2012D	344	Stainless Steel Cap
MPX2010DP	MPX2012DP	352	Side with Part Marking
MPX2010GP	MPX2012GP	350-03	Side with Port Attached
MPX2010GVP	MPX2012GVP	350-04	Stainless Steel Cap
MPX2010GS	MPX2012GS	371-06	Side with Port Attached
MPX2010GVS	MPX2012GVS	371-05	Stainless Steel Cap
MPX2010GSX	MPX2012GSX	371C	Side with Port Attached
MPX2010GVSX	MPX2012GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX2010 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

			MPX Series	
Device Type	Options	Case Type	Order Number	Device Marking
Basic Element	Differential	Case 344	MPX2010D MPX2012D	MPX2010D MPX2012D
Ported Elements	Differential	Case 352	MPX2010DP MPX2012DP	MPX2010DP MPX2012DP
	Gauge	Case 350-03	MPX2010GP MPX2012GP	MPX2010GP MPX2012GP
	Gauge Vacuum	Case 350-04	MPX2010GVP MPX2012GVP	MPX2010GVP MPX2012GVP
	Gauge Stove Pipe	Case 371-06	MPX2010GS MPX2012GS	MPX2010D MPX2012D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX2010GVS MPX2012GVS	MPX2010D MPX2012D
	Gauge Axial	Case 371C	MPX2010GSX MPX2012GSX	MPX2010D MPX2012D
	Gauge Vacuum Axial	Case 371D	MPX2010GVSX MPX2012GVSX	MPX2010D MPX2012D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

0 to 7.3 PSI On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

MPX2050
MPX2051
MPX2052
SERIES

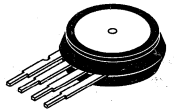
Motorola Preferred Devices

0–7.3 PSI
X-ducer™
SILICON
PRESSURE SENSORS

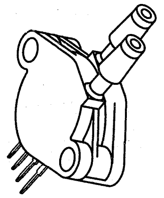
The MPX2050, MPX2051 and MPX2052 series device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output — directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. This device was designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, and non-invasive blood pressure measurement.

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Full Scale Span Calibrated to 40 mV (typical)
- Easy to Use Chip Carrier Package Options
- Ratiometric to Supply Voltage

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	200	kPa
Burst Pressure	P_{burst}	500	kPa
Supply Voltage (Note 11)	V_{Smax}	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX2050 sensor circuit.

X-ducer is a trademark of Motorola Inc.

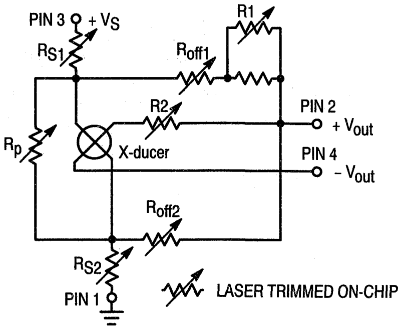


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 3 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	50	kPa
Supply Voltage(11)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 5	MPX2050, MPX2052 MPX2051	V_{FSS}	38.5 37.5	40 40	41.5 42.5	mV
Zero Pressure Offset, Figure 5	MPX2050, MPX2052 MPX2051	V_{off}	−1.0 −2.0	— —	1.0 2.0	mV
Sensitivity		$\Delta V/\Delta P$	—	0.8	—	mV/kPa
Linearity(3)(11) Figure 2	MPX2050 MPX2051 MPX2052	— — —	−0.25 −0.50 −0.55	— — —	0.25 0.50 0.25	%FSS
Pressure Hysteresis(4) (0 to 50 kPa)		—	−0.1	—	0.1	%FSS
Temperature Hysteresis(5) (−40°C to +125°C)		—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 6		TCV_{FSS}	−1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 6		TCV_{off}	−1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(8) (10% to 90%)		t_R	—	1.0	—	ms
Temperature Error Band, Figure 6		—	0	—	85	°C
Stability(9)		—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 50 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 50 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range −40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 50 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 50 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).
11. Recommended voltage supply: 10 V ±0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltage above +16 V may induce additional error due to device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

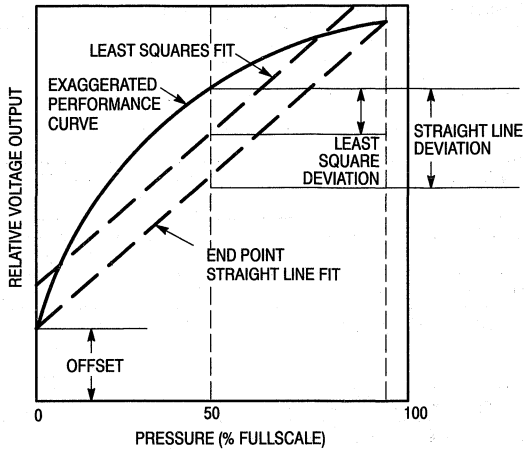
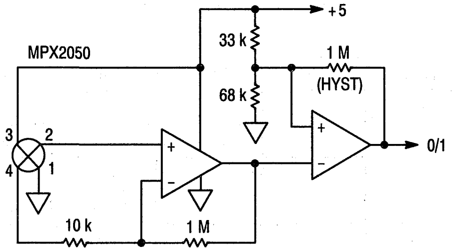


Figure 2. Linearity Specification Comparison

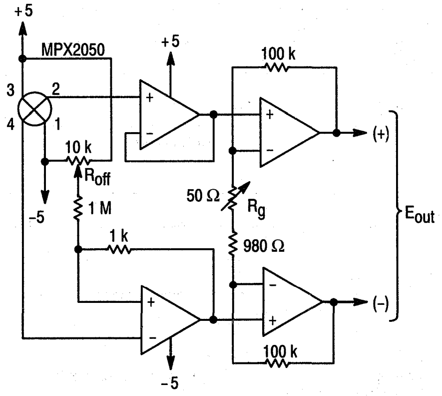
EXAMPLE INTERFACE CIRCUITS

MPX2050 sensors with on-chip compensation can be used individually or in multiples in research, design, or development projects to optimize a design. The small size and low cost of the compensated MPX2050 series of sensors makes these devices ideally suited for such applications.



Output switches low at 55% full-scale input; switches high at 45% input. 1 M Hysteresis resistor may be removed or value changed according to user requirements.

Figure 3. Single-ended Supply, TTL or CMOS Logic Compatible Comparator



DVM µP compatible input. Set SPAN with R_g, the OFFSET with R_{off}. Differential output is ±8 Vdc with full-scale pressure (vacuum) applied.

Figure 4. Precision Pressure-to-Voltage Converter using Quad Op Amp

These are offered as basic suggestions only: actual component selection and values are determined by the final circuit requirements.

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 5 shows the minimum, maximum and typical output characteristics of the MPX2050 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full-Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 6.

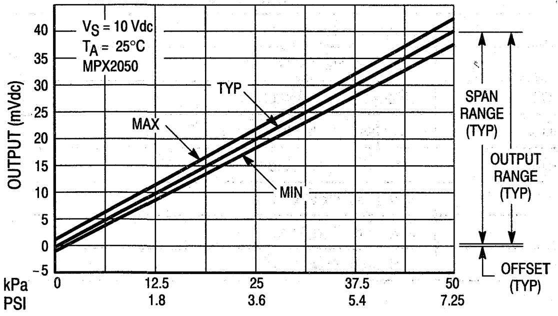


Figure 5. Output versus Pressure Differential

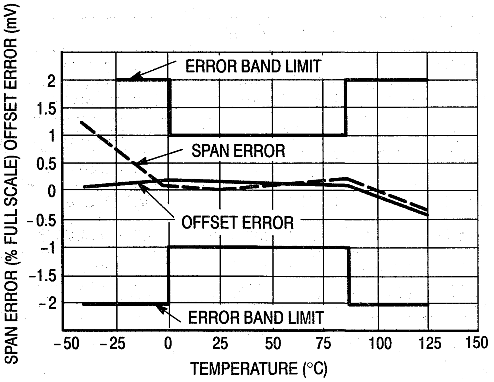


Figure 6. Temperature Error Band Limit and Typical Span and Offset Errors

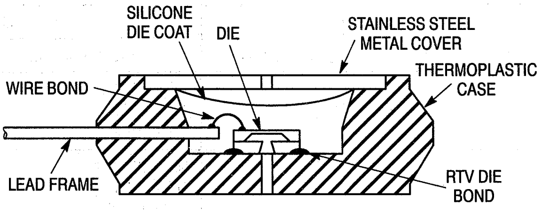


Figure 7. Cross-Sectional Diagrams (not to scale)

Figure 7 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2050 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number			Case Type	Pressure Side Identifier
MPX2050D	MPX2051D	MPX2052D	344	Stainless Steel Cap
MPX2050DP	MPX2051DP	MPX2052DP	352	Side with Part Marking
MPX2050GP	MPX2051GP	MPX2052GP	350-03	Side with Port Attached
MPX2050GVP	MPX2051GVP	MPX2052GVP	350-04	Stainless Steel Cap
MPX2050GS	MPX2051GS	MPX2052GS	371-06	Side with Port Attached
MPX2050GVS	MPX2051GVS	MPX2052GVS	371-05	Stainless Steel Cap
MPX2050GSX	MPX2051GSX	MPX2052GSX	371C	Side with Port Attached
MPX2050GVSX	MPX2051GVSX	MPX2052GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX2050 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	344	MPX2050D MPX2051D MPX2052D	MPX2050D MPX2051D MPX2052D
Ported Elements	Differential	352	MPX2050DP MPX2051DP MPX2052DP	MPX2050DP MPX2051DP MPX2052DP
	Gauge	350-03	MPX2050GP MPX2051GP MPX2052GP	MPX2050GP MPX2051GP MPX2052GP
	Gauge Vacuum	350-04	MPX2050GVP MPX2051GVP MPX2052GVP	MPX2050GVP MPX2051GVP MPX2052GVP
	Gauge Stove Pipe	371-06	MPX2050GS MPX2051GS MPX2052GS	MPX2050D MPX2051D MPX2052D
	Gauge Vacuum Stove Pipe	371-05	MPX2050GVS MPX2051GVS MPX2052GVS	MPX2050D MPX2051D MPX2052D
	Gauge Axial	371C	MPX2050GSX MPX2051GSX MPX2052GSX	MPX2050D MPX2051D MPX2052D
	Gauge Vacuum Axial	371D	MPX2050GVSX MPX2051GVSX MPX2052GVSX	MPX2050D MPX2051D MPX2052D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX2100
MPX2101
SERIES

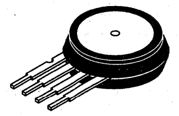
Motorola Preferred Devices

0 to 14.5 PSI On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

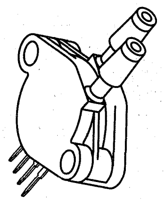
0–14.5 PSI
X-ducer™
SILICON
PRESSURE SENSORS

The MPX2100 and MPX2101 series device is a silicon piezoresistive pressure sensors providing a highly accurate and linear voltage output — directly proportional to the applied pressure. The sensor is a single, monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. This device was designed for use inapplications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Full Scale Span Calibrated to 40 mV (typical)
- Easy to Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage (Note 11)	V_{Smax}	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the positive pressure side. Vacuum down to the reference can be measured with the indicated accuracy.

The output voltage of the differential element, differential ported and gauge ported sensors increases with increasing pressure applied to the positive pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the positive pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX2100 sensor circuit.

X-ducer is a trademark of Motorola Inc.

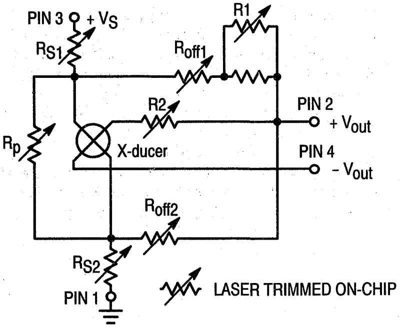


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 4 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range (1)		P_{OP}	0	—	100	kPa
Supply Voltage(11)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 5	MPX2100A, MPX2100D, MPX2101D MPX2101A	V_{FSS}	38.5 37.5	40 40	41.5 42.5	mV
Zero Pressure Offset, Figure 5	MPX2100D, MPX2101D MPX2100A MPX2101A	V_{off}	−1.0 −2.0 −3.0	— — —	1.0 2.0 3.0	mV
Sensitivity		ΔV/ΔP	—	0.4	—	mV/kPa
Linearity(3) Figure 2	MPX2100A, MPX2100D MPX2101A, MPX2101D	— —	−0.25 −0.5	— —	0.25 0.5	%FSS
Pressure Hysteresis(4) (0 to 100 kPa)		—	− 0.1	—	0.1	%FSS
Temperature Hysteresis(5) (−40°C to +125°C)		—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 6		TCV_{FSS}	−1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 6		TCV_{off}	−1.0	—	1.0	mV
Input Impedance		Z_{in}	1000	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(8) (10% to 90%)		t_R	—	1.0	—	ms
Temperature Error Band, Figure 6		—	0	—	85	°C
Stability(9)		—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPA

NOTES:

1. 1 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 100 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 100 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range −40°C to +125°C.
6. Slope end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 100 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 100 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).
11. Recommended voltage supply: 10 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +16 V may induce additional error due to device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

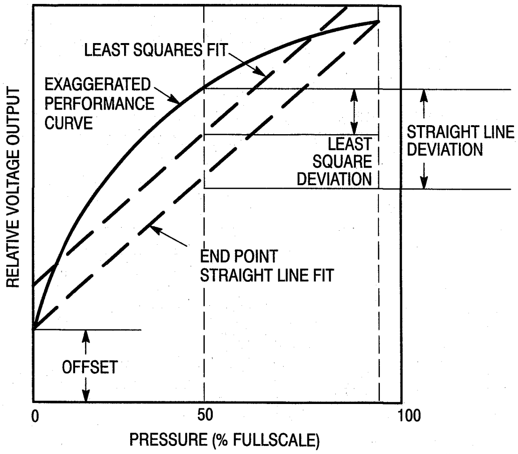
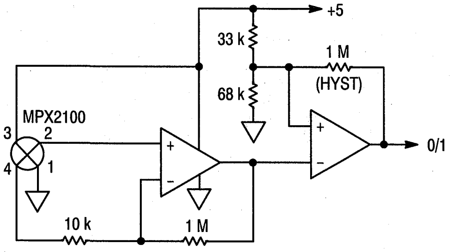


Figure 2. Linearity Specification Comparison

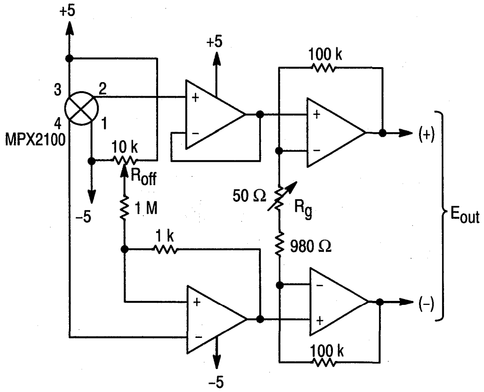
EXAMPLE INTERFACE CIRCUITS

The MPX2100 series sensors with on-chip compensation can be used individually or in multiples in research, design, or development projects to optimize a design. The small size and low cost of the compensated MPX2100 series sensors make these devices ideally suited for such applications.



Output switches low at 55% full-scale input; switches high at 45% input. 1 M Hysteresis resistor may be removed or value changed according to user requirements.

Figure 3. Single-ended Supply, TTL or CMOS Logic Compatible Comparator



DVM µP compatible input. Set SPAN with R_g, the OFFSET with R_{off}. Differential output is ±8 Vdc with full-scale pressure applied.

Figure 4. Precision Pressure-to-Voltage Converter using Quad Op Amp

These are offered as basic suggestions only: actual component selection and values are determined by the final circuit requirements.

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 5 shows the output characteristics of the MPX2100 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 6.

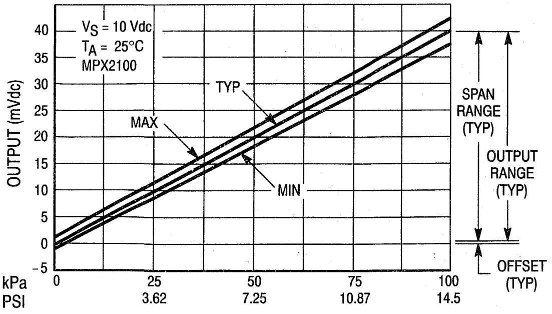


Figure 5. Output versus Pressure Differential

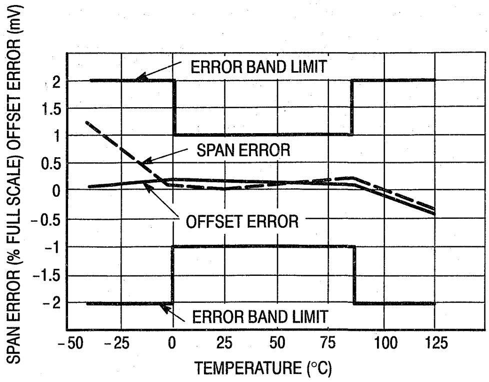
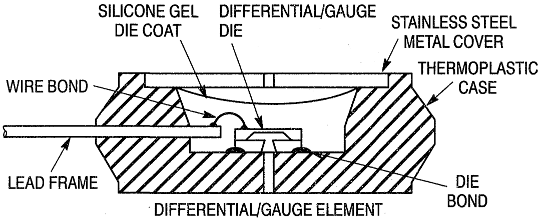


Figure 6. Temperature Error Band Limit and Typical Span and Offset Errors



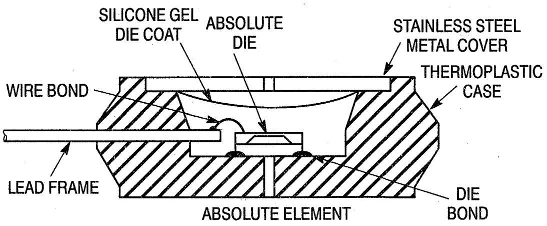


Figure 7. Cross-Sectional Diagrams (not to scale)

Figure 7 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2100 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number				Case Type	Pressure Side Identifier
MPX2100A	MPX2100D	MPX2101A	MPX2101D	344	Stainless Steel Cap
MPX2100DP		MPX2101DP		352	Side with Part Marking
MPX2100AP	MPX2100GP	MPX2101AP	MPX2101GP	350-03	Side with Port Attached
MPX2100GVP		MPX2101GVP		350-04	Stainless Steel Cap
MPX2100AS	MPX2100GS	MPX2101AS	MPX2101GS	371-06	Side with Port Attached
MPX2100GVS		MPX2101GVS		371-05	Stainless Steel Cap
MPX2100ASX	MXP2100GSX	MPX2101ASX	MXP2101GSX	371C	Side with Port Attached
MPX2100GVSX		MPX2101GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX2100 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute, Differential	Case 344	MPX2100A MPX2100D MPX2101A MPX2101D	MPX2100A MPX2100D MPX2101A MPX2101D
Ported Elements	Differential	Case 352	MPX2100DP MPX2101DP	MPX2100DP MPX2101DP
	Absolute, Gauge	Case 350-03	MPX2100AP MPX2100GP MPX2101AP MPX2101GP	MPX2100AP MPX2100GP MPX2101AP MPX2101GP
	Gauge Vacuum	Case 350-04	MPX2100GVP MPX2101GVP	MPX2100GVP MPX2101GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX2100AS MPX2100GS MPX2101AS MPX2101GS	MPX2100A MPX2100D MPX2101A MPX2101D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX2100GVS MPX2101GVS	MPX2100D MPX2101D
	Absolute, Gauge Axial	Case 371C	MPX2100ASX MPX2100GSX MPX2101ASX MPX2101GSX	MPX2100A MPX2100D MPX2101A MPX2101D
	Gauge Vacuum Axial	Case 371D	MPX2100GVSX MPX2101GVSX	MPX2100D MPX2101D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX2200
MPX2201
SERIES

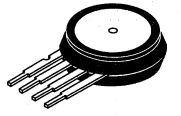
Motorola Preferred Devices

0 to 29 PSI On-Chip Temperature Compensated & Calibrated, Pressure Sensors

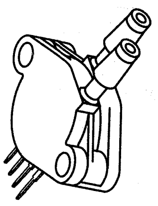
0–29 PSI
X-ducer™
SILICON
PRESSURE SENSORS

The MPX2200 and MPX2201 series device is a silicon piezoresistive pressure sensor providing a highly accurate and linear voltage output — directly proportional to the applied pressure. The sensor is a single monolithic silicon diaphragm with the strain gauge and a thin-film resistor network integrated on-chip. The chip is laser trimmed for precise span and offset calibration and temperature compensation. They are designed for use in applications such as pump/motor controllers, robotics, level indicators, medical diagnostics, pressure switching, barometers, altimeters, etc.

- Low Cost
- Temperature Compensated Over 0°C to +85°C
- Patented Silicon Shear Stress Strain Gauge
- ±0.25% Full Scale Linearity
- Easy to Use Chip Carrier Package
- Available in Absolute, Differential and Gauge Configurations



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	2000	kPa
Supply Voltage (Note 12)	$V_{S\,max}$	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure side. Vacuum down to the reference can be measured with the indicated accuracy.

The output voltage of the differential element, differential ported and gauge ported sensor increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units.

The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic diagram of the MPX2200 sensor circuit.

X-ducer is a trademark of Motorola Inc.

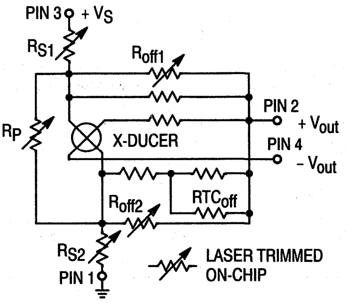


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 5 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristics		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage(12)		V_S	—	10	16	Vdc
Supply Current		I_o	—	6.0	—	mAdc
Full Scale Span(2), Figure 5	MPX2200A, MPX2200D MPX2201D MPX2201A	V_{FSS}	38.5 37.5	40 40	41.5 42.5	mV
Zero Pressure Offset, Figure 5	MPX2200A, MPX2200D MPX2200A MPX2201A	V_{off}	−1.0 −2.0 −3.0	— — —	+1.0 +2.0 +3.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(3)(11) Figure 2	MPX2200A, MPX2200D MPX2201A, MPX2201D	—	−0.25 −0.5	— —	±0.25 +0.5	%FSS
Pressure Hysteresis(4) (0 to 200 kPa)		—	−0.1	± 0.05	+0.1	%FSS
Temperature Hysteresis(5) (−40°C to +125°C)		—	—	± 0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 6		TCV_{FSS}	−1.0	± 0.2	+1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 6		TCV_{off}	−1.0	± 0.2	+1.0	mV
Input Impedance		Z_{in}	1300	—	2500	Ω
Output Impedance		Z_{out}	1400	—	3000	Ω
Response Time(8) (10% to 90%)		t_R	—	1.0	—	ms
Temperature Error Band, Figure 6		—	0	—	85	°C
Stability(9)		—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight, (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 200 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 200 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range −40°C to +125°C.
6. Slope end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 200 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 200 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).
11. Using "best fit straight line" method: typical linearity is ±0.05%.
12. Recommended voltage supply: 10 V ±0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +16 V may induce additional error due to increased device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off} + \text{sensitivity} \times P$ over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

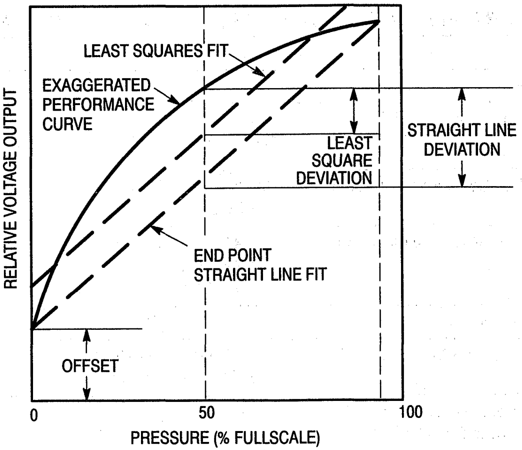


Figure 2. Linearity Specification Comparison

EXAMPLE INTERFACE CIRCUITS

MPX2000 sensors with on-chip compensation can be used individually or in multiples in research, design, or development projects to optimize a design. The small size and low cost of the compensated MPX2000 series of sensors make these devices ideally suited for such applications.

Many process control functions can also be served by MPX2000 sensors handling pressure ranges up to 29 PSI in gauge, vacuum and differential measurements. Wind tunnel measurements, vacuum forming or vacuum pickup monitoring are among the many potential applications.

These circuit designs are offered as basic suggestions only; actual component selection and values are determined by the final circuit requirements.

SOLID STATE PRESSURE SWITCH

A low-cost, set-point pressure switch for motor control applications. This circuit has been used successfully to control compressor and pump motors, as well as heaters in liquid level applications.

FLUID PRESSURE CIRCUIT

Fluid pressure transducer circuit with inverted output. In this configuration, the circuit provides a 4.0 Vdc output with zero pressure applied, decreasing to 0 Vdc at full rated pressure.

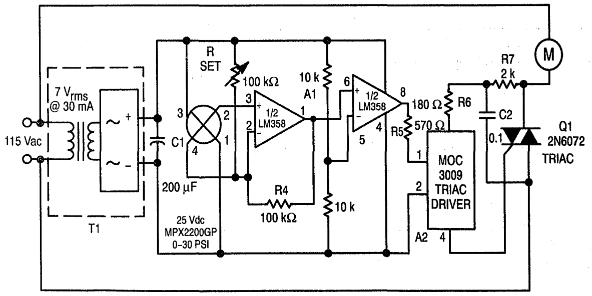


Figure 3. Solid State Pressure Switch

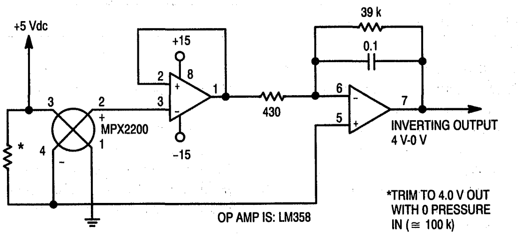


Figure 4. Fluid Pressure Circuit

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 5 shows the output characteristics of the MPX2200 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 6.

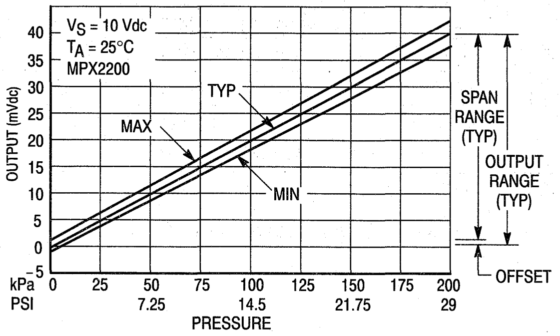


Figure 5. Output versus Pressure Differential

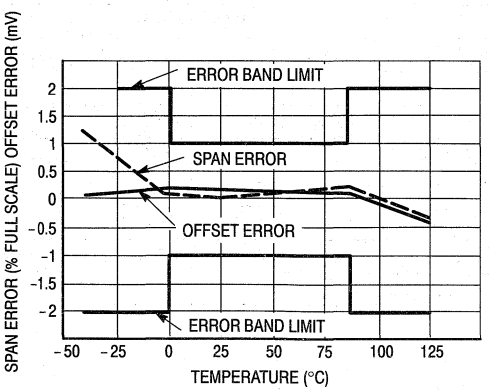


Figure 6. Temperature Error Band Limit and Typical Span and Offset Errors

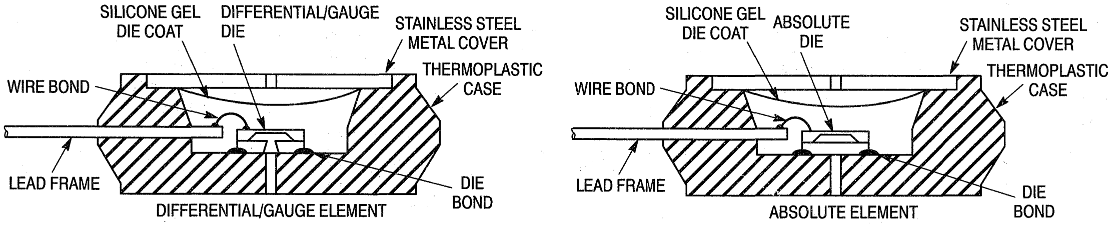


Figure 7. Cross-Sectional Diagrams (not to scale)

Figure 7 illustrates an absolute sensing die (right) and the differential or gauge die in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX2200 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number				Case Type	Pressure Side Identifier
MPX2200A	MPX2200D	MPX2201A	MPX2201D	344	Stainless Steel Cap
MPX2200DP		MPX2201DP		352	Side with Part Marking
MPX2200AP	MPX2200GP	MPX2201AP	MPX2201GP	350-03	Side with Port Attached
MPX2200GVP		MPX2201GVP		350-04	Stainless Steel Cap
MPX2200AS	MPX2200GS	MPX2201AS	MPX2201GS	371-06	Side with Port Attached
MPX2200GVS		MPX2201GVS		371-05	Stainless Steel Cap
MPX2200ASX	MPX2200GSX	MPX2201ASX	MPX2201GSX	371C	Side with Port Attached
MPX2200GVSX		MPX2201GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX2200 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

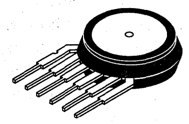
Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marketing
Basic Element	Absolute, Differential	Case 344	MPX2200A MPX2200D MPX2201A MPX2201D	MPX2200A MPX2200D MPX2201A MPX2201D
Ported Elements	Differential	Case 352	MPX2200DP MPX2201DP	MPX2200DP MPX2201DP
	Absolute, Gauge	Case 350-03	MPX2200AP MPX2200GP MPX2201AP MPX2201GP	MPX2200AP MPX2200GP MPX2201AP MPX2201GP
	Gauge Vacuum	Case 350-04	MPX2200GVP MPX2201GVP	MPX2200GVP MPX2201GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX2200AS MPX2200GS MPX2201AS MPX2201GS	MPX2200A MPX2200D MPX2201A MPX2201D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX2200GVS MPX2201GVS	MPX2200D MPX2201D
	Absolute, Gauge Axial	Case 371C	MPX2200ASX MPX2200GSX MPX2201ASX MPX2201GSX	MPX2200A MPX2200D MPX2201A MPX2201D
	Gauge Vacuum Axial	Case 371D	MPX2200GVSX MPX2201GVSX	MPX2200D MPX2201D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

Manifold Absolute Pressure Sensor On-Chip Signal Conditioned, 0.2 V to 4.9 V Output, Temperature Compensated & Calibrated

MPX4100
MPX4101
SERIES
Motorola Preferred Devices

4100A: 20–105 kPa
4101A: 15–102 kPa
X-ducer™
SILICON
PRESSURE SENSOR



CASE 867
Style 1

The Motorola MPX4100/4101A series Manifold Absolute Pressure (MAP) sensor for engine control is designed to sense absolute air pressure within the intake manifold. This measurement can be used to compute the amount of fuel required for each cylinder.

Motorola's MAP sensor integrates on-chip, Bi-Polar op amp circuitry and thin film resistor networks to provide a high output signal and temperature compensation. The small form factor and high reliability of on-chip integration make the Motorola MAP sensor a logical and economical choice for the automotive system designer.

- 1.5% Total Accuracy Over 0–85°C
- Specifically designed for Intake Manifold Absolute Pressure Sensing in Engine Control Systems
- Ideally suited for direct Microprocessor Interfacing
- Patented Silicon Shear Stress Strain Gauge
- Temperature Compensated Over −40 to +125°C
- Customized Output Available — Consult Factory
- Durable Epoxy Unibody Element

MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage	V_{Smax}	5.3	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

Pin Number					
1	2	3	4	5	6
V_{out}	Ground	V_S	N/C	N/C	N/C

NOTE: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

The MPX4100A/4101A series piezoresistive transducer is a state-of-the-art, monolithic, signal conditioned, silicon pressure sensor. This patented, single element X-ducer combines advanced micromachining techniques, thin film metalization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure. A vacuum of approximately 40–60 μTorr is sealed behind the sensor diaphragm providing an accurate, reliable pressure reference. (See Figure 2.)

Figure 1 shows a schematic of the internal circuitry integrated on-chip to provide temperature compensation, offset and span calibration and signal conditioning.

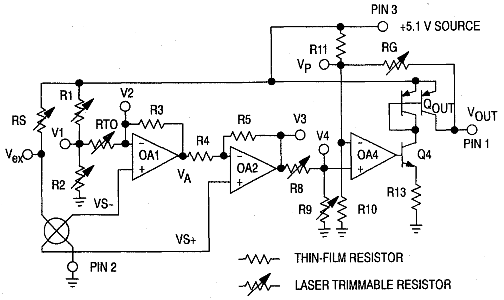


Figure 1. Fully Integrated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

REV1 1/94

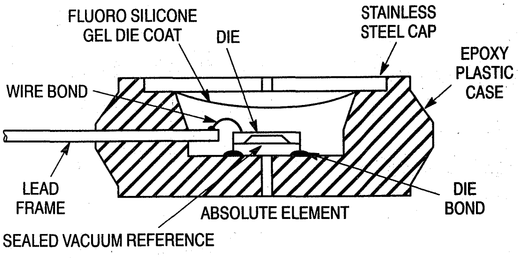


Figure 2. Cross Sectional Diagram (Not to Scale)

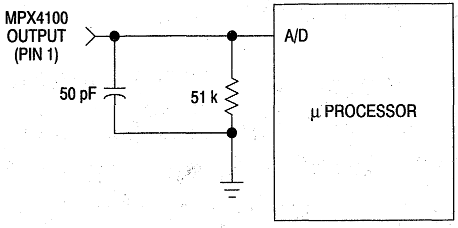


Figure 3. Typical Decoupling Filter for Sensor to Microprocessor Interface

Figure 2 illustrates an absolute sensing configuration package in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm. The MPX4100 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long-term stability. Contact the factory for information regarding media compatibility in your application.

Note: Stainless steel cap is not installed on device with port attach options.

Figure 3 shows a typical decoupling circuit for interfacing the output of the integrated map sensor to the A/D input of a microprocessor.

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 4 shows the output characteristics of the MPX4100A at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

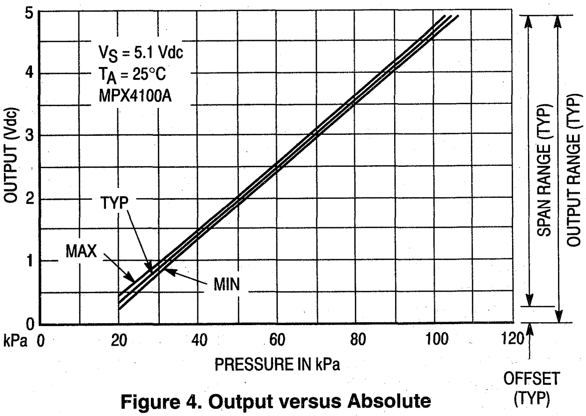


Figure 4. Output versus Absolute Pressure Differential

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted)

Characteristic for MPX4100 Series	Symbol	Min	Typ	Max	Unit
Absolute Pressure Range	P_{OP}	20	—	105	kPa
Supply Voltage (5)	V_S	4.8	5.1	5.3	Vdc
Supply Current	I_o	—	8.0	15	mAdc
Full Scale Span, Figure 4	V_{FSS}	4.509	4.590	4.671	V
Sensitivity	$\Delta V/\Delta P$	—	54	—	mV/kPa
Accuracy (0–85°C) (6)	—	—	±0.2	1.5	%FSS
Response Time (2) (10% to 90%)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{o+}	—	0.1	—	mA
Stability (3)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up Time	—	—	15	—	ms
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

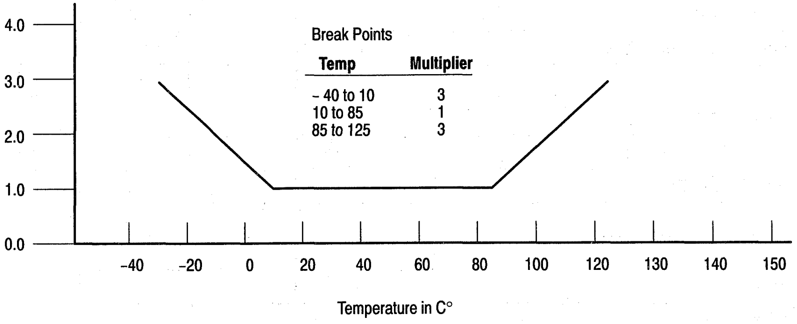
NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a rated pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 20 to 105 kPa.
4. Using best fit straight line method: typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5.1 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

Transfer Function (MPX4100A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.01059 – 0.1518)
+/– (Pressure Error x Temp. Mult. x 0.01059 x V_S)
V_S = 5.1 V ± 5% P_{in} kPa

Temperature Error Multiplier

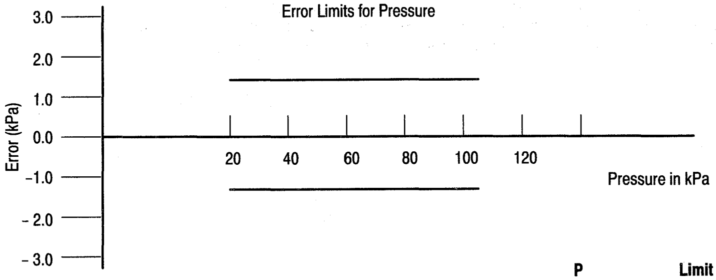


MPX4100 Series

Break Points

Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band



P	Limit (kPa)
20	+/- 1.5
40	+/- 1.5
94	+/- 1.5
105	+/- 1.5

OPERATING CHARACTERISTICS (V_S = 5.1 Vdc, T_A = 25°C unless otherwise noted)

Characteristic for MPX4101 Series	Symbol	Min	Typ	Max	Unit
Absolute Pressure Range	P_{OP}	15	—	102	kPa
Supply Voltage (5)	V_S	4.8	5.1	5.3	Vdc
Supply Current	I_o	—	8.0	15	mAdc
Full Scale Span, Figure 5	V_{FSS}	4.618	4.700	4.780	V
Sensitivity	ΔV/ΔP	—	54	—	mV/kPa
Accuracy (0–85°C) (6)	—	—	±0.2	1.5	%FSS
Response Time (2) (10% to 90%)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{o+}	—	0.1	—	mA
Stability (3)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up Time	—	—	15	—	ms
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:
1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a rated pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, −40°C to +125°C.
   b. 1.5 million pressure cycles, 15 to 102 kPa.
4. Using best fit straight line method: typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5.1 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 5 shows the output characteristics of the MPX4101A at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

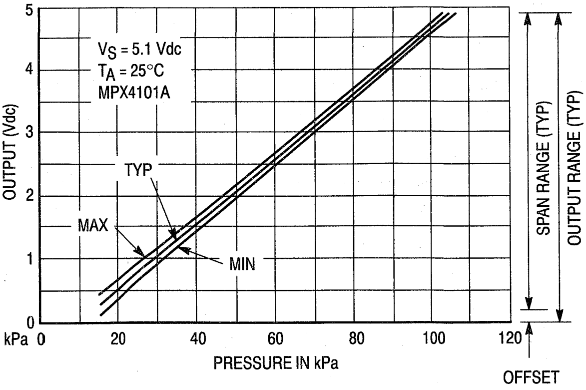
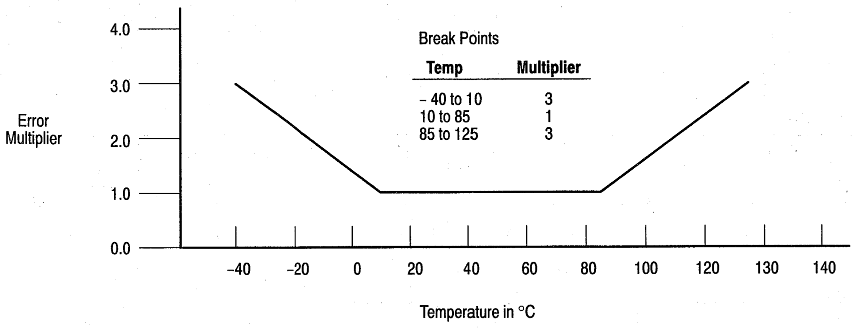


Figure 5. Output versus Absolute Pressure Differential

Transfer Function (MPX4101A)

Nominal Transfer Value: $V_{out} = V_S\ (P \times 0.01059\ - 0.10941)$
$\pm$ (Pressure Error x Temp. Mult. x 0.01059 x V_S)
$V_S = 5.1\ V \pm 5\%\ P_{in}$ kPa

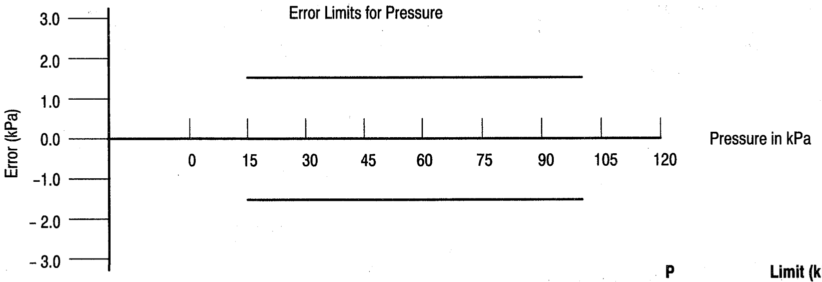
Temperature Error Multiplier


MPX4101 Series

Break Points

Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band


Error Limits for Pressure

P	Limit (kPa)
15	+/- 1.5
40	+/- 1.5
94	+/- 1.5
102	+/- 1.5

ORDERING INFORMATION

The MPX4100A and 4101A series MAP silicon pressure sensors are available in the basic element package, or with pressure port fittings that provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case No.	MPX Series Order No.	Marking
Basic Element	Absolute, Element	867	MPX4100A MPX4101A	MPX4100A MPX4101A
Ported Elements	Absolute, Ported	867B	MPX4100AP MPX4101AP	MPX4100AP MPX4101AP
	Absolute, Stove Pipe Port	867E	MPX4100AS MPX4101AS	MPX4100A MPX4101A
	Absolute, Axial Port	867F	MPX4100ASX MPX4101ASX	MPX4100A MPX4101A

CONVERSION TABLE FOR COMMON UNITS OF PRESSURE

	kiloPascals	mm Hg	millibars	inches H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038
1 mm Hg	0.133322	1.00000	1.33322	0.535257	0.0193368
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038
1 inch H_2O	0.249081	1.86826	2.49081	1.00000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038
1 cm H_2O	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

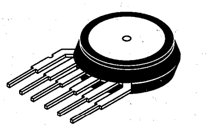
0 to 7.3 PSI On-Chip Signal Conditioned, 0.2 V to 4.8 V Output, Temperature Compensated & Calibrated, Silicon Pressure Sensors

MPX5050
SERIES

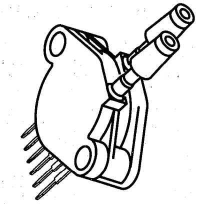
Motorola Preferred Devices

0–7.3 PSI
X-ducer™
SILICON
PRESSURE SENSORS

- 2.5% Total Accuracy Over 0–85°C
- Ideally Suited for Microprocessor or Microcontroller Based Systems
- Temperature Compensated Over – 40 to 125°C.
- Patented Silicon Shear Stress Strain Gauge
- Easy-to-Use Chip Carrier Package Options
- Available in Differential and Gauge Configurations
- Durable Epoxy Unibody Element



BASIC CHIP CARRIER ELEMENT
CASE 867
Style 1



DIFFERENTIAL PORT OPTION
CASE 867C
Style 1

Pin Number					
1	2	3	4	5	6
V_{out}	Ground	V_S	N/C	N/C	N/C

NOTE: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Overpressure	P_{max}	200	kPa
Burst Pressure	P_{burst}	700	kPa
Supply Voltage (Note 5)	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	–50 to +150	°C
Operating Temperature	T_A	–40 to +125	°C

The MPX5050 series piezoresistive transducer is a state-of-the-art, monolithic silicon pressure sensor designed for a wide range of applications, but particularly for those employing a microcontroller or microprocessor with A/D inputs. This patented, single element X-ducer combines advanced micromachining techniques, thin-film metallization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a schematic of the internal circuitry integrated on-chip to provide temperature compensation, offset and span calibration and signal conditioning.

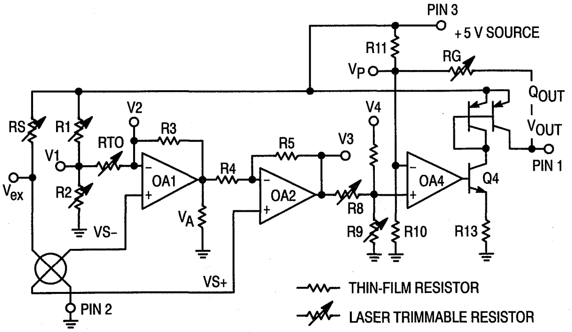


Figure 1. Fully Integrated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

REV 1 1/94

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	50	kPa
Supply Voltage	V_S	—	5.0	6.0	Vdc
Supply Current	I_o	—	7.0	9.0	mAdc
Full Scale Span	V_{FSS}	4.588	4.7	4.812	V
Zero Pressure Offset	V_{off}	0.088	0.2	0.312	V
Sensitivity	V/P	—	90	—	mV/kPa
Accuracy (0–85°C)	—	—	± 0.2	2.5	%FSS
Response Time(2) (10% to 90%)	t_R	—	1.0	—	ms
Output Source Current at Full Scale Output	I_{O+}	—	0.1	—	mA
Stability(3)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a 0 to 50 kPa pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within + 10°C to + 85°C after:
   a. 1000 temperature cycles, 0°C to + 85°C.
   b. 1.5 million pressure cycles, 0 to 50 kPa.
4. Using best fit straight line method: Typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION AND SIGNAL CONDITIONING

Figure 2 shows the output characteristics of the MPX5050 at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

Figure 3 illustrates the differential or gauge configuration in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX5050 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

Note: Stainless steel cap is not installed on devices with ports attached on the pressure (top) side.

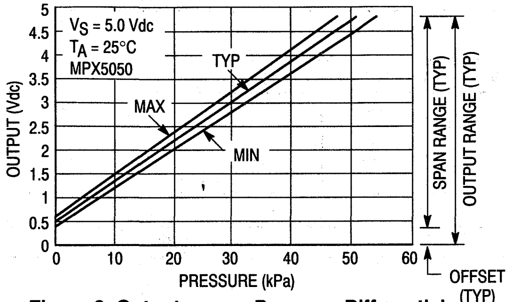


Figure 2. Output versus Pressure Differential

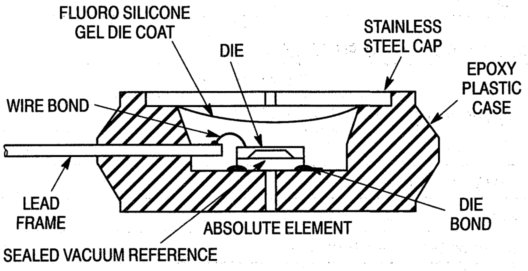


Figure 3. Cross Sectional Diagram (Not to Scale)

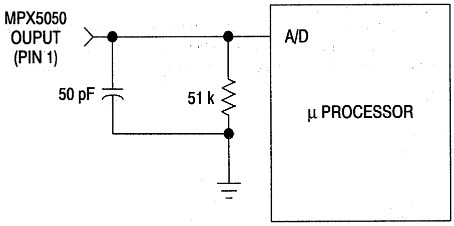


Figure 4. Typical Decoupling Filter for Sensor to Microprocessor Interface

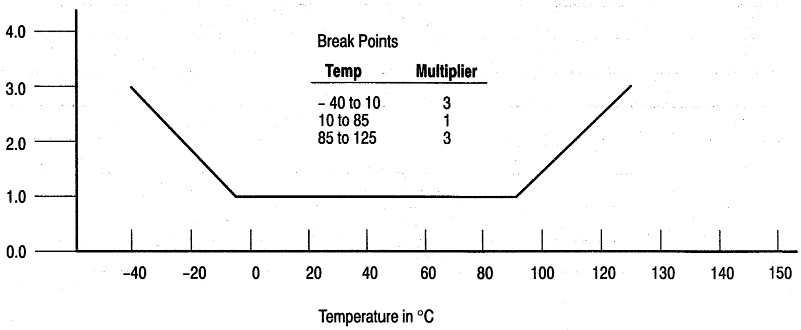
Figure 4 shows a typical decoupling circuit for interfacing the output of the MPX5050 to the A/D input of a microprocessor. Proper decoupling of the power supply is recommended.

Transfer Function

Nominal Transfer Value: $V_{out} = V_S (P \times 0.018 + 0.04)$
$+/- (\text{Pressure Error} \times \text{Temp. Mult.} \times 0.018 \times V_S)$
$V_S = 5.0\ V \pm 5\%$ P kPa

Temperature Error Multiplier

MPX5050 Series

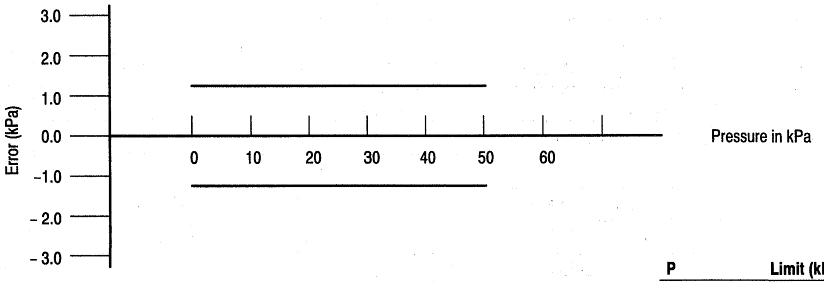


Break Points

Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band

Error Limits for Pressure



P	Limit (kPa)
20	+/- 1.25
30	+/- 1.25
40	+/- 1.25
50	+/- 1.25

PRESSURE / VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing fluoro silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number	Case Type	Pressure Side Identifier
MPX5050D	867	Stainless Steel Cap
MPX5050DP	867C	Side with Part Marking
MPX5050GP	867B	Side with Port Attached
MPX5050GVP	867D	Stainless Steel Cap
MPX5050GS	867E	Side with Port Attached
MPX5050GVS	867A	Stainless Steel Cap
MPX5050GSX	867F	Side with Port Attached
MPX5050GVSX	867G	Stainless Steel Cap

ORDERING INFORMATION

The MPX5050 pressure sensor is available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings that provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	867	MPX5050D	MPX5050D
Ported Elements	Differential Dual Ports	867C	MPX5050DP	MPX5050DP
	Gauge	867B	MPX5050GP	MPX5050GP
	Gauge Vacuum Port	867D	MPX5050GVP	MPX5050GVP
	Gauge, Axial	867E	MPX5050GS	MPX5050D
	Gauge Vacuum Axial	867A	MPX5050GVS	MPX5050D
	Gauge, Axial PC Mount	867F	MPX5050GSX	MPX5050D
	Gauge Vacuum Axial PC Mount	867G	MPX5050GVSX	MPX5050D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

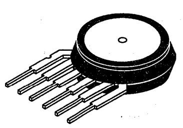
On-Chip Signal Conditioned, 0.2 V to 4.8 V Output, Temperature Compensated & Calibrated, Silicon Pressure Sensors

MPX5100 SERIES

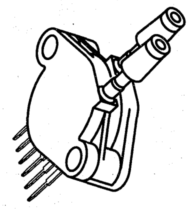
Motorola Preferred Devices

MPX5100D: 0–100 kPa
MPX5100A: 15–115 kPa
X-ducer™
SILICON
PRESSURE SENSORS

- 2.5% Total Accuracy Over 0–85°C
- Durable Epoxy Unibody Element
- Ideally Suited for Microprocessor or Microcontroller Based Systems
- Temperature Compensated Over – 40 to 125°C
- Patented Silicon Shear Stress Strain Gauge
- Easy to use Chip Carrier Package Options
- Available in Absolute, Differential & Gauge Configurations



BASIC CHIP
CARRIER ELEMENT
CASE 867
Style 1



DIFFERENTIAL
PORT OPTION
CASE 867C
Style 1

Pin Number					
1	2	3	4	5	6
V_{out}	Ground	V_S	N/C	N/C	N/C

NOTE: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

MAXIMUM RATINGS (T_C = 25°C unless otherwise noted)

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage (Note 5)	V_{Smax}	6.0	Vdc
Storage Temperature	T_{stg}	–50 to +150	°C
Operating Temperature	T_A	– 40 to 125	°C

The MPX5100 series piezoresistive transducer is a state-of-the-art, monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element X-ducer combines advanced micromachining techniques, thin film metallization and bipolar semiconductor processing to provide an accurate, high level analog output signal that is proportional to applied pressure.

Figure 1 shows a schematic of the internal circuitry integrated on-chip to provide temperature compensation, offset and span calibration and signal conditioning.

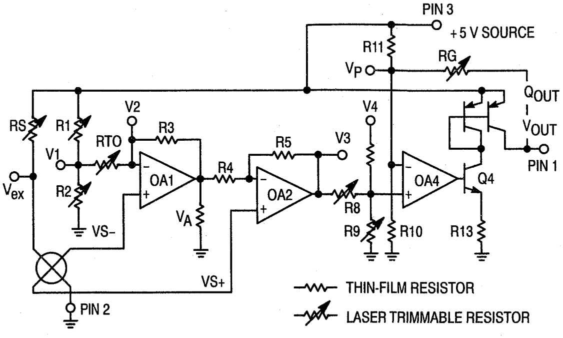


Figure 1. Fully Integrated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

REV 2 1/94

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range	MPX5100D MPX5100A	P_{OP}	0 15	— —	100 115	kPa
Supply Voltage		V_S	—	5.0	6.0	Vdc
Supply Current		I_o	—	8.0	15	mAdc
Full Scale Span		V_{FSS}	4.388	4.5	4.612	V
Sensitivity		ΔV/ΔP	—	45	—	mV/kPa
Accuracy		—	—	± 0.2	2.5	%FSS
Response Time (10% to 90%)		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mA
Stability (3)		—	—	± 0.5	—	%FS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight, Basic Element (Case 867)	—	—	4.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. For a 0 to 100 kPa pressure step change.
3. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, 0°C to +85°C.
   b. 1.5 million pressure cycles, 0 to 100 kPa.
4. Using best fit straight line method: typical linearity error is ± 0.1%.
5. Pressure sensor is designed to operate with +5 V ± 0.2 V supply. Supply voltages other than recommended, may result in additional signal error.
6. Accuracy consists of the following errors: Non-linearity, temperature and pressure hysteresis, offset and span stability, T_C Span and T_C Offset.
7. Operating characteristics based on positive pressure differential to the vacuum side (gauge/differential) or sealed reference (absolute).

ON-CHIP TEMPERATURE COMPENSATION, CALIBRATION and SIGNAL CONDITIONING

Figure 2 shows the output characteristics of the MPX5100 at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on full scale span and offset are shown in the operating characteristics.

This performance over temperature is achieved by integrating the shear-stress strain gauge, temperature compensation, calibration and signal conditioning circuitry onto a single monolithic chip.

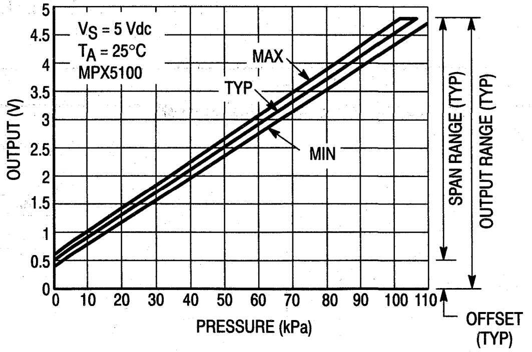
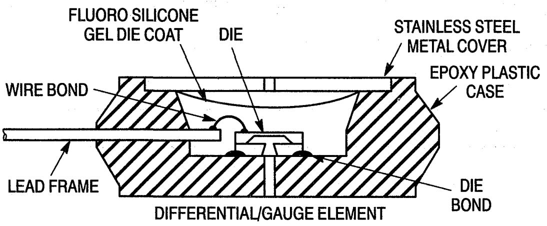


Figure 2. Output versus Pressure Differential



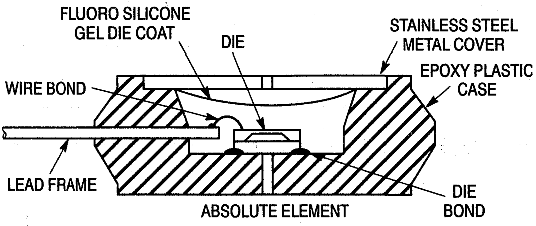


Figure 3. Cross Sectional Diagrams (Not to Scale)

Figure 3 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 867). A fluoro silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX5100A and MPX5100D series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

Figure 4 shows a typical decoupling circuit for interfacing the output of the MPX5100 to the A/D input of a microprocessor. Proper decoupling of the power supply is recommended.

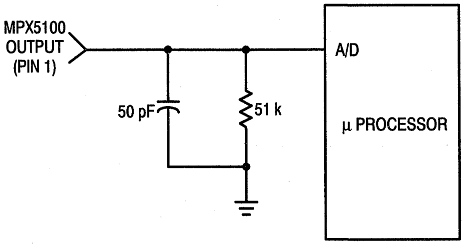


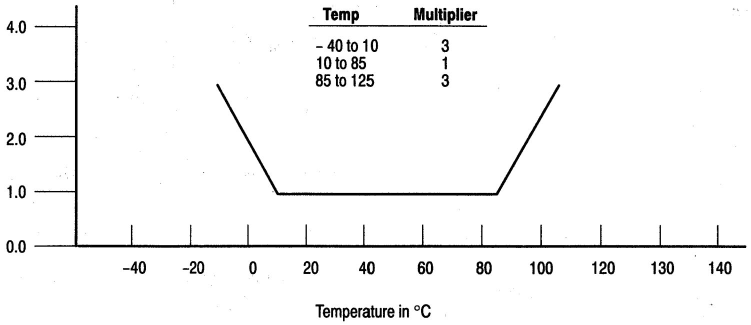
Figure 4. Typical Decoupling Filter for Sensor to Microprocessor Interface

Transfer Function (MPX5100D)

Nominal Transfer Value: $V_{out} = V_S \,(P \times 0.009 + 0.04)$
$+/- \,(\text{Pressure Error} \times \text{Temp. Mult.} \times 0.009 \times V_S)$
$V_S = 5.0\ \text{V} \pm 5\%$ P kPa

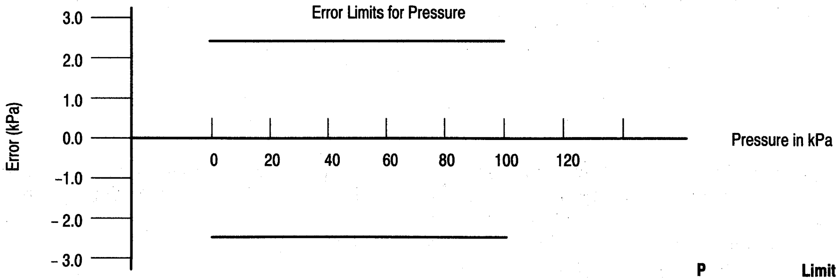
Temperature Error Multiplier

MPX5100D Series



Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band



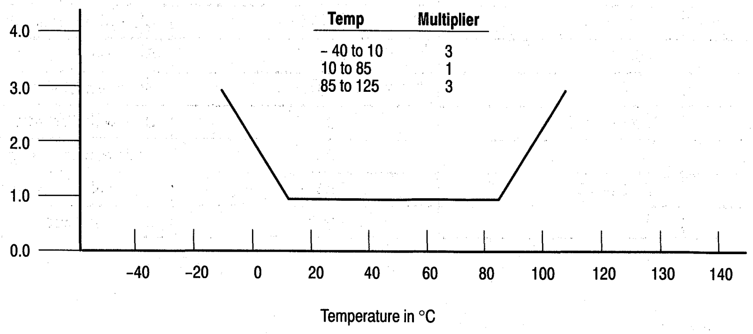
P	Limit (kPa)
20	+/- 2.5
40	+/- 2.5
80	+/- 2.5
100	+/- 2.5

Transfer Function (MPX5100A)

Nominal Transfer Value: $V_{out} = V_S$ (P x 0.009 – 0.095)
+/– (Pressure Error x Temp. Mult. x 0.009 x V_S)
$V_S = 5.0$ V ± 5% P kPa

Temperature Error Multiplier

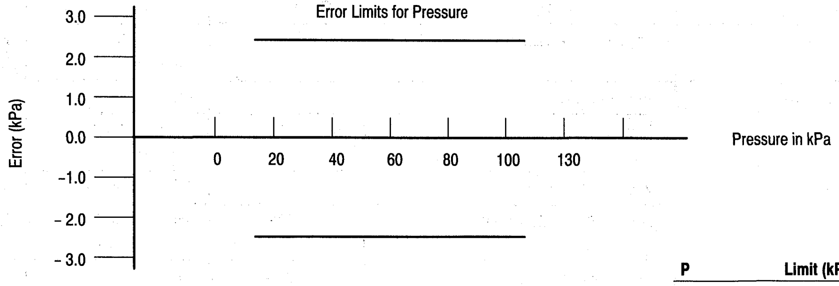
MPX5100A Series



Temp	Multiplier
- 40 to 10	3
10 to 85	1
85 to 125	3

Pressure Error Band

Error Limits for Pressure



P	Limit (kPa)
15	+/- 2.5
40	+/- 2.5
94	+/- 2.5
115	+/- 2.5

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing fluoro silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX5100A	MPX5100D	867	Stainless Steel Cap
MPX5100DP		867C	Side with Part Marking
MPX5100AP	MPX5100GP	867B	Side with Port Attached
MPX5100GVP		867D	Stainless Steel Cap
MPX5100AS	MPX5100GS	867E	Side with Port Attached
MPX5100GVS		867A	Stainless Steel Cap
MPX5100ASX	MPX5100GSX	867F	Side with Port Attached
MPX5100GVSX		867G	Stainless Steel Cap

ORDERING INFORMATION:

The MPX5100 pressure sensor is available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings that provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential, Absolute	867	MPX5100A MPX5100D	MPX5100A MPX5100D
Ported Elements	Differential Dual Ports	867C	MPX5100DP	MPX5100DP
	Gauge	867B	MPX5100AP MPX5100GP	MPX5100AP MPX5100GP
	Gauge Vacuum Port	867D	MPX5100GVP	MPX5100GVP
	Gauge, Absolute Axial	867E	MPX5100AS MPX5100GS	MPX5100A MPX5100D
	Gauge Vacuum Axial	867A	MPX5100GVS	MPX5100D
	Gauge, Absolute Axial PC Mount	867F	MPX5100ASX MPX5100GSX	MPX5100A MPX5100D
	Gauge Vacuum Axial PC Mount	867G	MPX5100GVSX	MPX5100D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX7050 SERIES

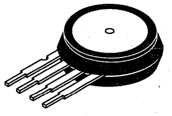
Motorola Preferred Devices

0–7.3 PSI
X-ducer™
HIGH Z_{in} SILICON
PRESSURE SENSORS

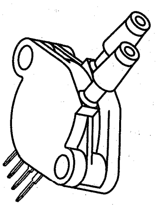
0 to 7.3 PSI High Z_{in}, On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

The new MPX7050 series pressure sensor incorporates all the innovative features of Motorola's MPX2000 series family including the patented, single piezoresistive strain gauge (X-ducer) and on-chip temperature compensation and calibration. In addition, the MPX7050 series has a high input impedance of typically 10 kΩ for those portable, low power and battery-operated applications. This device is suitable for those systems in which users must have a dependable, accurate pressure sensor that will not consume significant power. The MPX7050 series device is a logical and economical choice for applications such as portable medical instrumentation, and remote sensing systems with 4–20 mAmp transmission.

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Full Scale Span Calibrated to 40 mV (typical)
- Easy to Use Chip Carrier Package Options
- Available in Differential and Gauge Configurations
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	200	kPa
Burst Pressure	P_{burst}	500	kPa
Supply Voltage (Note 11)	V_{Smax}	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The output voltage of the differential element, differential ported and gauge ported sensors increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units. The output voltage of the gauge vacuum ported sensor increases with increasing vacuum (decreasing pressure) applied to the vacuum side with the pressure side at ambient. Figure 1 shows the schematic of the MPX7050 sensor circuit.

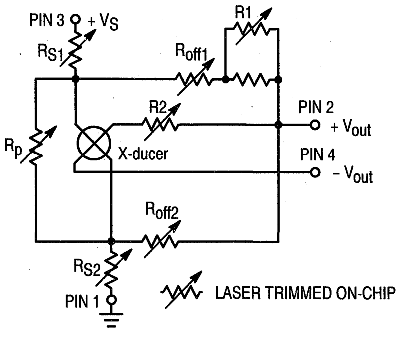


Figure 1. Temperature Compensated Pressure Sensor Schematic

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

REV 1 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	50	kPa
Supply Voltage(11)	V_S	—	10	16	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Full Scale Span(2), Figure 4	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset, Figure 4	V_{off}	–1.0	—	1.0	mV
Sensitivity	$\Delta V/\Delta P$	—	0.80	—	mV/kPa
Linearity(3) Figure 2	—	–0.25	—	0.25	%FSS
Pressure Hysteresis(4) (0 to 50 kPa)	—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 5	TCV_{FSS}	–1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 5	TCV_{off}	–1.0	—	1.0	mV
Input Impedance	Z_{in}	5000	10,000	15,000	Ω
Output Impedance	Z_{out}	2500	3100	6000	Ω
Response Time(8) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band, Figure 5	—	0	—	85	°C
Stability(9)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristics	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 50 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 50 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope of end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope of end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 50 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, –40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 50 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential).
11. Recommended voltage supply: 10 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +16 V may induce additional error due to device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off} + \text{sensitivity} \times P$ over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

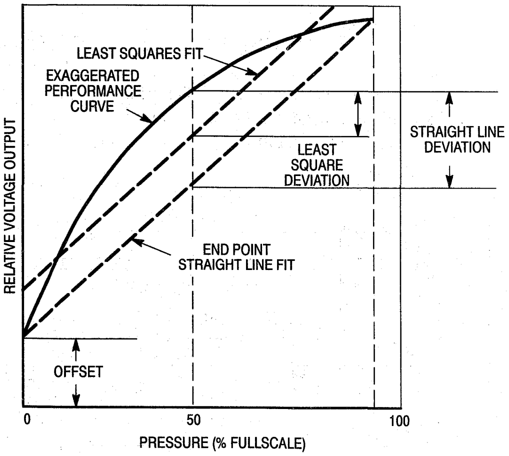


Figure 2. Linearity Specification Comparison

EXAMPLE INTERFACE CIRCUITS

Figure 3 is a block diagram of a typical 4–20 mA current loop system which illustrates a simple two chip solution to converting pressure to a 4–20 mA signal. This system is designed to be powered with a 24 Vdc supply. Pressure is converted to a differential voltage by the Motorola MPX7050 pressure sensor. The voltage signal proportional to the monitored pressure is then converted to the 4–20 mA current signal with the Burr-Brown XTR101 Precision Two-Wire Transmitter. The current signal can be monitored by a meter in a series with the supply or by measuring the voltage drop across R_L. A key advantage to this system is that circuit performance is not affected by a long transmission line.

For more information, please refer to Application Note AN1303. Call Motorola Literature Distribution at 1-800-441-2447 to order this Application Note.

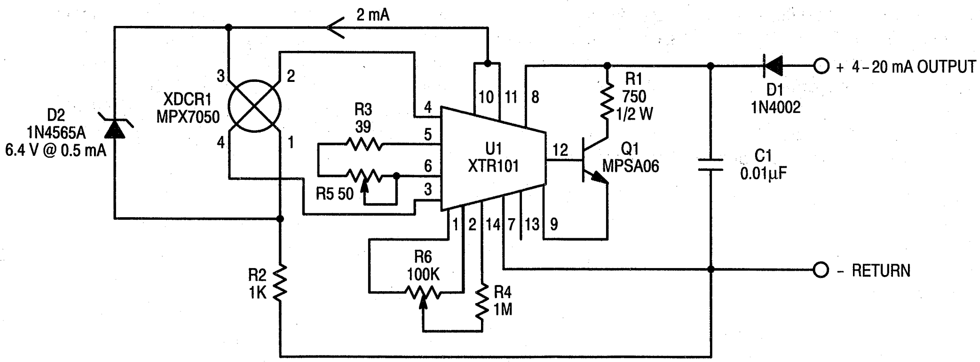


Figure 3. 4–20 mA Pressure Transducer

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 4 shows the output characteristics of the MPX7050 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 5.

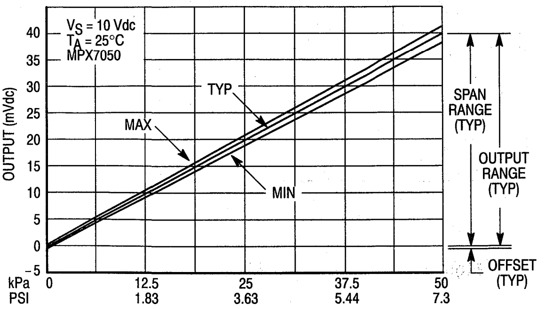


Figure 4. Output versus Pressure Differential

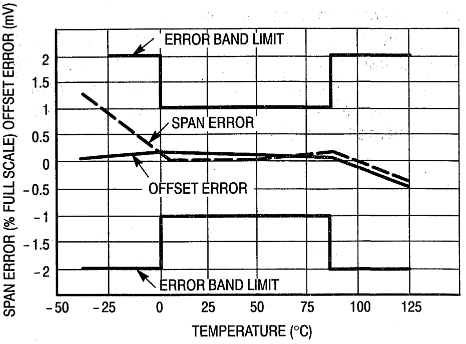


Figure 5. Temperature Error Band Limit and Typical Span and Offset Errors

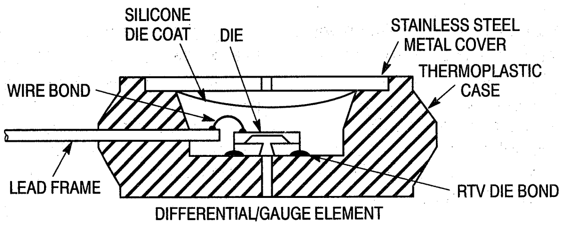


Figure 6. Cross-Sectional Diagram (not to scale)

Figure 6 illustrates the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX7050 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number	Case Type	Pressure Side Identifier
MPX7050D	344	Stainless Steel Cap
MPX7050DP	352	Side with Part Marking
MPX7050GP	350-03	Side with Port Attached
MPX7050GVP	350-04	Stainless Steel Cap
MPX7050GS	371-06	Side with Port Attached
MPX7050GVS	371-05	Stainless Steel Cap
MPX7050GSX	371C	Side with Port Attached
MPX7050GVSX	371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX7050 series pressure sensors are available in differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Differential	Case 344	MPX7050D	MPX7050D
Ported Elements	Differential, Dual Ported	Case 352	MPX7050DP	MPX7050DP
	Gauge	Case 350-03	MPX7050GP	MPX7050GP
	Gauge, Vacuum	Case 350-04	MPX7050GVP	MPX7050GVP
	Gauge, Stove Pipe	Case 371-06	MPX7050GS	MPX7050D
	Gauge, Vacuum Stove Pipe	Case 371-05	MPX7050GVS	MPX7050D
	Gauge, Axial	Case 371C	MPX7050GSX	MPX7050D
	Gauge, Vacuum Axial	Case 371D	MPX7050GVSX	MPX7050D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX7100
SERIES

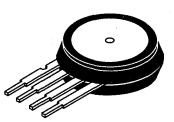
Motorola Preferred Devices

0 to 14.5 PSI High Z_{in}, On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

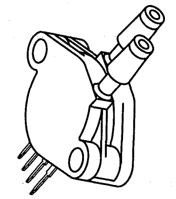
0–14.5 PSI
X-ducer™
HIGH Z_{in} SILICON
PRESSURE SENSORS

The new MPX7100 series pressure sensor incorporates all the innovative features of Motorola's MPX2000 series family including the patented, single piezoresistive strain gauge (X-ducer) and on-chip temperature compensation and calibration. In addition, the MPX7100 series has a high input impedance of typically 10 kΩ for those portable, low power and battery-operated applications. This device is suitable for those systems in which users must have a dependable, accurate pressure sensor that will not consume significant power. The MPX7100 series device is a logical and economical choice for applications such as portable medical instrumentation, remote sensing systems with 4–20 mAmp transmission and field barometers/altimeters.

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Full Scale Span Calibrated to 40 mV (typical)
- Easy to Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage



BASIC CHIP CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	1000	kPa
Supply Voltage (Note 11)	V_{Smax}	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure side. Vacuum down to the reference can be measured with the indicated accuracy.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units. Figure 1 shows the schematic diagram of the MPX7100 sensor circuit.

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

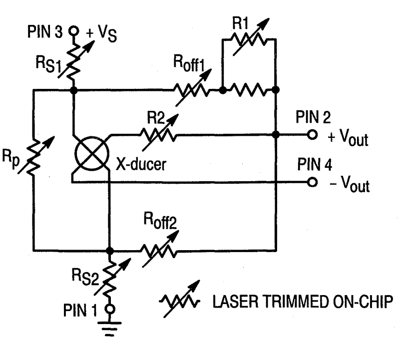


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 1 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range(1)	P_{OP}	0	—	100	kPa
Supply Voltage(11)	V_S	—	10	16	Vdc
Supply Current	I_o	—	1.0	—	mAdc
Full Scale Span(2), Figure 4 MPX7100A, MPX7100D	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset, Figure 4 MPX7100D	V_{off}	–1.0	—	1.0	mV
MPX7100A		–2.0	—	2.0	
Sensitivity	$\Delta V/\Delta P$	—	0.4	—	mV/kPa
Linearity(3)(11) Figure 2 MPX7100D	—	–0.25	—	0.25	%FSS
MPX7100A	—	–0.1	—	0.1	
Pressure Hysteresis(4) (0 to 100 kPa)	—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)	—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 5	TCV_{FSS}	–1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 5	TCV_{off}	–1.0	—	1.0	mV
Input Impedance	Z_{in}	5000	10,000	15,000	Ω
Output Impedance	Z_{out}	2500	3100	6000	Ω
Response Time(8) (10% to 90%)	t_R	—	1.0	—	ms
Temperature Error Band, Figure 5	—	0	—	85	°C
Stability(9)	—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 100 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 100 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 100 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
   a. 1000 temperature cycles, –40°C to +125°C.
   b. 1.5 million pressure cycles, 0 to 100 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).
11. Recommended voltage supply: 10 V ± 0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltages above +16 V may induce additional error due to device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

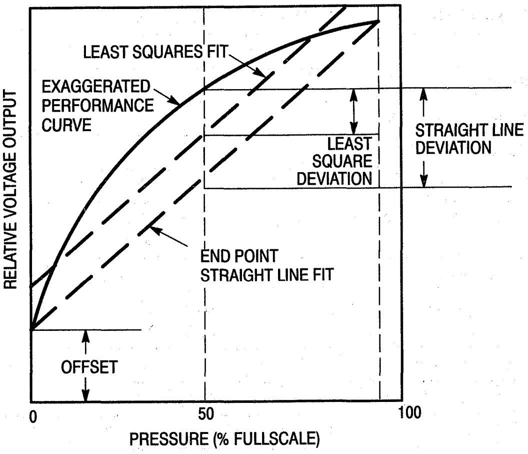


Figure 2. Linearity Specification Comparison

EXAMPLE INTERFACE CIRCUITS

Figure 3 is a block diagram of a typical 4–20 mA current loop system which illustrates a simple two chip solution to converting pressure to a 4–20 mA signal. This system is designed to be powered with a 24 Vdc supply. Pressure is converted to a differential voltage by the Motorola MPX7100 pressure sensor. The voltage signal proportional to the monitored pressure is then converted to the 4–20 mA current signal with the Burr-Brown XTR101 Precision Two-Wire Transmitter. The current signal can be monitored by a meter in a series with the supply or by measuring the voltage drop across R_L. A key advantage to this system is that circuit performance is not affected by a long transmission line.

For more information, please refer to Application Note AN1303, or call Motorola Literature Distribution at 1-800-441-2447 to order this Application Note.

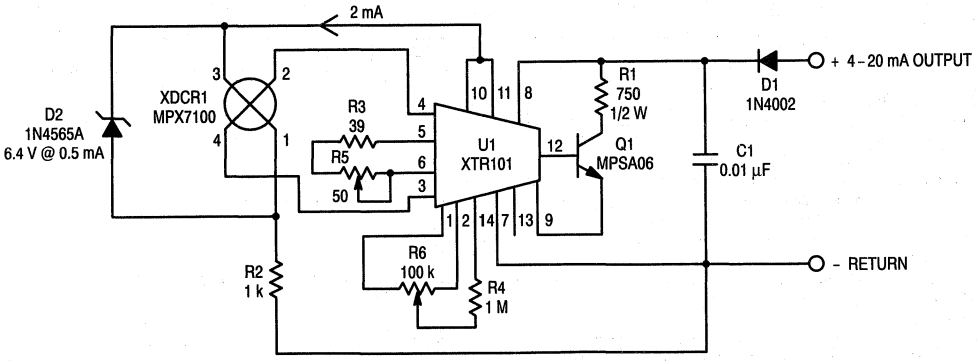


Figure 3. 4–20 mA Pressure Transducer

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 4 shows the output characteristics of the MPX7100 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 5.

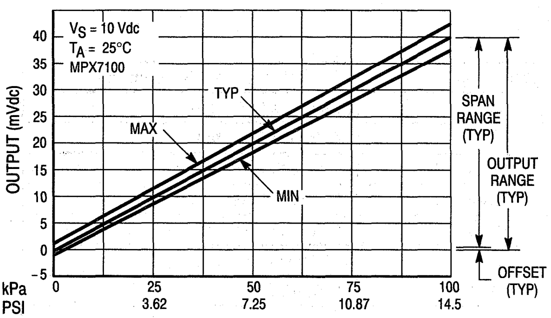


Figure 4. Output versus Pressure Differential

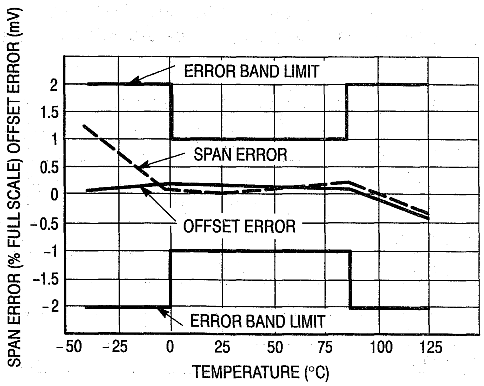


Figure 5. Temperature Error Band Limit and Typical Span and Offset Errors

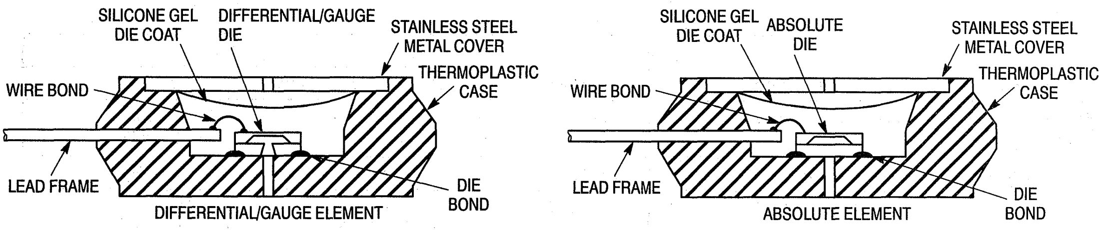


Figure 6. Cross-Sectional Diagrams (not to scale)

Figure 6 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX7100 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PRESSURE/VACUUM SIDE IDENTIFICATION TABLE

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX7100A	MPX7100D	344	Stainless Steel Cap
MPX7100DP		352	Side with Part Marking
MPX7100AP	MPX7100GP	350-03	Side with Port Attached
MPX7100GVP		350-04	Stainless Steel Cap
MPX7100AS	MPX7100GS	371-06	Side with Port Attached
MPX7100GVS		371-05	Stainless Steel Cap
MPX7100ASX	MPX7100GSX	371C	Side with Port Attached
MPX7100GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX7100 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

			MPX Series	
Device Type	Options	Case Type	Order Number	Device Marking
Basic Element	Absolute, Differential	Case 344	MPX7100A MPX7100D	MPX7100A MPX7100D
Ported Elements	Differential, Dual Ported	Case 352	MPX7100DP	MPX7100DP
	Absolute, Gauge	Case 350-03	MPX7100AP MPX7100GP	MPX7100AP MPX7100GP
	Gauge Vacuum	Case 350-04	MPX7100GVP	MPX7100GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX7100AS MPX7100GS	MPX7100A MPX7100D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX7100GVS	MPX7100D
	Absolute, Gauge Axial	Case 371C	MPX7100ASX MPX7100GSX	MPX7100A MPX7100D
	Gauge Vacuum Axial	Case 371D	MPX7100GVSX	MPX7100D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

MPX7200 SERIES

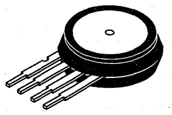
Motorola Preferred Devices

0 to 29 PSI High Z_{in}, On-Chip Temperature Compensated & Calibrated, Silicon Pressure Sensors

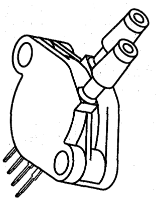
0–29 PSI
X-ducer™
HIGH Z_{in} SILICON
PRESSURE SENSORS

The new MPX7200 series pressure sensor incorporates all the innovative features of Motorola's MPX2000 series family including the patented, single piezoresistive strain gauge (X-ducer) and on-chip temperature compensation and calibration. In addition, the MPX7200 series has a high input impedance of typically 10 kΩ for those portable, low power and battery-operated applications. This device is suitable for those systems in which users must have a dependable, accurate pressure sensor that will not consume significant power. The MPX7200 series device is a logical and economical choice for applications such as portable medical instrumentation, remote sensing systems with 4–20 mAmp transmission and field barometers/altimeters.

- Temperature Compensated Over 0°C to +85°C
- Unique Silicon Shear Stress Strain Gauge
- Full Scale Span Calibrated to 40 mV (typical)
- Easy to Use Chip Carrier Package Options
- Available in Absolute, Differential and Gauge Configurations
- Ratiometric to Supply Voltage



BASIC CHIP
CARRIER ELEMENT
CASE 344
Style 1



DIFFERENTIAL
PORT OPTION
CASE 352
Style 1

Pin Number			
1	2	3	4
Ground	$+V_{out}$	V_S	$-V_{out}$

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Overpressure	P_{max}	400	kPa
Burst Pressure	P_{burst}	2000	kPa
Supply Voltage (Note 11)	$V_{S\ max}$	16	Vdc
Storage Temperature	T_{stg}	−50 to +150	°C
Operating Temperature	T_A	−40 to +125	°C

VOLTAGE OUTPUT versus APPLIED DIFFERENTIAL PRESSURE

The differential voltage output of the X-ducer is directly proportional to the differential pressure applied.

The absolute basic elements and absolute ported elements have a built in reference vacuum. The output voltage will decrease as vacuum, relative to ambient, is drawn on the pressure side. Vacuum down to the reference can be measured with the indicated accuracy.

The output voltage of the differential element, differential ported and gauge ported sensors, increases with increasing pressure applied to the pressure side relative to the vacuum side. Similarly, output voltage increases as increasing vacuum is applied to the vacuum side relative to the pressure side of the differential units. Figure 1 shows the schematic diagram of the MPX7200 sensor circuit.

X-ducer is a trademark of Motorola Inc.

Preferred devices are Motorola recommended choices for future use and best overall value.

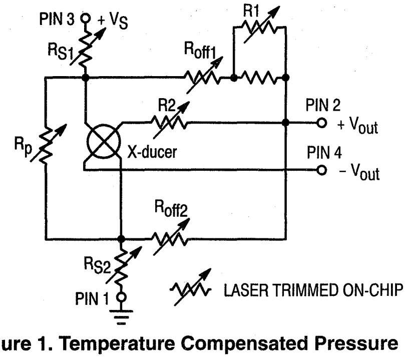


Figure 1. Temperature Compensated Pressure Sensor Schematic

REV 1 1/94

OPERATING CHARACTERISTICS (V_S = 10 Vdc, T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range(1)		P_{OP}	0	—	200	kPa
Supply Voltage(11)		V_S	—	10	16	Vdc
Supply Current		I_o	—	1.0	—	mAdc
Full Scale Span(2), Figure 4	MPX7200A, MPX7200D	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset, Figure 4	MPX7200D MPX7200A	V_{off}	–1.0 –2.0	— —	1.0 2.0	mV
Sensitivity		ΔV/ΔP	—	0.2	—	mV/kPa
Linearity(3)(11) Figure 2	MPX7200D MPX7200A	— —	–0.25 –0.1	— —	0.25 0.1	%FSS
Pressure Hysteresis(4) (0 to 200 kPa)		—	–0.1	—	0.1	%FSS
Temperature Hysteresis(5) (–40°C to +125°C)		—	—	±0.5	—	%FSS
Temperature Effect on Full Scale Span(6) (0 to +85°C), Figure 5		TCV_{FSS}	–1.0	—	1.0	%FSS
Temperature Effect on Offset(7) (0 to +85°C), Figure 5		TCV_{off}	–1.0	—	1.0	mV
Input Impedance		Z_{in}	5000	10,000	15,000	Ω
Output Impedance		Z_{out}	2500	3100	6000	Ω
Response Time(8) (10% to 90%)		t_R	—	1.0	—	ms
Temperature Error Band, Figure 5		—	0	—	85	°C
Stability(9)		—	—	±0.5	—	%FSS

MECHANICAL CHARACTERISTICS

Characteristic	Symbol	Min	Typ	Max	Unit
Weight (Basic Element Case 344)	—	—	2.0	—	Grams
Warm-Up	—	—	15	—	Sec
Cavity Volume	—	—	—	0.01	IN^3
Volumetric Displacement	—	—	—	0.001	IN^3
Common Mode Line Pressure	—	—	—	690	kPa

NOTES:

1. 1.0 kPa (kiloPascal) equals 0.145 PSI.
2. Measured at 10 Vdc excitation for 200 kPa pressure differential. V_{FSS} and FSS are like terms representing the algebraic difference between full scale output and zero pressure offset.
3. Maximum deviation from end-point straight line fit at 0 and 200 kPa.
4. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing pressures.
5. Maximum output difference at any pressure point within P_{OP} for increasing and decreasing temperatures in the range –40°C to +125°C.
6. Slope end-point straight line fit to full scale span at 0°C and +85°C relative to +25°C.
7. Slope end-point straight line fit to zero pressure offset at 0°C and +85°C relative to +25°C.
8. For a 0 to 200 kPa pressure step change.
9. Stability is defined as the maximum difference in output at any pressure within P_{OP} and temperature within +10°C to +85°C after:
    a. 1000 temperature cycles, –40°C to +125°C.
    b. 1.5 million pressure cycles, 0 to 200 kPa.
10. Operating characteristics based on positive pressure differential relative to the vacuum side (gauge/differential) or sealed reference (absolute).
11. Recommended voltage supply: 10 V ±0.2 V, regulated. Sensor output is ratiometric to the voltage supply. Supply voltage above +16 V may induce additional error due to device self-heating.

LINEARITY

Linearity refers to how well a transducer's output follows the equation: $V_{out} = V_{off}$ + sensitivity x P over the operating pressure range. There are two basic methods for calculating nonlinearity: (1) end point straight line fit (see Figure 2) or (2) a least squares best line fit. While a least squares fit gives the "best case" linearity error (lower numerical value), the calculations required are burdensome.

Conversely, an end point fit will give the "worst case" error (often more desirable in error budget calculations) and the calculations are more straightforward for the user. Motorola's specified pressure sensor linearities are based on the end point straight line method measured at the midrange pressure.

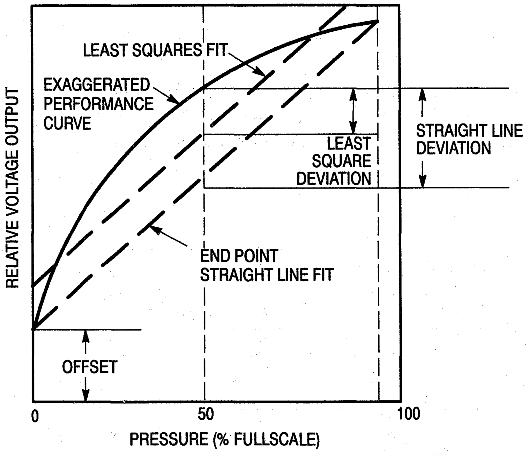
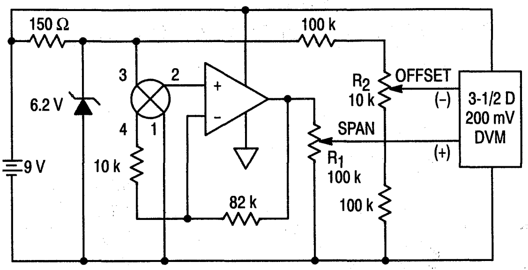


Figure 2. Linearity Specification Comparison

EXAMPLE CIRCUITS

The MPX7000 series, high Z_{in} devices with on-chip compensation and calibration circuitry, are ideal for users with applications requiring low current draw. Figure 3 shows an example of a battery driven manometer circuit employing an MPX7200D (29 psi).



Full-scale output equals 200 mV; use R1 to scale conversion units, R2 to adjust Offset.

Figure 3. Battery Operated, DVM Compatible Manometer

ON-CHIP TEMPERATURE COMPENSATION and CALIBRATION

Figure 4 shows the output characteristics of the MPX7200 series at 25°C. The output is directly proportional to the differential pressure and is essentially a straight line.

The effects of temperature on Full Scale Span and Offset are very small and are shown under Operating Characteristics and in Figure 5.

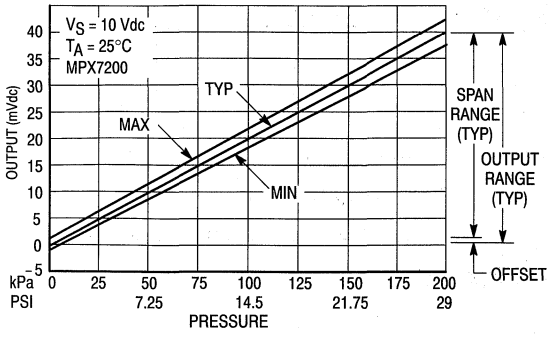


Figure 4. Output versus Pressure Differential

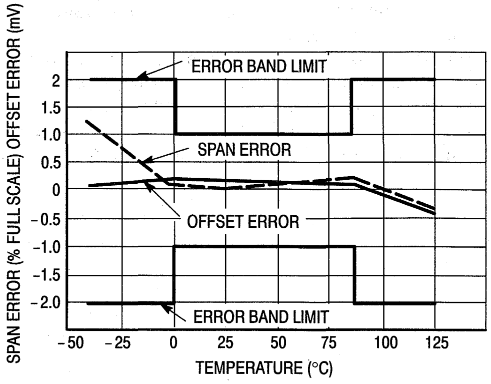


Figure 5. Temperature Error Band Limit and Typical Span and Offset Errors

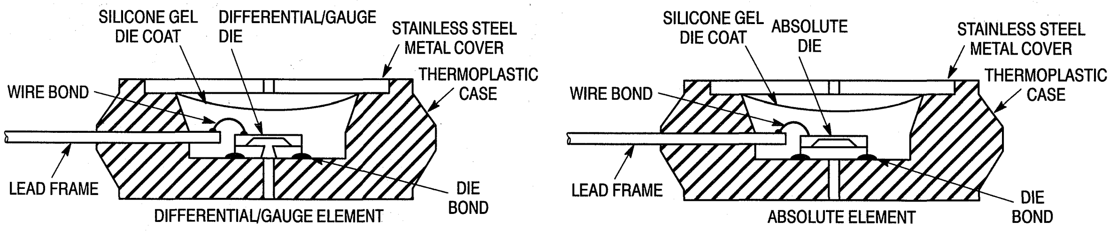


Figure 6. Cross-Sectional Diagrams (not to scale)

Figure 6 illustrates the absolute sensing configuration (right) and the differential or gauge configuration in the basic chip carrier (Case 344). A silicone gel isolates the die surface and wire bonds from harsh environments, while allowing the pressure signal to be transmitted to the silicon diaphragm.

The MPX7200 series pressure sensor operating characteristics and internal reliability and qualification tests are based on use of dry air as the pressure media. Media other than dry air may have adverse effects on sensor performance and long term stability. Contact the factory for information regarding media compatibility in your application.

NOTE: Stainless steel cap is not installed on devices with a port attached on the pressure (gel) side.

PORT DESIGNATION

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum (back) side. The Pressure side is the side containing the silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e., top side pressure is greater than or equal to back side pressure).

The Pressure side may be identified by using the table below:

Part Number		Case Type	Pressure Side Identifier
MPX7200A	MPX7200D	344	Stainless Steel Cap
MPX7200DP		352	Side with Part Marking
MPX7200AP	MPX7200GP	350-03	Side with Port Attached
MPX7200GVP		350-04	Stainless Steel Cap
MPX7200AS	MPX7200GS	371-06	Side with Port Attached
MPX7200GVS		371-05	Stainless Steel Cap
MPX7200ASX	MPX7200GSX	371C	Side with Port Attached
MPX7200GVSX		371D	Stainless Steel Cap

ORDERING INFORMATION:

MPX7200 series pressure sensors are available in absolute, differential and gauge configurations. Devices are available in the basic element package or with pressure port fittings which provide printed circuit board mounting ease and barbed hose pressure connections.

Device Type	Options	Case Type	MPX Series	
			Order Number	Device Marking
Basic Element	Absolute, Differential	Case 344	MPX7200A MPX7200D	MPX7200A MPX7200D
Ported Elements	Differential	Case 352	MPX7200DP	MPX7200DP
	Absolute, Gauge	Case 350-03	MPX7200AP MPX7200GP	MPX7200AP MPX7200GP
	Gauge Vacuum	Case 350-04	MPX7200GVP	MPX7200GVP
	Absolute, Gauge Stove Pipe	Case 371-06	MPX7200AS MPX7200GS	MPX7200A MPX7200D
	Gauge Vacuum Stove Pipe	Case 371-05	MPX7200GVS	MPX7200D
	Absolute, Gauge Axial	Case 371C	MPX7200ASX MPX7200GSX	MPX7200A MPX7200D
	Gauge Vacuum Axial	Case 371D	MPX7200GVSX	MPX7200D

MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

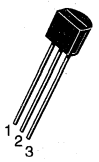
Silicon Temperature Sensors

MTS102
MTS103
MTS105

Designed for use in temperature sensing applications in automotive, consumer and industrial products requiring low cost and high accuracy.

- Precise Temperature Accuracy Over Extreme Temperature MTS102: ± 2°C from – 40°C to +150°C
- Precise Temperature Coefficient
- Fast Thermal Time Constant
  - 3 Seconds — Liquid
  - 8 Seconds — Air
- Linear V_{BE} versus Temperature Curve Relationship
- Other Packages Available

SILICON
TEMPERATURE
SENSORS



CASE 29-04, STYLE 1
TO-226AA
(TO-92)

Pin Number		
1	**2**	**3**
Emitter	Base	Collector

MAXIMUM RATINGS

Rating	Symbol	Value	Unit
Emitter-Base Voltage	V_{EB}	4.0	Vdc
Collector Current — Continuous*	I_C	100	mAdc
Operating and Storage Junction Temperature Range	T_J, T_{stg}	–55 to +150	°C

* See Note 5 on following page.

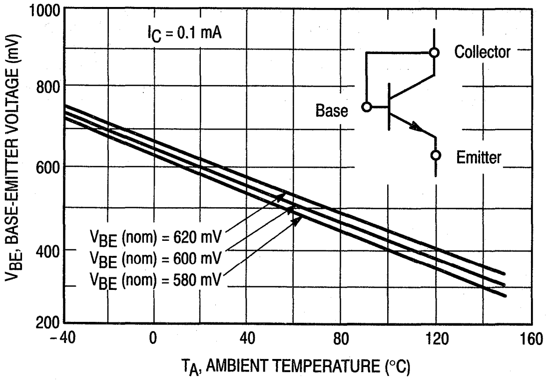


Figure 1. Base-Emitter Voltage versus Ambient Temperature

ELECTRICAL CHARACTERISTICS (T_A = 25°C unless otherwise noted)

Characteristic		Symbol	Min	Typ	Max	Unit
Supply Voltage		V_S	−0.2	—	35	Vdc
Output Voltage		V_{out}	−1.0	—	6.0	Vdc
Output Current		I_O	—	—	10	mAdc
Emitter-Base Breakdown Voltage (I_E = 100 μAdc, I_C = 0)		$V_{(BR)EBO}$	4.0	—	—	Vdc
Base-Emitter Voltage (I_C = 0.1 mA)		V_{BE}	580	595	620	mV
Base-Emitter Voltage Matching, Note 1 (I_C = 0.1 mA, T_A = 25°C ±0.05°C)	MTS102 MTS103 MTS105	ΔV_{BE}	−3.0 −4.0 −7.0	— — —	3.0 4.0 7.0	mV
Temperature Matching Accuracy, Note 2 (T1 = 40°C, T2= +150°C, T_A = 25°C ± 0.05°C)	MTS102 MTS103 MTS105	ΔT	−3.0 −3.0 −5.0	— — —	3.0 3.0 5.0	°C
Temperature Coefficient, Notes 3 and 4 (V_{BE} = 595 mV, I_C = 0.1 mA)		T_C	−2.28	−2.265	−2.26	mV/°C
Thermal Time Constant Liquid Flowing Air		τ_{TH}	 — —	 3.0 8.0	 — —	s
Dependence of T_C on V_{BE} @ 25°C (Note 4, Figure 3)		$\Delta T_C / \Delta V_{BE}$	—	0.0033	—	mV/°C mV

THERMAL CHARACTERISTICS

Thermal Resistance, Junction to Ambient	$R_{\theta JA}$	—	—	200	°C/W

MECHANICAL CHARACTERISTICS

Weight	—	—	87	—	Grams

NOTES:

1. All devices within any one group or package will be matched for V_{BE} to the tolerance identified in the electrical characteristics table. Each device will be labeled with the mean V_{BE} value for that group.
2. All devices within an individual group, as described in Note 1, will track within the specified temperature accuracy. This includes variations in T_C, V_{BE}, and nonlinearity in the range –40 to +150°C. Nonlinearity is typically less than ± 1°C in this range. (See Figure 4)
3. The T_C as defined by a least-square linear regression for V_{BE} versus temperature over the range −40 to +150°C for a nominal V_{BE} of 595 mV at 25°C. For other nominal V_{BE} values the value of the T_C must be adjusted for the dependence of the T_C on V_{BE} (see Note 4).
4. For nominal VBE at 25°C other than 595 mV, the T_C must be corrected using the equation $T_C = -2.265 + 0.003\ (V_{BE} - 595)$ where V_{BE} is in mV and the T_C is in mV/°C. The accuracy of this T_C is typically ±0.01 mV/°C.
5. For maximum temperature accuracy, I_C should not exceed 2 mA. (See Figure 2)

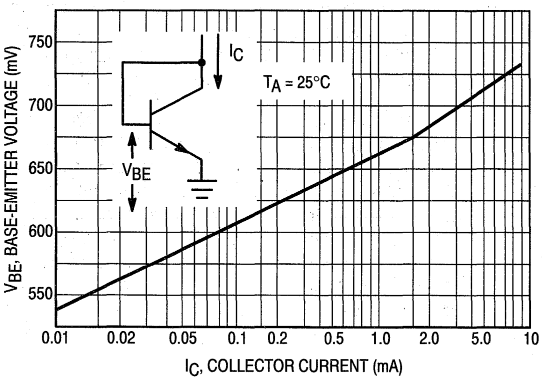


Figure 2. Base-Emitter Voltage versus Collector-Emitter Current

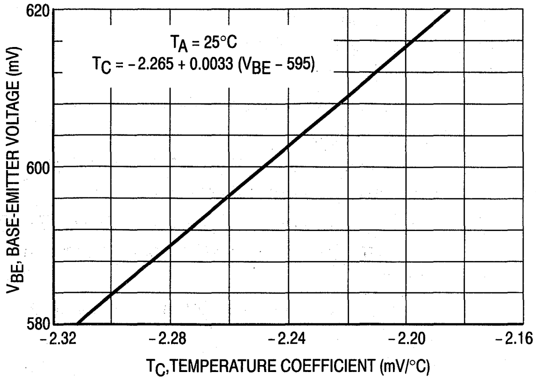


Figure 3. Temperature Coefficient versus Base-Emitter Voltage

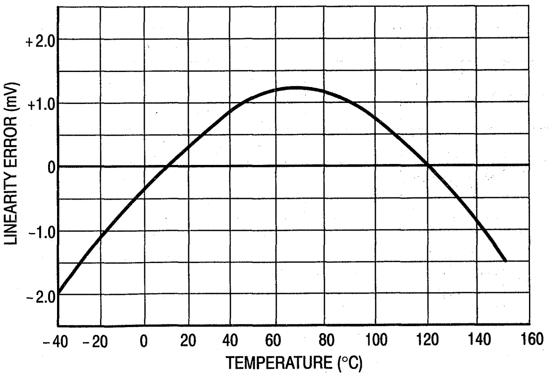


Figure 4. Linearity Error versus Temperature

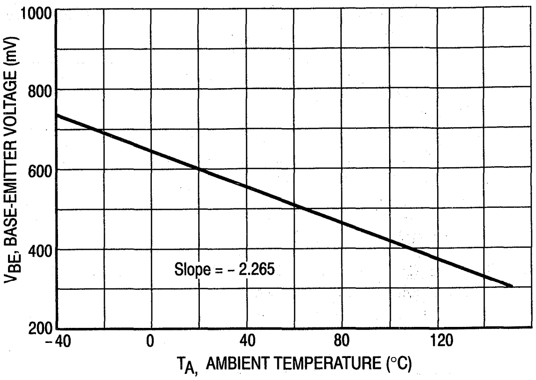
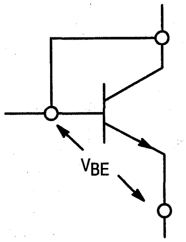


Figure 5. V_{BE} versus Ambient Temperature

APPLICATIONS INFORMATION

The base and collector leads of the device should be connected together in the operating circuit (pins 2 and 3). They are not internally connected.



The following example describes how to determine the V_{BE} versus temperature relationship for a typical shipment of various V_{BE} groups.

EXAMPLE:

Given — Customer receives a shipment of MTS102 devices. The shipment consists of three groups of different nominal V_{BE} values.

Group 1: V_{BE} (nom) = 595 mV
Group 2: V_{BE} (nom) = 580 mV
Group 3: V_{BE} (nom) = 620 mV

Find — V_{BE} versus temperature Relationship.

1. Determine value of T_C:
   a. If V_{BE} (nom) = 595 mV, $T_C = -2.265$ mV/°C from the Electrical Characteristics table.
   b. If V_{BE} (nom) is less than or greater than 595 mV determine T_C from the relationship described in Note 4.

   $T_C = -2.265 + 0.0033\,(V_{BE} - 595)$ or see Figure 3.

2. Determine the V_{BE} value at extremes, – 40°C and +150°C:

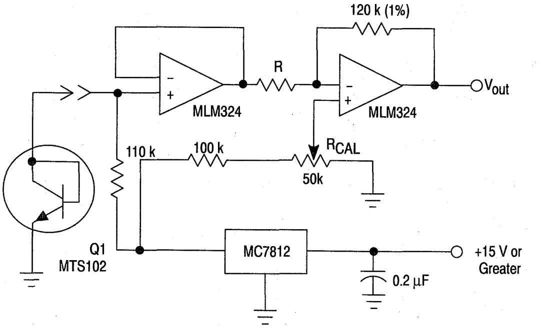
   $V_{BE}(T_A) = V_{BE}(25°C) + (T_C)(T_A - 25°C)$ where $V_{BE}(T_A)$ = value of V_{BE} at desired temperature.

3. Plot the V_{BE} versus T_A curve using two V_{BE} values: V_{BE} (– 40°C), V_{BE}(25°C), or V_{BE}(+150°C)

4. Given any measured V_{BE}, the value of T_A (to the accuracy value specified: MTS102 – ± 2°C, MTS103 – ± 35°C, MTS105 – ± 5°C) can be read from Figure 5 or calculated from equation 2.

5. Higher temperature accuracies can be achieved if the collector current, I_C, is controlled to react in accordance with and to compensate for the linearity error. Using this concept, practical circuits have been built in which allow these sensors to yield accuracies within ± 0.1°C and ± 0.01°C.
   Reference: "Transistors -- A Hot Tip for Accurate Temperature Sensing", Pat O'Neil and Carl Derrington, *Electronics 1979.*

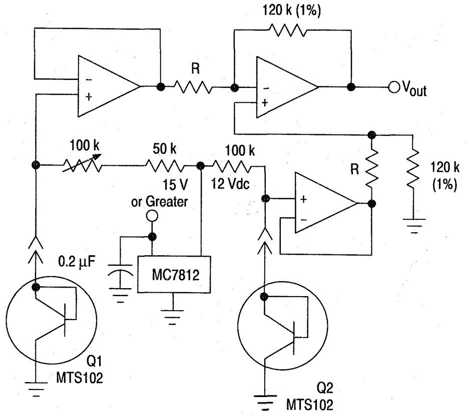
TYPICAL CIRCUITS



NOTE: With Q1 at a known temperature, adjust R_{CAL} to set output voltage to V_{out} = TEMP x 10 mV, Output of MTS102, 3, 5 is then converted to V_{out} = 10 mV/° – (°F, °C or °K)

R = 27 kΩ (1%) for °C or °K

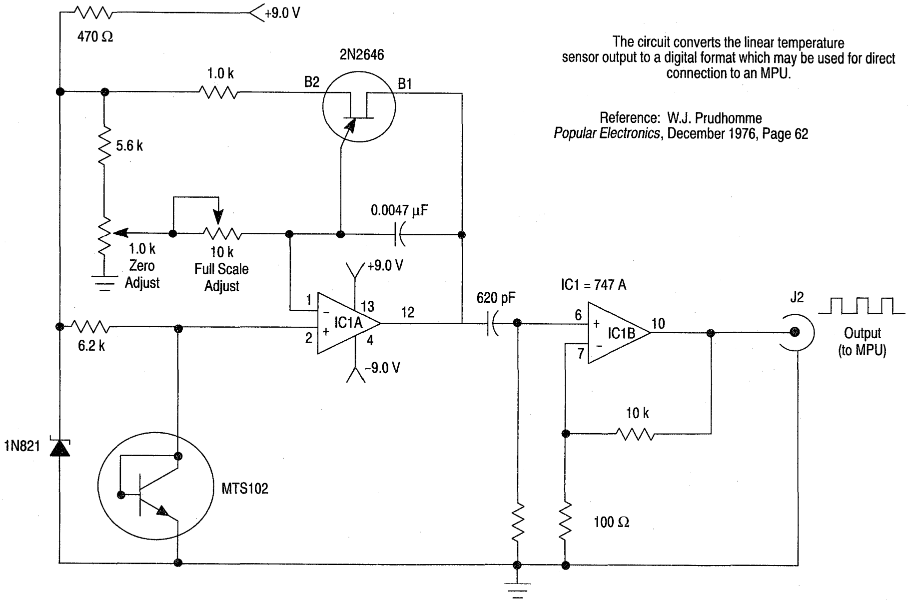
Figure 6. Absolute Temperature Measurement



NOTE: With Q1 and Q2 at identical temperature, adjust R_{CAL} for V_{out} = 0.000 V

R = 15 kΩ (1%) for °F

Figure 7. Differential Temperature Measurement 0 To 150°C

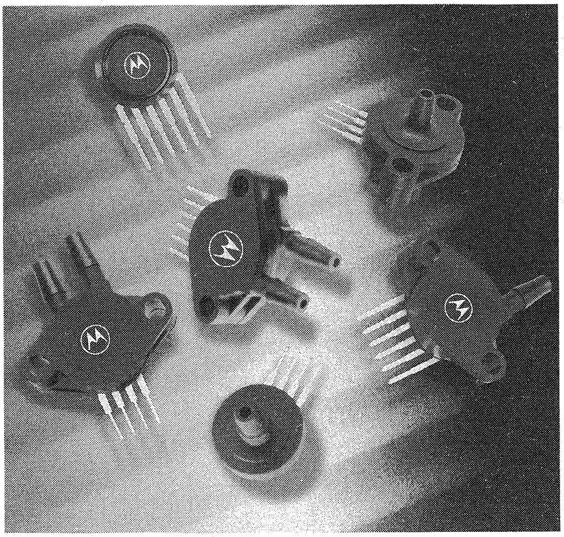


The circuit converts the linear temperature sensor output to a digital format which may be used for direct connection to an MPU.

Reference: W.J. Prudhomme
Popular Electronics, December 1976, Page 62

All resistors are 10% 1/4 watt except 6.2 k which is 5% 1/4 watt.

Figure 8. Temperature Sensor to Digital MPU Circuit



Section Four

Quality and Reliability

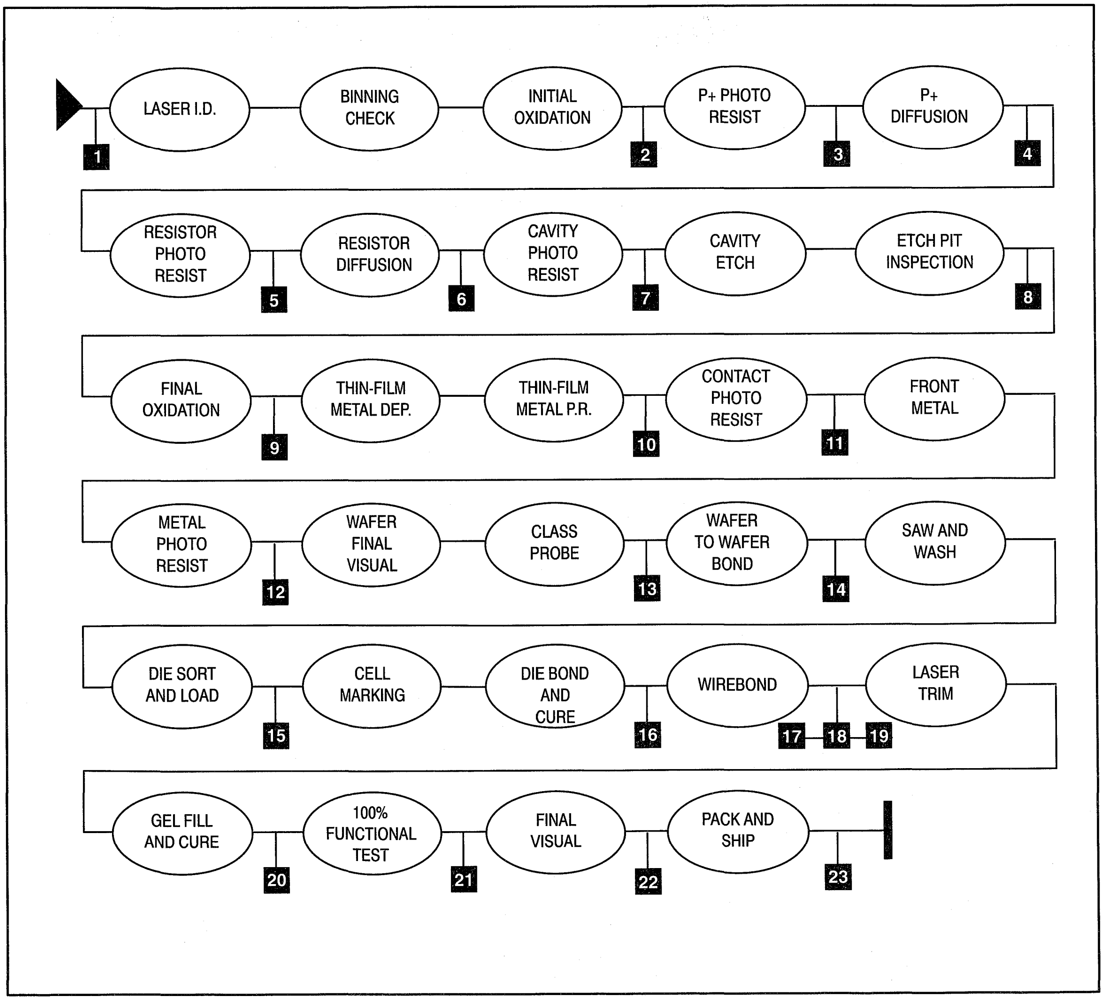
Quality and Reliability — Overview

A Major Objective of the Production Cycle

From rigid incoming inspection of piece parts and materials to stringent outgoing quality verification, the Motorola assembly and process flow is encompassed by an elaborate system of test and inspection stations; stations to ensure a step-by-step adherence to prescribed procedure. This produces the high level of quality for which Motorola is known . . . from start to finish.

As illustrated in the process flow overview, every major manufacturing step is followed by an appropriate in-process QA inspection to insure product conformance to specification. In addition, Statistical Process Control (S.P.C.) techniques are utilized on all critical processes to insure processing equipment is capable of producing the product to the target specification while minimizing the variability. Quality control in wafer processing, assembly, and final test impart Motorola sensor products with a level of reliability that easily exceeds almost all industrial, consumer, and military requirements. It is this built-in quality that insures failure-free shipments of Motorola sensor products.

Compensated Sensor Flow Chart



Reliability Issues for Silicon Pressure Sensors

by Theresa Maudie and Bob Tucker, Signal Products Division, Communications, Power and Signal Technologies Group

ABSTRACT

Reliability testing for silicon pressure sensors is of greater importance than ever before with the dramatic increase in sensor usage. This growth is seen in applications replacing mechanical systems, as well as new designs. Across all market segments, the expectation for the highest reliability exists. While sensor demand has grown across all of these segments, the substantial increase of sensing applications in the automotive arena is driving the need for improved reliability and test capability. Unfortunately, sensor reliability is a subject that has not been widely discussed or publicized. The purpose of this paper is to take a closer look at these reliability issues for silicon pressure sensors.

INTRODUCTION

Discussing reliability as it pertains to semiconductor electronics is certainly not a new subject. However, when developing new technologies like sensors how reliability testing will be performed is not always obvious. Pressure sensors are an intriguing dilemma. Since they are electromechanical devices, different types of stresses should be considered to insure the different elements are exercised as they would be in an actual application. In addition, the very different package outlines relative to other standard semiconductor packages require special fixtures and test set-ups. However, as the sensor marketplace continues to grow, reliability testing becomes more important than ever to insure that products being used across all market segments will meet standard reliability lifetime expectations.

RELIABILITY DEFINITION

Reliability is (1) the probability of a product performing its intended function over its intended lifetime and under the operating conditions encountered. The four key elements of the definition are probability, performance, lifetime, and operating conditions. Probability implies that the reliability lifetime estimates will be made based on statistical techniques where samples are tested to predict the lifetime of the manufactured products. Performance is a key in that the sample predicts the performance of the product at a given point in time but the variability in manufacturing must be controlled so that all devices perform to the same functional level. Lifetime is the period of time over which the product is intended to perform. This lifetime could be as small as one week in the case of a disposable blood pressure transducer or as long as 30 years as often specified for communication applications. Environment is the area that also plays a key role since the operating conditions of the product can greatly influence the reliability of the product.

Environmental factors that can be seen during the lifetime of any semiconductor product include temperature, humidity, electric field, magnetic field, current density, pressure differential, vibration, and/or a chemical interaction. Reliability testing is generally formulated to take into account all of these potential factors either individually or in multiple combinations. Once the testing has been completed predictions can be made for the intended product customer base.

If a failure would be detected during reliability testing, the cause of the failure can be categorized into one of the following: design, manufacturing, materials, or user. The possible impact on the improvements that may need to be made for a product is influenced by the stage of product development. If a product undergoes reliability testing early in its development phase, the corrective action process can generally occur in an expedient manner and at minimum cost. This would be true whether the cause of failure was attributed to the design, manufacturing, or materials. If a reliability failure is detected once the product is in full production, changes can be very difficult to make and generally are very costly. This scenario would sometimes result in a total redesign.

The potential cause for a reliability failure can also be user induced. This is generally the area that the least information is known, especially for a commodity type manufacturer that achieves sales through a global distribution network. It is the task of the reliability engineer to best anticipate the multitudes of environments that a particular product might see, and determine the robustness of the product by measuring the reliability lifetime parameters. The areas of design, manufacturing, and materials are generally well understood by the reliability engineer, but without the correct environmental usage, customer satisfaction can suffer from lack of optimization.

RELIABILITY STATISTICS

Without standardization of the semiconductor sensor standards the end customer is placed in a situation of possible jeopardy. If non-standard reliability data is generated and published by manufacturers, the information can be perplexing to disseminate and compare. Reliability lifetime statistics can be confusing for the novice user of the information, "let the buyer beware".

The reporting of reliability statistics is generally in terms of failure rate, measured in FITs, or failure rate for one billion device hours. In most cases, the underlying assumption used in reporting either the failure rate or the MTBF is that the failures occurring during the reliability test follow an exponential life distribution. The inverse of the failure rate is the MTBF, or mean time between failure. The details on the various life distributions will not be explored here but the key concern about the exponential distribution is that the failure rate over time is constant. Other life distributions, such as the lognormal or Weibull can take on different failure rates over time, in particular, both distributions can represent a wear out or increasing failure rate that might be seen on a product reaching the limitations on its lifetime or for certain types of failure mechanisms.

The time duration use for the prediction of most reliability statistics is of relatively short duration with respect to the product's lifetime ability and failures are usually not observed. When a test is terminated after a set number of hours is achieved, or time censored, and no failures are observed, the failure rate can be estimated by use of the chi-square distribution which relates observed and expected frequencies of an event to established confidence intervals (4). The relationship between failure rate and the chi-square distribution is as follows:

$$\lambda_{L1} = \frac{\chi 2\ (\alpha,\ \text{d.f.})}{2t}$$

Where:

λ = failure rate
L1 = lower one side confidence limit
χ^2 = chi-square function
α = risk, (1 – confidence level)
d.f. = degrees of freedom = 2r + 2
r = number of failures
t = device hours

Chi-square values for 60% and 90% confidence intervals for up to 12 failures are shown in Table 1.

As indicated by the table, when no failures occur, an estimate for the chi-square distribution interval is obtainable. This interval estimate can then be used to solve for the failure rate, as shown in the equation above. If no failures occur, the failure rate estimate is solely a function of the accumulated device hours. This estimate can vary dramatically as additional device hours are accumulated.

As a means of showing the influence of device hours with no failures on the failure rate value, a graphical representation of cumulative device hours versus the failure rate measured in FITs is shown in Figure 1.

A descriptive example between two potential vendors best serves to demonstrate the point. If vendor A is introducing a new product and they have put a total of 1,000 parts on a high temperature storage test for 500 hours each, their corresponding cumulative device hours would be 500,000 device hours. Vendor B has been in the business for several years on the same product and has tested a total of 500,000 parts for 10 hours each to the same conditions as part of an in-line burn-in test for a total of 5,000,000 device hours. The corresponding failure rate for a 60% confidence level for vendor A would be 1,833 FITs, vendor B would have a FIT rate of 183 FITs.

Table 1. Chi-Square Table

Chi-Square Distribution Function			
60% Confidence Level		90% Confidence Level	
No. Fails	χ^2 Quantity	No. Fails	χ^2 Quantity
0	1.833	0	4.605
1	4.045	1	7.779
2	6.211	2	10.645
3	8.351	3	13.362
4	10.473	4	15.987
5	12.584	5	18.549
6	14.685	6	21.064
7	16.780	7	23.542
8	18.868	8	25.989
9	20.951	9	28.412
10	23.031	10	30.813
11	25.106	11	33.196
12	27.179	12	35.563

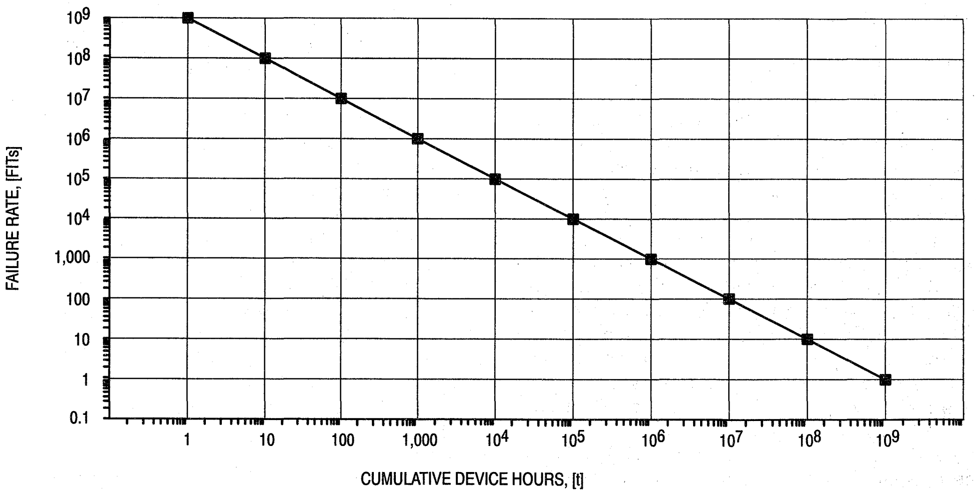


Figure 5. Depiction of the influence on the cumulative device hours with no failures and the Failure Rate as measured in FITs.

One could thus imply that the reliability performance indicates that vendor B has an order of magnitude improvement in performance over vendor A with neither one seeing an occurrence of failure during their performance.

The incorrect assumption of a constant failure rate over time can potentially result in a less reliable device being designed into an application. The reliability testing assumptions and test methodology between the various vendors needs to be critiqued to insure a full understanding of the product performance over the intended lifetime, especially in the case of a new product.

INDUSTRY RELIABILITY STANDARDS

Reliability standards for large market segments are often developed by "cross-corporation" committees that evaluate the requirements for the particular application of interest. It is the role of these committees to generate documents intended as guides for technical personnel of the end users and suppliers, to assist with the following functions: specifying, developing, demonstrating, calibrating, and testing the performance characteristics for the specific application.

One such committee which has developed a standard for a particular application is the Blood Pressure Monitoring Committee of the Association for the Advancement of Medical Instrumentation (AAMI) (2). Their document, the "American National Standard for Interchangeability and Performance of Resistive Bridge Type Blood Pressure Transducers", has an objective to provide performance requirements, test methodology, and terminology that will help insure that safe, accurate blood pressure transducers are supplied to the marketplace.

In the automotive arena, the Society of Automotive Engineers (SAE) develops standards for various pressure sensor applications such as SAE document J1346, "Guide to Manifold Absolute Pressure Transducer Representative Test Method" (3).

While these two very distinct groups have successfully developed the requirements for their solid-state silicon pressure sensor needs, no real standard has been set for the general industrial marketplace to insure products being offered have been tested to insure reliability under industrial conditions. Motorola has utilized MIL-STD-750 as a reference document in establishing reliability testing practices for the silicon pressure sensor, but the differences in the technology between a discrete semiconductor and a silicon pressure sensor varies dramatically. The additional tests that are utilized in semiconductor sensor reliability testing are based on the worst case operational conditions that the device might encounter in actual usage.

ESTABLISHED SENSOR TESTING

Motorola has established semiconductor sensor reliability testing based on exercising to detect failures by the presence of the environmental stress. Potential failure modes and mechanisms are developed by allowing tests to run beyond normal test times, thus stressing to destruction. The typical reliability test matrix used to insure conformance to customers end usage is as follows:

PULSED PRESSURE TEMPERATURE CYCLING WITH BIAS (PPTCB)

This test is an environmental stress test combined with cyclic pressure loading in which devices are alternately subjected to a low and high temperature while operating under a cyclical pressure load. This test simulates the extremes in the operational life of a pressure sensor.

Typical Test Conditions: $T_A = -40°C$ to $+125°C$, dwell time 15 minutes, transfer time 15 minutes, bias = 100% rated voltage, pressure = 0 to full scale, pressure frequency = 2 to 10 seconds, test time = 168 to 1000 hours.

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Wire bond, wire, die bond, gel aeration, package failures, parametric stability.

HIGH HUMIDITY, HIGH TEMPERATURE WITH BIAS (H^3TB)

A combined environmental/electrical stress test in which devices are subjected to an elevated ambient temperature and humidity while the units are biased.

Typical Test Conditions: $T_A = 85°C$, relative humidity = 85%, bias = 100% rated voltage, test time = 168 to 1000 hours

Potential Failure Modes: Open, short, parametric shift.

Potential Failure Mechanisms: Wire bond, package failure, parametric stability.

HIGH TEMPERATURE WITH BIAS (HTB)

This operational test exposes the pressure sensor to a high temperature ambient environment in which the device is biased to the rated voltage.

Typical Test Conditions: $T_A = +125°C$, bias = 100% rated voltage, test time = 168 to 1000 hours.

Potential Failure Modes: Parametric shift in offset or linearity.

Potential Failure Mechanisms: Die stability.

HIGH AND LOW TEMPERATURE STORAGE LIFE (HTSL AND LTSL)

High and low temperature storage life testing is performed to simulate the potential storage or operational conditions that the pressure sensor might encounter in actual usage. The test also evaluates the devices thermal integrity at worst case temperature.

Typical Test Conditions: $T_A = +125°C$ or $T_A = -40°C$, test time = 168 to 1000 hours.

Potential Failure Modes: Parametric shifts in offset and linearity.

Potential Failure Mechanisms: Bulk die defects or diffusion defects.

TEMPERATURE CYCLING (TC)

This is a environmental test in which the pressure sensor is alternatively subjected to hot and cold temperature extremes with a short stabilization time at each temperature in an air medium. This test will stress the devices by generating thermal mismatches between materials.

Typical Test Conditions: T_A = – 40°C to +125°C, Dwell time 15 minutes, transfer time 5 minutes, test time = 100 to 1000 cycles.

Potential Failure Modes: Open, parametric shift in offset or linearity.

Potential Failure Mechanisms: Wire bond, die bond, package failures, gel aeration.

MECHANICAL SHOCK

This is an environmental test where the sensor device is tested to determine its ability to withstand a sudden change in mechanical stress due to an abrupt change in motion. This test simulates motion that may be seen in handling, transportation, or actual use.

Typical Test Conditions: Acceleration = 1500 g's, orientation = X_1, X_2, Y_1, Z_1, Z_2 plane, time = 0.5 millisecond, blows = 5.

Potential Failure Modes: Open, parametric shift in offset.

Potential Failure Mechanisms: Diaphragm fracture, package failure, die and wire bonds.

VARIABLE FREQUENCY VARIATION

A test to examine the ability of the pressure sensor device to withstand deterioration due to mechanical resonance.

Typical Test Conditions: Frequency = 100 Hz to 2 kHz, orientation = X_1, X_2, Y_1, Z_1, Z_2 plane, time = 48 minutes.

Potential Failure Modes: Open, parametric shift in offset.

Potential Failure Mechanisms: Diaphragm fracture, package failure, die and wire bonds.

SOLDERABILITY

The purpose of this test is to measure the ability of device leads/terminals to be soldered after an extended period of storage (shelf life).

Typical Test Conditions: Steam aging = 8 hours, Flux = R, Solder = SN60, SN63.

Potential Failure Modes: Pin holes, non-wetting, dewetting.

Potential Failure Mechanisms: Poor plating, contaminated leads.

BACK SIDE BLOWOFF

This test is performed to determine the ability of the pressure sensor element to withstand excessive pressure in the sensing environment. The test is performed from the back side by trying to lift the die from the package due to the positive pressure being applied.

Typical Test Conditions: Pressure = 6 times rated pressure, blow = 1, time = 15 seconds.

Potential Failure Modes: Open, parametric shift in offset, span.

Potential Failure Mechanisms: Die bond, package failure.

SALT ATMOSPHERE

A test to simulate a sea coast condition and the ability of the pressure sensor's packaging to resist corrosion.

Typical Test Conditions: Rate of salt deposited in the test area is between 50g/m2/day, temperature = 35°C, time = 24 hours.

Potential Failure Modes: Open, parametric shifts in offset, span.

Potential Failure Mechanisms: Package failure, corrosion, contamination.

A sufficient sample size manufactured over a pre-defined time interval to maximize process and time variability is tested based on the guidelines of the matrix shown above. This test methodology is employed on all new product introductions and process changes on current products. Summary statistics from several recent reliability studies performed on silicon pressure sensors are shown in Table 2.

A silicon pressure sensor has a typical usage environment of pressure, temperature, and voltage. Unlike the typical bipolar transistor life tests which incorporate current density and temperature to accelerate failures, a silicon pressure sensor's acceleration of its lifetime performance is primarily based on the pressure and temperature interaction with a presence of bias. This rationale was incorporated into the development of the Pulsed Pressure Temperature Cycling with Bias (PPTCB) test where the major acceleration factor is the pressure and temperature component. It is also why PPTCB is the standard sensor operational life test.

Table 2. Summary Data for Recent Reliability Studies

PPTCB			H^{3}TB			HTB		
Cum. Hrs.	Result	FITs 60%	Cum. Hrs.	Result	FITs 60%	Cum. Hrs.	Result	FITs 60%
230550	0	3975	630000	0	1455	134028	0	6838
HTSL			**LTSL**			**TC**		
Cum. Hrs.	Result	FITs 60%	Cum. Hrs.	Result	FITs 60%	Cum. Hrs.	Result	FITs 60%
1113000	0	823	417000	0	2198	1235500	0	742
MECH SHOCK			**VARI. FREQ. VIBR.**			**SALT ATM.**		
Cum. Hrs.	Result		Cum. Hrs.	Result		Cum. Hrs.	Result	
123	0		122	0		83	0	

To insure that silicon pressure sensors are designed and manufactured for reliability, an in-depth insight into what mechanisms cause particular failures is required. It is safe to say that unless a manufacturer has a clear understanding of everything that can go wrong with the device, it cannot design a device for the highest reliability. Figure 2 provides a look into the sensor operating concerns for a variety of potential usage applications. This information is utilized when developing the Failure Mode and Effects Analysis (FMEA). The FMEA then serves as the documentation that demonstrates all design and process concerns have been addressed to offer the most reliable approach. By understanding how to design products, control processes, and eliminate the concerns raised, a reliable product is achieved.

ACCELERATED LIFE TESTING

It is very difficult to access the reliability statistics for a product when very few or no failures occur. With cost as a predominant factor in any industrial setting and time of the utmost importance, the reliability test must be optimized. Optimization of reliability testing will allow the maximum amount of information on the product being tested to be gained in a minimum amount of time, this is accomplished by using accelerated life testing techniques.

A key underlying assumption in the usage of accelerated life testing to estimate the life of a product at a lower or nominal stress is that the failure mechanism encountered at the high stress is the same as that encountered at the nominal stress. The most frequently applied accelerated environmental stress for semiconductors is temperature, it will be briefly explained here for its utilization in determining the lifetime reliability statistics for silicon pressure sensors.

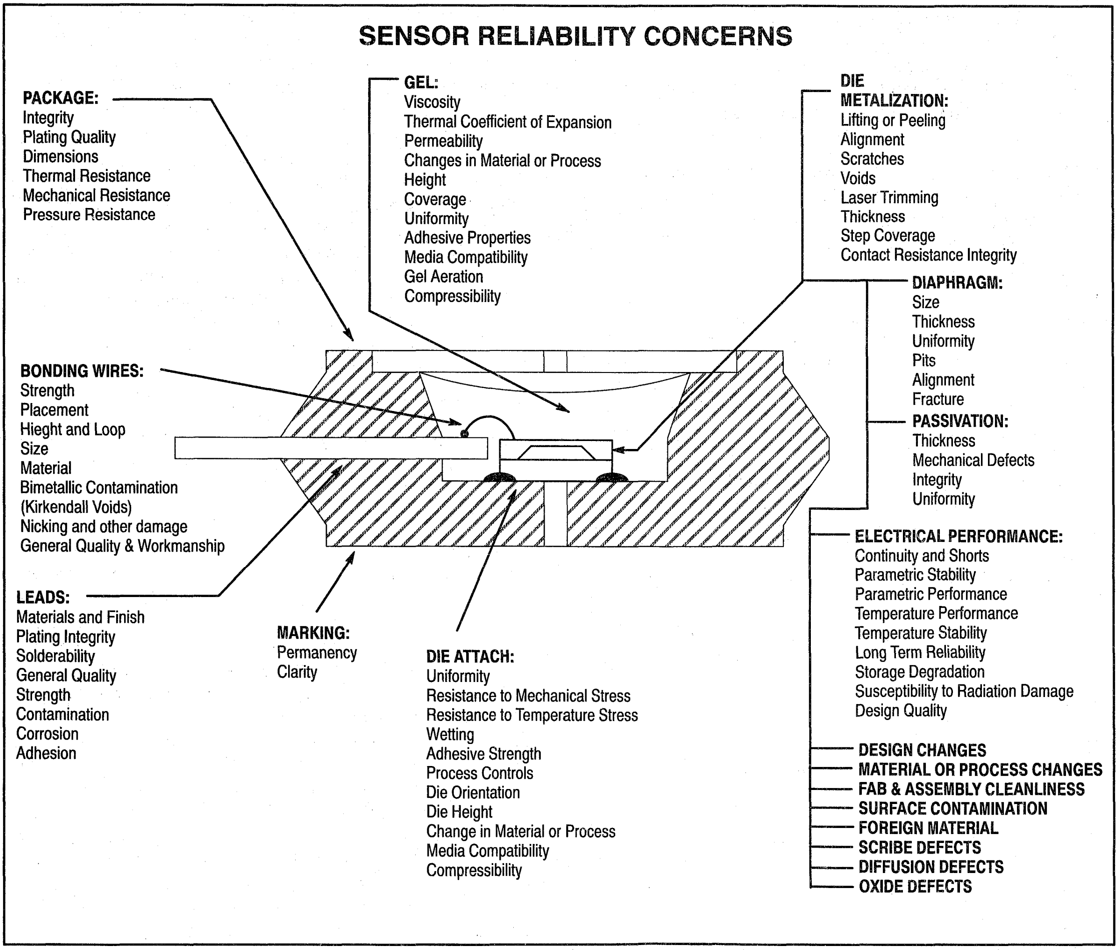


Figure 6. Process & Product Variability Concerns During Reliability Testing

The temperature acceleration factor for a particular failure mechanism can be related by taking the ratio for the reaction rate of the two different stress levels as expressed by the Arrhenius type of equation. The mathematical derivation of the first order chemical reaction rate computes to:

$$AF = \frac{(R_T)_{HS}}{(R_T)_{LS}} = \frac{t_{HS}}{t_{LS}}$$

$$AF = \exp\left[\frac{(e_A)_{HS}}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

AF = Acceleration Factor

RT = Reaction Rate

t = time

T = temperature [°K]

ea = activation energy of expressed in electron-volts [eV]

k = Boltzman's constant, 8.6171×10^{-5} eV/°K

LS = Low stress or nominal temperature

HS = High stress or test temperature

The activation energy is dependent on the failure mechanism and typically varies from 0.3 to 1.8 electron-volts. The activation energy is directly proportional to the degree of influence that temperature has on the chemical reaction rate. A listing of typical activation energies is included in reference (5) and (6).

As an example, Table 2 shows that a total of 134,028 cumulative device hours with no incidence has been accumulated on recent reliability studies for High Temperature with Bias (HTB). The test conditions for HTB are 125°C and 100% rated voltage. If a customer's actual usage conditions were 35°C at full rated voltage, an estimate of the failure rate or Mean Time Between Failures (MTBF) can be obtained if the assumption is made that the failure rate is constant over time. The first step is to calculate the equivalent device hours for the customer's use conditions by solving for the acceleration factor.

From the acceleration factor above, if eA is assumed equal to 1,

$$AF = \exp\left[\frac{(e_A)}{k}\left(\frac{1}{T_{LS}} - \frac{1}{T_{HS}}\right)\right]$$

Where:

eA = 1eV

k = 8.6171×10^{-5} eV/°K

TLS = 35°C + 273.16 = 308.16°K

THS = 125°C + 273.16 = 398°K

then;

AF = 4,975.65

Therefore, the equivalent cumulative device hours at the customer's use condition is:

tLS = AF x tHS = (134,028 x 4,975.65)

or

tLS = 66,876,236 device hours

Computing the failure rate for a 60% confidence level with no failures is:

$$\lambda = \frac{\chi 2\ (\alpha,\ \text{d.f.})}{2t}$$

or

λ = 1.3E–9

or

λ = 1.3 FITs

The inverse of the failure, λ, or the MTBF is:

MTBF4 = $1/\lambda$

or

MTBF = 727,633,645 device hours

PRESSURE SENSOR SOLUTIONS

When considering (7) the potential failure mechanisms in FMEA, the possibility of connections failing during the lifetime of the product is one of the most critical items. In addition, the manufacturing defects of open or intermittent connection is one of the frequently cited causes of electronic device failure. This is definitely one of the areas where an integrated solution has an inherent advantage over a hybrid.

As sensor technology continues to progress, on chip integration allows for this enhanced reliability. One such example is the MPX5100D, a monolithic integrated pressure sensor which provides a high output voltage of four volts, with a five volt supply, requiring no further amplification. The MPX5100D has a total of three active connections from the die to the package. This means that only nine bond connections at the die, three to the leadframe, and three solder connections in the actual circuit. If this was a two-chip sensor, there would be a total of 23 connections.

As further integration takes place incorporating more functions on a chip surface (A/D conversion, microprocessor) further reliability enhancement will be seen.

CONCLUSION

The maturity level of the silicon pressure sensor and the number of manufacturers makes it timely to consider the establishment of a colloquium to standardize the reliability testing methodology for silicon pressure sensors. This paper's purpose was to introduce silicon pressure sensor reliability issues and hopefully start the process of standardization.

Reliability testing durations and acceptance numbers are used as a baseline for achieving adequate performance in the actual use condition that the silicon pressure sensor might encounter. The baseline for reliability testing can be related to the current record high jump bar height. Just as athletes in time achieve a higher level of performance by improvements in their level of physical and mental fitness, silicon pressure sensors must also incorporate improvements in the design, materials, and manufacturability to achieve the reliability growth demands the future market place will require. This philosophy of never ending improvement will promote consistent conformance to the customer's expectation and production of a best in class product.

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Reliability Tests for Automotive/Industrial Pressure Sensors

PULSE PRESSURE TEMPERATURE CYCLING WITH BIAS (PPTCB)

This test is an environmental stress test combined with cyclic pressure loading in which devices are alternately subjected to a low and a high temperature while operating under a cyclical pressure load. This test simulates the extremes in the operational life of a pressure sensor. PPTCB evaluates the sensor's overall performance as well as evaluating die, die bond, wire bond and package integrity. Conditions: temperature extremes are –40°C to +125°C with an 8 hour dwell at each temperature for 500 hours; pressure is cycled at 1 Hz and 100% full scale pressure for 1,800,000 cycles. Bias is 100% rated voltage.

HIGH HUMIDITY, HIGH TEMPERATURE WITH BIAS (H^3TB)

A combined environmental/electrical stress test in which devices are subjected to an elevated ambient temperature and humidity while the units are biased. Sensors are tested in this manner at 85°C and 85% relative humidity at 100% operational voltage for 500 hours. This test is useful for evaluating package integrity as well as detecting surface contamination and processing flaws.

MECHANICAL SHOCK
(Military Standard 750 Method 2016)

Sensor units are dropped shocked at 3,000 g's of force five times in each of six orientations (X1, X2, Y1, Y2, Z1, Z2). This test simulates potential environmental conditions and evaluates wire bond and diaphragm integrity.

VARIABLE VIBRATION FREQUENCY
(Military Standard 750 Method 2056)

Frequency is varied logarithimically from 100 Hz to 2 kHz and then back to 100 Hz. Sensors are tested in this manner for 4 cycles in each axis for 4 minutes each cycle. The test simulates potential environmental conditions and evaluates package and die integrity.

HIGH AND LOW TEMPERATURE STORAGE LIFE (HTSL And LTSL)

Sensor devices are subjected to storage temperatures of +125°C and –40°C for 1000 hours each temperature. This test simulates potential shipping and operational conditions and evaluates the products thermal integrity.

TEMPERATURE CYCLE (TC)
(Military Standard 750 Method 1051)

This is an environmental test in which devices are alternately subjected to a low and high temperature with a stabilization dwell at each temperature in an air medium. Sensors are tested in this method between –40°C and +125°C with a 15 minute dwell for a total of 1000 cycles. This test evaluates die bond, wire bond, and package integrity.

THERMAL SHOCK
(Military Standard 750 Method 1056)

This environmental test is identical to the TC test with the exception that the medium is liquid. This provides a rapid thermal transfer which evaluates the die bond, wire bond, and package integrity. Dwell time is 1 minute and a total of 500 cycles are performed.

SALT SPRAY
(Military Standard 750 Method 1041)

Sensor devices are subjected to a salt spray atmosphere in order to simulate a sea coast condition. This test evaluates sensor packaging's resistance to corrosion.

SOLDERABILITY
(Military Standard 750 Method 2026)

In this reliability test, devices are steam aged for 6 hours and then soldered dipped. The test evaluates the ability of sensor products to be soldered after a simulated storage environment.

Statistical Process Control

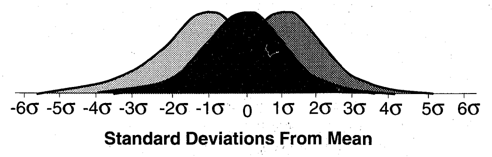
Motorola's Communications, Power and SIgnal Technologies Group (CPSTG) is continually pursuing new ways to improve product quality. Initial design improvement is one method that can be used to produce a superior product. Equally important to outgoing product quality is the ability to produce product that consistently conforms to specification. Process variability is the basic enemy of semiconductor manufacturing since it leads to product variability. Used in all phases of Motorola's product manufacturing, STATISTICAL PROCESS CONTROL (SPC) replaces variability with predictability. The traditional philosophy in the semiconductor industry has been adherence to the data sheet specification. Using SPC methods assures the product will meet specific process requirements throughout the manufacturing cycle. The emphasis is on defect prevention, not detection. Predictability through SPC methods requires the manufacturing culture to focus on constant and permanent improvements. Usually these improvements cannot be bought with state-of-the-art equipment or automated factories. With quality in design, process and material selection, coupled with manufacturing predictability, Motorola can produce world class products.

The immediate effect of SPC manufacturing is predictability through process controls. Product centered and distributed well within the product specification benefits Motorola with fewer rejects, improved yields and lower cost. The direct benefit to Motorola's customers includes better incoming quality levels, less inspection time and ship-to-stock capability. Circuit performance is often dependent on the cumulative effect of component variability. Tightly controlled component distributions give the customer greater circuit predictability. Many customers are also converting to just-in-time (JIT) delivery programs. These programs require improvements in cycle time and yield predictability achievable only through SPC techniques. The benefit derived from SPC helps the manufacturer meet the customer's expectations of higher quality and lower cost product.

Ultimately, Motorola will have Six Sigma capability on all products. This means parametric distributions will be centered within the specification limits with a product distribution of plus or minus Six Sigma about mean. Six Sigma capability, shown graphically in Figure 3, details the benefit in terms of yield and outgoing quality levels. This compares a centered distribution versus a 1.5 sigma worst case distribution shift.

New product development at Motorola requires more robust design features that make them less sensitive to minor variations in processing. These features make the implementation of SPC much easier.

A complete commitment to SPC is present throughout Motorola. All managers, engineers, production operators, supervisors and maintenance personnel have received multiple training courses on SPC techniques. Manufacturing has identified 22 wafer processing and 8 assembly steps considered critical to the processing of semiconductor products. Processes, controlled by SPC methods, that have shown significant improvement are in the diffusion, photolithography and metallization areas.



Distribution Centered	Distribution Shifted ± 1.5
At ± 3 σ 2700 ppm defective 99.73% yield	66810 ppm defective 93.32% yield
At ± 4 σ 63 ppm defective 99.9937% yield	6210 ppm defective 99.379% yield
At ± 5 σ 0.57 ppm defective 99.999943% yield	233 ppm defective 99.9767% yield
At ± 6 σ 0.002 ppm defective 99.9999998% yield	3.4 ppm defective 99.99966% yield

Figure 3. AOQL and Yield from a Normal Distribution of Product With 6σ Capability

To better understand SPC principles, brief explanations have been provided. These cover process capability, implementation and use.

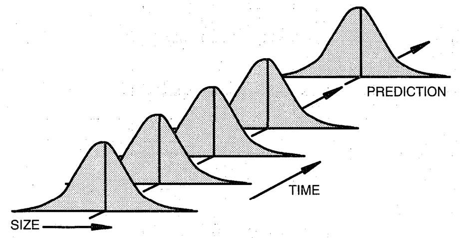
PROCESS CAPABILITY

One goal of SPC is to ensure a process is **CAPABLE**. Process capability is the measurement of a process to produce products consistently to specification requirements. The purpose of a process capability study is to separate the inherent **RANDOM VARIABILITY** from **ASSIGNABLE CAUSES**. Once completed, steps are taken to identify and eliminate the most significant assignable causes. Random variability is generally present in the system and does not fluctuate. Sometimes, these are considered basic limitations associated with the machinery, materials, personnel skills or manufacturing methods. Assignable cause inconsistencies relate to time variations in yield, performance or reliability.

Traditionally, assignable causes appear to be random due to the lack of close examination or analysis. Figure 4 shows the impact on predictability that assignable cause can have. Figure 5 shows the difference between process control and process capability.

A process capability study involves taking periodic samples from the process under controlled conditions. The performance characteristics of these samples are charted against time. In time, assignable causes can be identified and engineered out. Careful documentation of the process is key to accurate diagnosis and successful removal of the assignable causes. Sometimes, the assignable causes will remain unclear requiring prolonged experimentation.

Elements which measure process variation control and capability are Cp and Cpk respectively. Cp is the specification width divided by the process width or Cp = (specification width) / 6σ. Cpk is the absolute value of the closest specification value to the mean, minus the mean, divided by half the process width or Cpk = I closest specification $-\bar{X}/3\sigma$.



Process "under control" – all assignable causes are removed and future distribution is predictable.

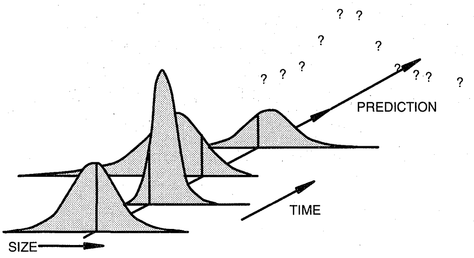


Figure 4. Impact of Assignable Causes on Process Predictable

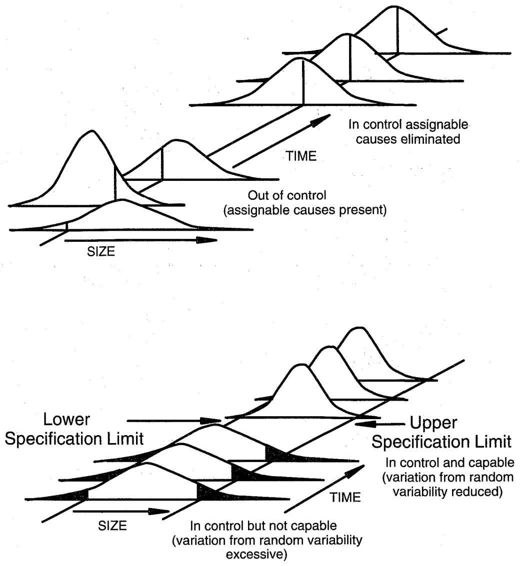


Figure 5. Difference Between Process Control and Process Capability

At Motorola, for critical parameters, the process capability is acceptable with a Cpk = 1.33. The desired process capability is a Cpk = 2 and the ideal is a Cpk = 5. Cpk, by definition, shows where the current production process fits with relationship to the specification limits. Off center distributions or excessive process variability will result in less than optimum conditions

SPC IMPLEMENTATION AND USE

DMTG uses many parameters that show conformance to specification. Some parameters are sensitive to process variations while others remain constant for a given product line. Often, specific parameters are influenced when changes to other parameters occur. It is both impractical and unnecessary to monitor all parameters using SPC methods. Only critical parameters that are sensitive to process variability are chosen for SPC monitoring. The process steps affecting these critical parameters must be identified also. It is equally important to find a measurement in these process steps that correlates with product performance. This is called a critical process parameter.

Once the critical process parameters are selected, a sample plan must be determined. The samples used for measurement are organized into **RATIONAL SUBGROUPS** of approximately 2 to 5 pieces. The subgroup size should be such that variation among the samples within the subgroup remain small. All samples must come from the same source e.g., the same mold press operator, etc.. Subgroup data should be collected at appropriate time intervals to detect variations in the process. As the process begins to show improved stability, the interval may be increased. The data collected must be carefully documented and maintained for later correlation. Examples of common documentation entries would include operator, machine, time, settings, product type, etc.

Once the plan is established, data collection may begin. The data collected will generate $\bar{X}$ and R values that are plotted with respect to time. $\bar{X}$ refers to the mean of the values within a given subgroup, while R is the range or greatest value minus least value. When approximately 20 or more $\bar{X}$ and R values have been generated, the average of these values is computed as follows:

$$\bar{\bar{X}} = (\bar{X} + \bar{X}2 + \bar{X}3 + ...)/K$$
$$\bar{R} = (R1 + R2 + R3 + ...)/K$$

where K = the number of subgroups measured.

The values of $\bar{\bar{X}}$ and $\bar{R}$ are used to create the process control chart. Control charts are the primary SPC tool used to signal a problem. Shown in Figure 6, process control charts show $\bar{X}$ and R values with respect to time and concerning reference to upper and lower control limit values. Control limits are computed as follows:

R upper control limit = $UCL_R = D4\ \bar{R}$

R lower control limit = $LCL_R = D3\ \bar{R}$

$\bar{X}$ upper control limit = $UCL_{\bar{X}} = \bar{\bar{X}} + A2\ \bar{R}$

$\bar{X}$ lower control limit = $LCL_{\bar{X}} = \bar{\bar{X}} - A2\ \bar{R}$

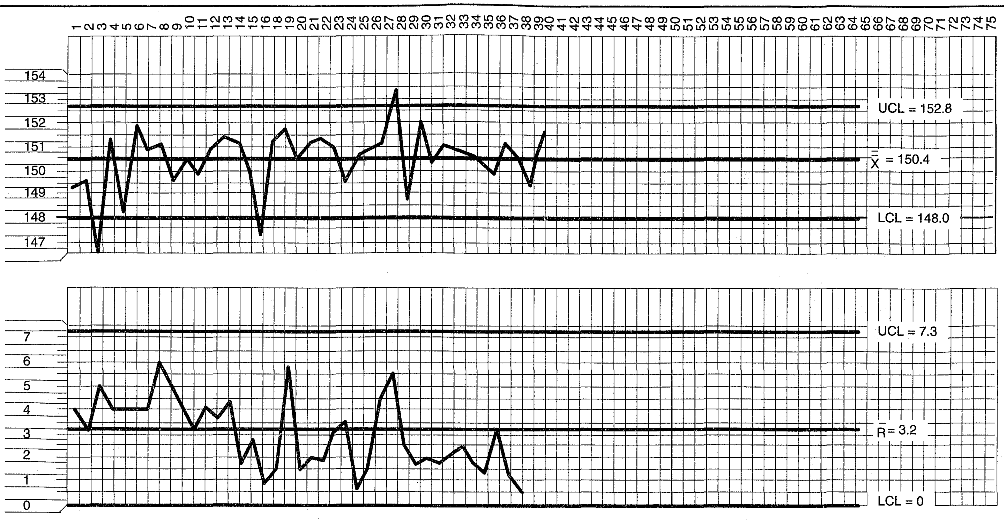


Figure 6. Example of Process Control Chart Showing Oven Temperature Data

Where D4, D3 and A2 are constants varying by sample size,with values for sample sizes from 2 to 10 shown in the following partial table:

n	2	3	4	5	6	7	8	9	10
D_4	3.27	2.57	2.28	2.11	2.00	1.92	1.86	1.82	1.78
D_3	*	*	*	*	*	0.08	0.14	0.18	0.22
A_2	1.88	1.02	0.73	0.58	0.48	0.42	0.37	0.34	0.31

* For sample sizes below 7, the LCL_R would technically be a negative number; in those cases there is no lower control limit; this means that for a subgroup size 6, six "identical" measurements would not be unreasonable.

Control charts are used to monitor the variability of critical process parameters. The R chart shows basic problems with piece to piece variability related to the process. The X chart can often identify changes in people, machines, methods, etc. The source of the variability can be difficult to find and may require experimental design techniques to identify assignable causes.

Some general rules have been established to help determine when a process is **OUT-OF-CONTROL**. Figure 7 shows a control chart subdivided into zones A, B, and C corresponding to 3 sigma, 2 sigma, and 1 sigma limits respectively. In Figure 8 through Figure 11 four of the tests that can be used to identify excessive variability and the presence of assignable causes are shown. As familiarity with a given process increases, more subtle tests may be employed successfully.

Once the variability is identified, the cause of the variability must be determined. Normally, only a few factors have a significant impact on the total variability of the process. The importance of correctly identifying these factors is stressed in the following example. Suppose a process variability depends on the variance of five factors A, B, C, D and E. Each has a variance of 5, 3, 2, 1 and 0.4 respectively.

Since:

$$\sigma \text{ tot} = \sqrt{\sigma A^2 + \sigma B^2 + \sigma C^2 + \sigma D^2 + \sigma E^2}$$

$$\sigma \text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 6.3$$

Now if only D is identified and eliminated then;

$$\sigma \text{ tot} = \sqrt{5^2 + 3^2 + 2^2 + (0.4)^2} = 6.2$$

This results in less than 2% total variability improvement. If B, C and D were eliminated, then;

$$\sigma \text{ tot} = \sqrt{5^2 + (0.4)^2} = 5.02$$

This gives a considerably better improvement of 23%. If only A is identified and reduced from 5 to 2, then;

$$\sigma \text{ tot} = \sqrt{2^2 + 3^2 + 2^2 + 1^2 + (0.4)^2} = 4.3$$

Identifying and improving the variability from 5 to 2 gives us a total variability improvement of nearly 40%.

Most techniques may be employed to identify the primary assignable cause(s). Out-of-control conditions may be correlated to documented process changes. The product may be analyzed in detail using best versus worst part comparisons or Product Analysis Lab equipment. Multi-variance analysis can be used to determine the family of variation (positional, critical or temporal). Lastly, experiments may be run to test theoretical or factorial analysis. Whatever method is used, assignable causes must be identified and eliminated in the most expeditious manner possible.

After assignable causes have been eliminated, new control limits are calculated to provide a more challenging variability criteria for the process. As yields and variability improve, it may become more difficult to detect improvements because they become much smaller. When all assignable causes have been eliminated and the points remain within control limits for 25 groups, the process is said to be in a state of control.

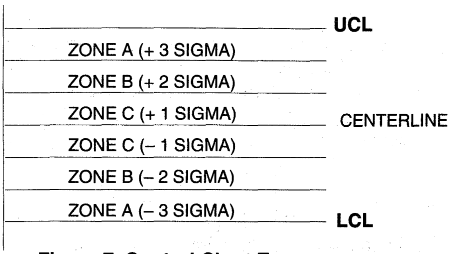


Figure 7. Control Chart Zones

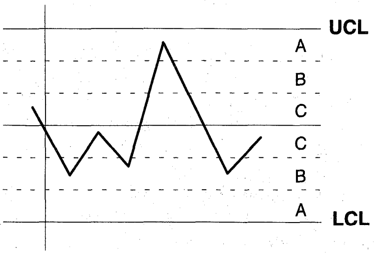


Figure 8. One Point Outside Control Limit Indicating Excessive Variability

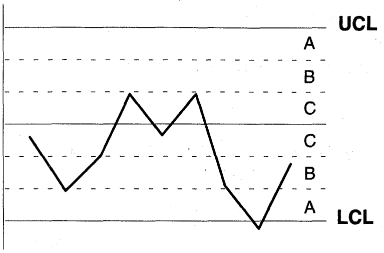


Figure 9. Two Out of Three Points in Zone A or Beyond Indicating Excessive Variability

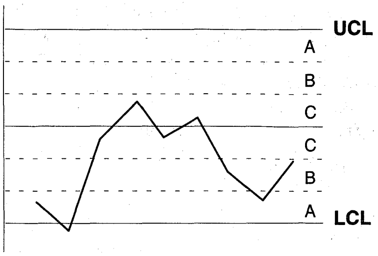


Figure 10. Four Out of Five Points in Zone B or Beyond Indicating Excessive Variability

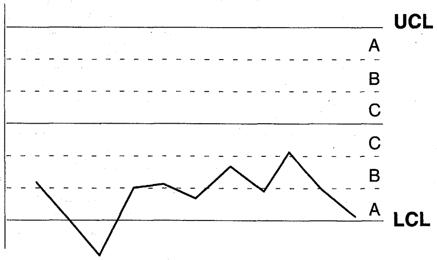


Figure 11. Seven Out of Eight Points in Zone C or Beyond Indicating Excessive Variability

SUMMARY

Motorola is committed to the use of STATISTICAL PROCESS CONTROLS. These principles, used throughout manufacturing, have already resulted in many significant improvements to the processes. Continued dedication to the SPC culture will allow Motorola to reach the Six Sigma and zero defect capability goals. SPC will further enhance the commitment to **TOTAL CUSTOMER SATISFACTION**.

Electrostatic Discharge Data

Electrostatic damage (ESD) to semiconductor devices has plagued the industry for years. Special packaging and handling techniques have been developed to protect these sensitive devices. While many of Motorola's semiconductors devices are not susceptible to ESD, all products are revered as sensitive and handled accordingly.

The data in this section was developed using the human-body model specified in MIL-STD-750C, Method 1020. The threshold values (Eth, kV) of ten devices was recorded, then the average value calculated. This data plus the device type, device source, package type, classification, polarity and general device description are supplied. Devices listed are mainly JEDEC registered 1N and 2N numbers. Military QPL devices and some customer specials are also in this database. The data in this report will be updated regularly, and the range will be added as new data becomes available.

The sensitivity classifications listed are as follows:

Class 1 . . .1 to 1999 volts

Class 2 . . .2000 to 3999 volts

Class 3 . . .4000 to > 15500 volts

The code "N/S" signifies a non-sensitive device. "SEN" are considered sensitive and should be handled according to ESD procedures. Of the various products manufactured by the Communications, Power and Signal Technologies Group, the following examples list general device families by not sensitive to extremely sensitive.

Not sensitive	FET current regulators
Least sensitive	Zener diodes (on a square mil/millijoule basis)
Less sensitive	Bipolar transistors
More sensitive	Bipolar darlington transistors
Very sensitive	Power TMOS® devices
Extremely sensitive	Hot carrier diodes and MOSFET transistors without gate protection

The data supplied herein, is listed in numerical or alphabetical order.

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX10D	XL0010V3	344	3-SEN	Uncompensated
MPX10DP	XL0010V3	352	3-SEN	Uncompensated
MPX10GP	XL0010V3	350-02	3-SEN	Uncompensated
MPX10GVP	XL0010V3	350-04	3-SEN	Uncompensated
MPX10GS	XL0010V3	371-06	3-SEN	Uncompensated
MPX10GVS	XL0010V3	371-05	3-SEN	Uncompensated
MPX10GSX	XL0010V3	371C	3-SEN	Uncompensated
MPX10GVSX	XL0010V3	371D	3-SEN	Uncompensated
MPX11D	XL0011V3	344	3-SEN	Uncompensated
MPX11DP	XL0011V3	352	3-SEN	Uncompensated
MPX11GP	XL0011V3	350-02	3-SEN	Uncompensated
MPX11GVP	XL0011V3	350-04	3-SEN	Uncompensated
MPX11GS	XL0011V3	371-06	3-SEN	Uncompensated
MPX11GVS	XL0011V3	371-05	3-SEN	Uncompensated
MPX11GSX	XL0011V3	371C	3-SEN	Uncompensated
MPX11GVSX	XL0011V3	371D	3-SEN	Uncompensated
MPX12D	XL0012V3	344	3-SEN	Uncompensated
MPX12DP	XL0012V3	352	3-SEN	Uncompensated
MPX12GP	XL0012V3	350-02	3-SEN	Uncompensated
MPX12GVP	XL0012V3	350-04	3-SEN	Uncompensated
MPX12GS	XL0012V3	371-06	3-SEN	Uncompensated
MPX12GVS	XL0012V3	371-05	3-SEN	Uncompensated
MPX12GSX	XL0012V3	371C	3-SEN	Uncompensated
MPX12GVSX	XL0012V3	371D	3-SEN	Uncompensated
MPX50D	XL0050V3	344	3-SEN	Uncompensated

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX50DP	XL0050V3	352	3-SEN	Uncompensated
MPX50GP	XL0050V3	350	3-SEN	Uncompensated
MPX50GVP	XL0050V3	350-04	3-SEN	Uncompensated
MPX50GS	XL0050V3	371-06	3-SEN	Uncompensated
MPX50GVS	XL0050V3	371-05	3-SEN	Uncompensated
MPX50GSX	XL0050V3	371C	3-SEN	Uncompensated
MPX50GVSX	XL0050V3	371D	3-SEN	Uncompensated
MPX51D	XL0051V3	344	3-SEN	Uncompensated
MPX51DP	XL0051V3	352	3-SEN	Uncompensated
MPX51GP	XL0051V3	350	3-SEN	Uncompensated
MPX51GVP	XL0051V3	350-04	3-SEN	Uncompensated
MPX51GS	XL0051V3	371-06	3-SEN	Uncompensated
MPX51GVS	XL0051V3	371-05	3-SEN	Uncompensated
MPX51GSX	XL0051V3	371C	3-SEN	Uncompensated
MPX51GVSX	XL0051V3	371D	3-SEN	Uncompensated
MPX52D	XL0051V3	344	3-SEN	Uncompensated
MPX52DP	XL0051V3	352	3-SEN	Uncompensated
MPX52GP	XL0051V3	350	3-SEN	Uncompensated
MPX52GVP	XL0051V3	350-04	3-SEN	Uncompensated
MPX52GS	XL0051V3	371-06	3-SEN	Uncompensated
MPX52GVS	XL0051V3	371-05	3-SEN	Uncompensated
MPX52GSX	XL0051V3	371C	3-SEN	Uncompensated
MPX52GVSX	XL0051V3	371D	3-SEN	Uncompensated
MPX100A	XL0100V2	344	3-SEN	Uncompensated
MPX100AP	XL0100V2	350	3-SEN	Uncompensated
MPX100AS	XL0100V2	371-06	3-SEN	Uncompensated
MPX100ASX	XL0100V2	371C	3-SEN	Uncompensated
MPX100D	XL0100V3	344	3-SEN	Uncompensated
MPX100DP	XL0100V3	352	3-SEN	Uncompensated
MPX100GP	XL0100V3	350	3-SEN	Uncompensated
MPX100GVP	XL0100V3	350-04	3-SEN	Uncompensated
MPX100GS	XL0100V3	371-06	3-SEN	Uncompensated
MPX100GVS	XL0100V3	371-05	3-SEN	Uncompensated
MPX100GSX	XL0100V3	371C	3-SEN	Uncompensated
MPX100GVSX	XL0100V3	371D	3-SEN	Uncompensated
MPX200A	XL0200V2	344	3-SEN	Uncompensated
MPX200AP	XL0200V2	350	3-SEN	Uncompensated
MPX200AS	XL0200V2	371-06	3-SEN	Uncompensated
MPX200ASX	XL0200V2	371C	3-SEN	Uncompensated
MPX200D	XL0200V3	344	3-SEN	Uncompensated
MPX200DP	XL0200V3	352	3-SEN	Uncompensated
MPX200GP	XL0200V3	350	3-SEN	Uncompensated
MPX200GVP	XL0200V3	350-04	3-SEN	Uncompensated

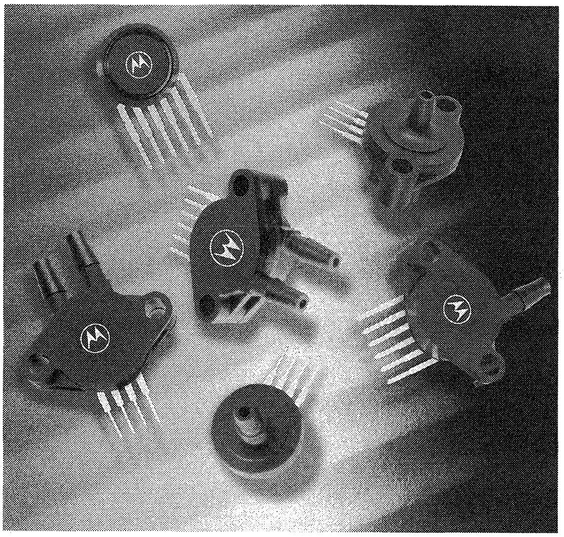
DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX200GS	XL0200V3	371-06	3-SEN	Uncompensated
MPX200GVS	XL0200V3	371-05	3-SEN	Uncompensated
MPX200GSX	XL0200V3	371C	3-SEN	Uncompensated
MPX200GVSX	XL0200V3	371D	3-SEN	Uncompensated
MPX201A	XL0200V2	344	3-SEN	Uncompensated
MPX201AP	XL0200V2	350	3-SEN	Uncompensated
MPX201AS	XL0200V2	371-06	3-SEN	Uncompensated
MPX201ASX	XL0200V2	371C	3-SEN	Uncompensated
MPX201D	XL0200V3	344	3-SEN	Uncompensated
MPX201DP	XL0200V3	352	3-SEN	Uncompensated
MPX201GP	XL0200V3	350	3-SEN	Uncompensated
MPX201GVP	XL0200V3	350-04	3-SEN	Uncompensated
MPX201GS	XL0200V3	371-06	3-SEN	Uncompensated
MPX201GVS	XL0200V3	371-05	3-SEN	Uncompensated
MPX201GSX	XL0200V3	371C	3-SEN	Uncompensated
MPX201GVSX	XL0200V3	371D	3-SEN	Uncompensated
MPX700A	XL0700V2	344	3-SEN	Uncompensated
MPX700AP	XL0700V2	350	3-SEN	Uncompensated
MPX700AS	XL0700V2	371-06	3-SEN	Uncompensated
MPX700ASX	XL0700V2	371C	3-SEN	Uncompensated
MPX700D	XL0700V1	344	3-SEN	Uncompensated
MPX700DP	XL0700V1	352	3-SEN	Uncompensated
MPX700GP	XL0700V1	350	3-SEN	Uncompensated
MPX700GVP	XL0700V1	350-04	3-SEN	Uncompensated
MPX700GS	XL0700V1	371-06	3-SEN	Uncompensated
MPX700GVS	XL0700V1	371-05	3-SEN	Uncompensated
MPX700GSX	XL0700V1	371C	3-SEN	Uncompensated
MPX700GVSX	XL0700V1	371D	3-SEN	Uncompensated
MPX2010D	XL2010V5	344	1-SEN	Temperature Compensated/Calibrated
MPX2010DP	XL2010V5	352	1-SEN	Temperature Compensated/Calibrated
MPX2010GP	XL2010V5	350	1-SEN	Temperature Compensated/Calibrated
MPX2010GVP	XL2010V5	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2010GS	XL2010V5	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2010GVS	XL2010V5	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2010GSX	XL2010V5	371C	1-SEN	Temperature Compensated/Calibrated
MPX2010GVSX	XL2010V5	371D	1-SEN	Temperature Compensated/Calibrated
MPX2012D	XL2010V5	344	1-SEN	Temperature Compensated/Calibrated
MPX2012DP	XL2010V5	352	1-SEN	Temperature Compensated/Calibrated
MPX2012GP	XL2010V5	350	1-SEN	Temperature Compensated/Calibrated
MPX2012GVP	XL2010V5	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2012GS	XL2010V5	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2012GVS	XL2010V5	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2012GSX	XL2010V5	371C	1-SEN	Temperature Compensated/Calibrated

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX2012GVSX	XL2010V5	371D	1-SEN	Temperature Compensated/Calibrated
MPX2040D	XL2300B	344	1-SEN	Temperature Compensated/Calibrated
MPX2050D	XL2050V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2050DP	XL2050V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2050GP	XL2050V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2050GVP	XL2050V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2050GS	XL2050V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2050GVS	XL2050V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2050GSX	XL2050V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2050GVSX	XL2050V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2051D	XL2050V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2051DP	XL2050V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2051GP	XL2050V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2051GVP	XL2050V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2051GS	XL2050V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2051GVS	XL2050V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2051GSX	XL2050V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2051GVSX	XL2050V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2052D	XL2050V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2052DP	XL2050V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2052GP	XL2050V3	350-02	1-SEN	Temperature Compensated/Calibrated
MPX2052GVP	XL2050V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2052GS	XL2050V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2052GVS	XL2050V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2052GSX	XL2050V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2052GVSX	XL2050V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2100A	XL2100V2	344	1-SEN	Temperature Compensated/Calibrated
MPX2100AP	XL2100V2	350	1-SEN	Temperature Compensated/Calibrated
MPX2100AS	XL2100V2	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2100ASX	XL2100V2	371C	1-SEN	Temperature Compensated/Calibrated
MPX2100D	XL2100V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2100DP	XL2100V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2100GP	XL2100V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2100GVP	XL2100V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2100GS	XL2100V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2100GVS	XL2100V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2100GSX	XL2100V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2100GVSX	XL2100V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2101A	XL2100V2	344	1-SEN	Temperature Compensated/Calibrated
MPX2101AP	XL2100V2	350	1-SEN	Temperature Compensated/Calibrated
MPX2101AS	XL2100V2	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2101ASX	XL2100V2	371C	1-SEN	Temperature Compensated/Calibrated
MPX2101D	XL2100V3	344	1-SEN	Temperature Compensated/Calibrated

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX2101DP	XL2100V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2101GP	XL2100V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2101GVP	XL2100V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2101GS	XL2100V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2101GVS	XL2100V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2101GSX	XL2100V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2101GVSX	XL2100V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2200A	XL2200V2	344	1-SEN	Temperature Compensated/Calibrated
MPX2200AP	XL2200V2	350	1-SEN	Temperature Compensated/Calibrated
MPX2200AS	XL2200V2	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2200ASX	XL2200V2	371C	1-SEN	Temperature Compensated/Calibrated
MPX2200D	XL2200V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2200DP	XL2200V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2200GP	XL2200V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2200GVP	XL2200V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2200GS	XL2200V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2200GVS	XL2200V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2200GSX	XL2200V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2200GVSX	XL2200V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX2201A	XL2200V2	344	1-SEN	Temperature Compensated/Calibrated
MPX2201AP	XL2200V2	350	1-SEN	Temperature Compensated/Calibrated
MPX2201AS	XL2200V2	371	1-SEN	Temperature Compensated/Calibrated
MPX2201ASX	XL2200V2	371C	1-SEN	Temperature Compensated/Calibrated
MPX2201D	XL2200V3	344	1-SEN	Temperature Compensated/Calibrated
MPX2201DP	XL2200V3	352	1-SEN	Temperature Compensated/Calibrated
MPX2201GP	XL2200V3	350	1-SEN	Temperature Compensated/Calibrated
MPX2201GVP	XL2200V3	350-04	1-SEN	Temperature Compensated/Calibrated
MPX2201GS	XL2200V3	371-06	1-SEN	Temperature Compensated/Calibrated
MPX2201GVS	XL2200V3	371-05	1-SEN	Temperature Compensated/Calibrated
MPX2201GSX	XL2200V3	371C	1-SEN	Temperature Compensated/Calibrated
MPX2201GVSX	XL2200V3	371D	1-SEN	Temperature Compensated/Calibrated
MPX4100A	XL4101S2	867	1-SEN	Signal-Conditioned
MPX4100AP	XL4101S2	867B	1-SEN	Signal-Conditioned
MPX4100ASX	XL4101S2	867F	1-SEN	Signal-Conditioned
MPX4101A	XL4101S2	867	1-SEN	Signal-Conditioned
MPX4101AP	XL4101S2	867B	1-SEN	Signal-Conditioned
MPX4101ASX	XL4101S2	867F	1-SEN	Signal-Conditioned
MPX4115A	XL4101S2	867	1-SEN	Signal-Conditioned
MPX4115AP	XL4101S2	867B	1-SEN	Signal-Conditioned
MPX4115AS	XL4101S2	867E	1-SEN	Signal-Conditioned
MPX4115ASX	XL4101S2	867F	1-SEN	Signal-Conditioned
MPX5050D	XL4050S1	867	1-SEN	Signal-Conditioned
MPX5050DP	XL4050S1	867C	1-SEN	Signal-Conditioned

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX5050GP	XL4050S1	867B	1-SEN	Signal-Conditioned
MPX5050GVP	XL4050S1	867D	1-SEN	Signal-Conditioned
MPX5050GS	XL4050S1	867E	1-SEN	Signal-Conditioned
MPX5050GVS	XL4050S1	867A	1-SEN	Signal-Conditioned
MPX5050GSX	XL4050S1	867F	1-SEN	Signal-Conditioned
MPX5050GVSX	XL4050S1	867G	1-SEN	Signal-Conditioned
MPX5100A	XL5100S2	867	1-SEN	Signal-Conditioned
MPX5100AP	XL5100S2	867B	1-SEN	Signal-Conditioned
MPX5100AS	XL5100S2	867E	1-SEN	Signal-Conditioned
MPX5100ASX	XL5100S2	867F	1-SEN	Signal-Conditioned
MPX5100D	XL5100S1	867	1-SEN	Signal-Conditioned
MPX5100DP	XL5100S1	867C	1-SEN	Signal-Conditioned
MPX5100GP	XL5100S1	867B	1-SEN	Signal-Conditioned
MPX5100GVP	XL5100S1	867D	1-SEN	Signal-Conditioned
MPX5100GS	XL5100S1	867E	1-SEN	Signal-Conditioned
MPX5100GVS	XL5100S1	867A	1-SEN	Signal-Conditioned
MPX5100GSX	XL5100S1	867F	1-SEN	Signal-Conditioned
MPX5100GVSX	XL5100S1	867G	1-SEN	Signal-Conditioned
MPX7050D	XL7050V3	344	1-SEN	High Impedance
MPX7050DP	XL7050V3	352	1-SEN	High Impedance
MPX7050GP	XL7050V3	350	1-SEN	High Impedance
MPX7050GVP	XL7050V3	350-04	1-SEN	High Impedance
MPX7050GS	XL7050V3	371-06	1-SEN	High Impedance
MPX7050GVS	XL7050V3	371-05	1-SEN	High Impedance
MPX7050GSX	XL7050V3	371C	1-SEN	High Impedance
MPX7050GVSX	XL7050V3	371D	1-SEN	High Impedance
MPX7100A	XL7100V2	344	1-SEN	High Impedance
MPX7100AP	XL7100V2	350	1-SEN	High Impedance
MPX7100AS	XL7100V2	371-06	1-SEN	High Impedance
MPX7100ASX	XL7100V2	371C	1-SEN	High Impedance
MPX7100D	XL7100V3	344	1-SEN	High Impedance
MPX7100DP	XL7100V3	352	1-SEN	High Impedance
MPX7100GP	XL7100V3	350	1-SEN	High Impedance
MPX7100GVP	XL7100V3	350-04	1-SEN	High Impedance
MPX7100GS	XL7100V3	371-06	1-SEN	High Impedance
MPX7100GVS	XL7100V3	371-05	1-SEN	High Impedance
MPX7100GSX	XL7100V3	371C	1-SEN	High Impedance
MPX7100GVSX	XL7100V3	371D	1-SEN	High Impedance
MPX7200A	XL7200V2	344	1-SEN	High Impedance
MPX7200AP	XL7200V2	350	1-SEN	High Impedance
MPX7200AS	XL7200V2	371-06	1-SEN	High Impedance
MPX7200ASX	XL7200V2	371C	1-SEN	High Impedance
MPX7200D	XL7200V3	344	1-SEN	High Impedance

DEVICE	LINE	CASE	CLASS	PRODUCT DESCRIPTION
MPX7200DP	XL7200V3	352	1-SEN	High Impedance
MPX7200GP	XL7200V3	350	1-SEN	High Impedance
MPX7200GVP	XL7200V3	350-04	1-SEN	High Impedance
MPX7200GS	XL7200V3	371-06	1-SEN	High Impedance
MPX7200GVS	XL7200V3	371-05	1-SEN	High Impedance
MPX7200GSX	XL7200V3	371C	1-SEN	High Impedance
MPX7200GVSX	XL7200V3	371D	1-SEN	High Impedance
MTS102	XL800.1	29-04	1-SEN	Temperature Sensor
MTS103	XL800.1	29-04	1-SEN	Temperature Sensor
MTS105	XL800.1	29-04	1-SEN	Temperature Sensor



Section Five

Application Notes

Applications Information

Example Circuits

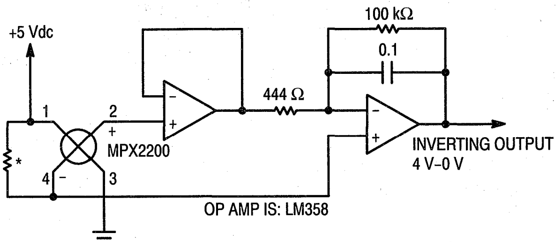
MPX2000 sensors with on-chip compensation can be used individually or in multiples in research, design, or development projects to optimize a design. The small size and low cost of the compensated MPX2000 series of sensors makes these devices ideally suited for such applications.

Many process control functions can also be served by MPX2000 sensors handling pressure ranges up to 30 PSI in gauge, vacuum and differential measurements. Wind tunnel measurements, vacuum forming or vacuum pickup monitoring are among the many potential applications.

Several specific applications examples are shown on the following pages. **These are offered as basic suggestions only; actual component selection and values are determined by the final circuit requirements.**

Fluid Pressure Circuit

Fluid pressure transducer circuit with inverted output. In this configuration, the circuit provides a 4 Vdc output with zero pressure applied, decreasing to 0 Vdc at full rated pressure. An ideal circuit for any type of liquid level monitoring.

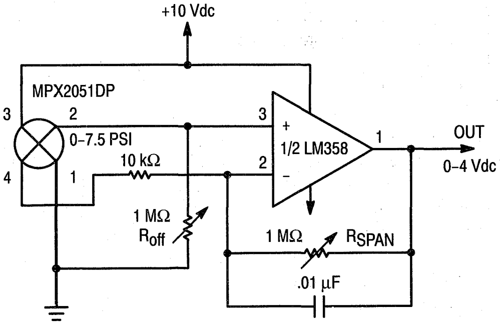


* TRIM TO 4.0 V OUT
WITH 0 PRESSURE IN. (≅ 100 k)

Fluid Pressure Circuit

Simple Pressure Sensor Amplifier

A single op-amp circuit which gives a 4 volt dc output for full-scale pressure input. The circuit is ratiometric, giving 2 Vdc out with a 5 volt supply. A good, low-cost general-purpose circuit for those applications where ±3% performance is acceptable, it can also be trimmed to provide ±1.5% accuracy over the 0–85°C temperature range. Multi-turn potentiometers are suggested for R_{off} and R_{span}.

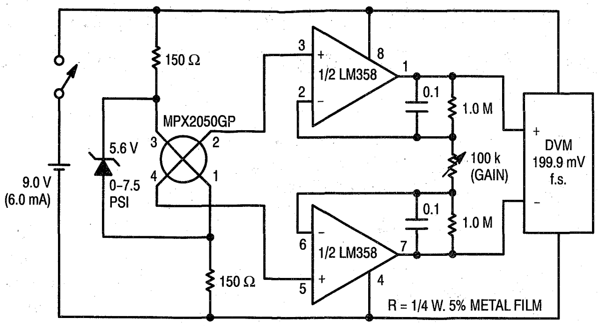


Simple Pressure Sensor Amplifier

Example Circuits (continued)

Portable Manometer

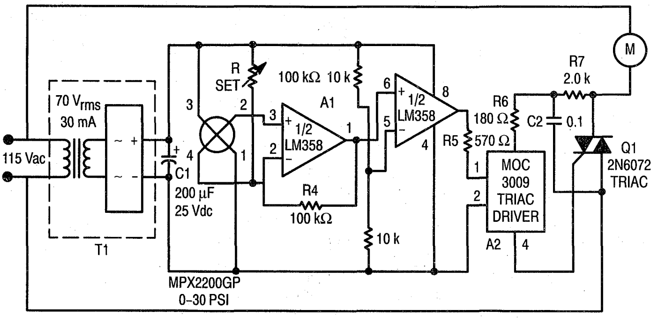
A DVM circuit used for portable equipment such as manometers and barometers. Precision performance is achievable using a high-grade instrumentation amplifier and substituting a precision regulator for the zener.



Portable Manometer

Solid State Pressure Switch

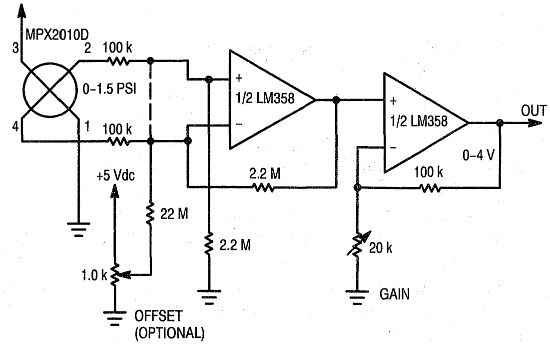
A low-cost, set-point pressure switch for motor control applications. This circuit has been used successfully to control compressor and pump motors, as well as heaters in liquid level applications.



Solid State Pressure Switch

Microprocessor Interface Circuit

High level input for an A/D converter. This circuit offers moderate performance with typical logic supply. Improved performance over temperature is possible using metal-film resistors and an LM158 op-amp. Maximum output is approximately 4.5 Vdc referenced to ground.



Microprocessor Interface Circuit

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN840

Temperature Compensation Methods For The Motorola X-ducer Pressure Sensor Element

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INTRODUCTION

The X-ducer piezoresistive pressure sensor element is a semiconductor device that gives an electrical output signal proportional to the pressure applied to the device. This device uses a unique transverse voltage diffused semiconductor strain gauge which is sensitive to stresses produced in a thin silicon diaphragm by the applied pressure.

Because this strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in the thermal expansion of the strain gauge and the diaphragm, as are often encountered in bonded strain gauge pressure sensors. However, the properties of the strain gauge itself are temperature dependant, requiring that the device be temperature compensated if it is to be used over an extensive temperature range. The purpose of this Application Note is to illustrate how this temperature compensation can be accomplished, so as to aid the user in applications where temperature compensation is necessary.

The methods discussed here are not the only methods for temperature compensating the X-ducer piezoresistive pressure sensor. They are relatively simple, however, and have been found to be adequate where accuracies of a few percent or less are sufficient. Moreover, they are applicable to the entire product line for the X-ducer pressure sensor element and, in many applications, can provide good performance without consideration of part-to-part variations consistent with the specifications of these devices.

TEMPERATURE CHARACTERISTICS

Figure 1 shows a typical operating curve for an MPX100D pressure sensor element. Other members of this product family which cover different operating pressure ranges exhibit similar behavior. As can be seen from this figure, the output of this device varies with operating temperature. It is this variation with temperature which requires that the device be temperature compensated.

This temperature variation can be characterized in terms of the effect of temperature on (1) the full scale span, which is the change in output over the operating pressure range, and (2) the zero pressure offset, which is the output at zero applied pressure (differential or absolute, depending on the type of the device). The effect of temperature on these two characteristics is specified by the temperature coefficient of span, which is the slope of the straight line connecting the value of the full scale span at –40°C and +125°C normalized by the value of the full scale span at 25°C, and the temperature coefficient of offset, which is the slope of the straight line connecting the value of the zero pressure offset at –40°C and +125°C. To properly compensate the device for the effect of temperature, both the full scale span and the zero pressure offset must be temperature compensated.

TEMPERATURE COMPENSATION OF FULL SCALE SPAN

From Figure 1, it is evident that the full scale span of the X-ducer piezoresistive pressure sensor element decreases with increasing temperature. The typical temperature coefficient of span is –0.19%/°C, although this can vary somewhat from part to part. This temperature dependence is one of the better characterized operating parameters, depending on the bulk material properties of the diffused strain gauge. The primary factors which affect the temperature coefficient of span are the sheet resistance and the junction depth of the diffused strain gauge.

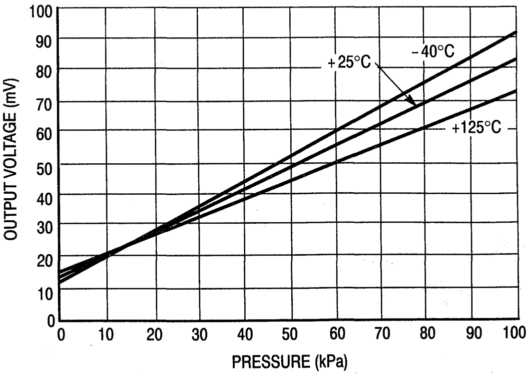


Figure 1. MPX100D Output Voltage versus Applied Pressure (3.0 Volts Excitation)

Since, at any fixed pressure, the output of the X-ducer piezoresistive pressure sensor element is ratiometric to the excitation voltage applied to the device, the most common method for the temperature compensation of full scale span is to increase the excitation voltage with increasing temperature in such a manner that it exactly opposes the decrease in full scale span with increasing temperature. Figure 2 shows an experimentally measured curve for the normalized excitation voltage required to compensate the full scale span of an MPX100D pressure sensor element over the temperature range of –40°C to +100°C. This curve is very linear with temperature, the expression for the excitation voltage V_X given in Figure 2 fitting the experimentally measured data with a regression coefficient of 0.99999. In this case, the temperature coefficient required for the excitation voltage in order to compensate the full scale span is +2102 ppm/°C. This value corresponds to a temperature coefficient of span of –2102 ppm/°C, which is on the low end of the specified value for this characteristic. However, the exact value is not important to the present discussion, and many of the design procedures outlined are valid for the entire range specified for the temperature coefficient of span for the X-ducer piezoresistive pressure sensor element.

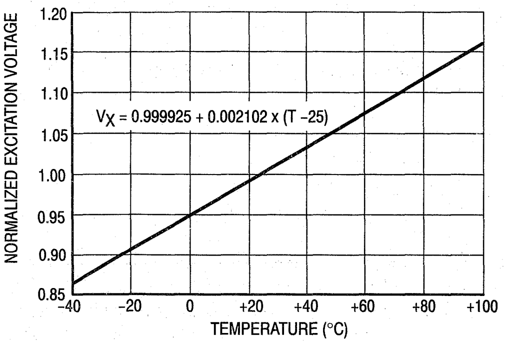


Figure 2. Normalized Excitation Voltage versus Temperature (For Constant Span)

There are many ways of generating a temperature dependent voltage such as that given in Figure 2 for the temperature compensation of full scale span. One of the simplest and most direct methods is to use the temperature characteristics of the resistance of the diffused strain gauge itself. Figure 3 shows the variation in the input resistance of the same device used for Figure 2 over the temperature range –40°C to +100°C. The expression for this resistance, R_X, given in the figure shows a small second order term which causes the temperature coefficient of resistance (TCR) to increase with increasing temperature. The TCR at 25°C is 2405 ppm/°C which agrees well with the specified typical value for the TCR of 0.24%/°C.

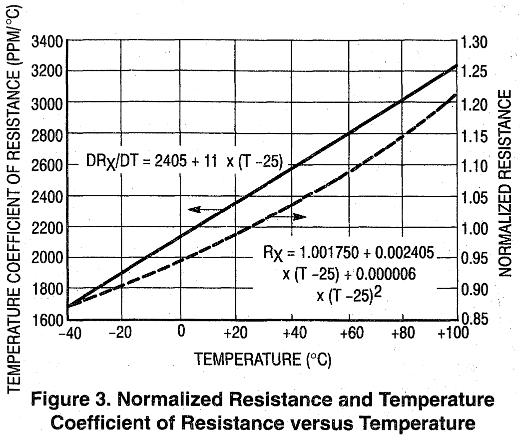


Figure 3. Normalized Resistance and Temperature Coefficient of Resistance versus Temperature

To understand how this temperature variation in the resistance of the X-ducer piezoresistive pressure sensor element can be used to temperature compensate the full scale span of the device, consider a hypothetical case where (1) the input resistance is linear with temperature and (2) the TCR is equal to 2102 ppm/°C. In this special case, if a constant current were to be used to excite the device, the excitation voltage V_X appearing across the diffused strain gauge would match exactly with the *ideal* value required for compensation of the full scale span given in Figure 2. This technique for temperature compensation of full scale span is called self-temperature compensation. There are several difficulties with the practical implementation of self-temperature compensation methods, however, notably the fact that the TCR of the device and the temperature coefficient of span must be exactly equal in magnitude and opposite in sign. In actual practice, there is little chance that this condition will be satisfied.

Because of this, the X-ducer piezoresistive pressure sensor element was intentionally designed so that the TCR of the device would be greater in absolute value than the temperature coefficient of span. Under these conditions, the effective TCR of the sensor element can now be modified by placing additional passive resistive elements either in parallel or in series with the X-ducer. The effect of these passive elements is to reduce the TCR of the network involving these passive elements and the X-ducer piezoresistive pressure sensor element. If the TCR of the X-ducer is greater than that required for perfect self-temperature compensation, the effective TCR of the network can be lowered to a point where self-temperature compensation can be realized. All the methods described herein for temperature compensation of full scale span utilize this approach to achieve self-temperature compensation.

SELF-TEMPERATURE COMPENSATION

As noted in the previous section, to achieve self-temperature compensation using the X-ducer piezoresistive pressure sensor, additional passive resistive components must be placed in a network with the X-ducer to reduce the TCR of the device to the point needed for self-temperature compensation. While there are many such networks, the simplest ones are: (1) a single resistive element in parallel with the X-ducer, and (2) a single resistive element in series with the X-ducer. Here, we will restrict our considerations to these two simple cases. As will be seen, both of these networks can give excellent temperature compensation.

For perfect temperature compensation of the full scale span, the excitation voltage, $V_X(T)$, must match that shown in Figure 2. Therefore, the objective is to obtain an excitation voltage of the form

$$V_X(T) = V_X\,h(T) \qquad (1)$$

where

$$h(T) = 0.999925 + 0.002102 \times (T-25). \qquad (2)$$

To do this, we will place a passive resistive element in either parallel or series with the X-ducer piezoresistive pressure sensor element which has a resistance, R(T), of the form

$$R(T) = R\,g(T) \qquad (3)$$

where g(T) is a function of temperature yet to be defined. The definition is determined by the fact that when this resistive element is placed in either parallel or series with the X-ducer, the temperature variation of the excitation voltage must match that given by Equation 1.

We know that the resistance of the X-ducer, $R_X(T)$ is given by the equation

$$R_X(T) = R_X\, f(T) \qquad (4)$$

where

$$f(T) = 1.001750 + 0.002405 \times (T-25) + 0.00006 \times (T-25)^2. \qquad (5)$$

Therefore, it can be easily shown that for a series resistive element, the function g(T) must be given by

$$g(T) = (R_X/R)\, f(T)\, [(1 + R/R_X)/h(T) - 1]. \qquad (6)$$

Similarly, for a parallel resistive element, the function g(T) must satisfy the relationship

$$g(T) = h(t)f(T)/[(1 + R/R_X)f(T) - (R/R_X)h(T)]. \qquad (7)$$

Figures 4 and 5 show the behavior of the function g(T) for series and parallel compensation resistive elements respectively over the temperature range –40°C to +100°C. Characteristic curves are shown for various resistance ratios, $R{:}R_X$, of the resistance of the compensation resistive element to the resistance of the X-ducer. We will discuss the significance of these characteristic curves separately for the case of a parallel compensation resistive element and the case of a series compensation resistive element, since different techniques are required to achieve the desired temperature dependence, g(T), for the compensation resistive element.

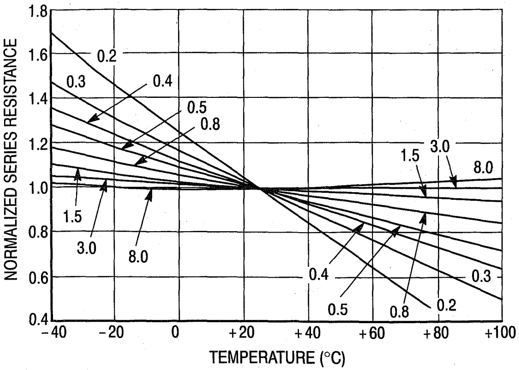


Figure 4. Normalized Series Resistance for "Ideal" Span Temperature Compensation versus Temperature for a Given Resistance Ratio ($R{:}R_X$)

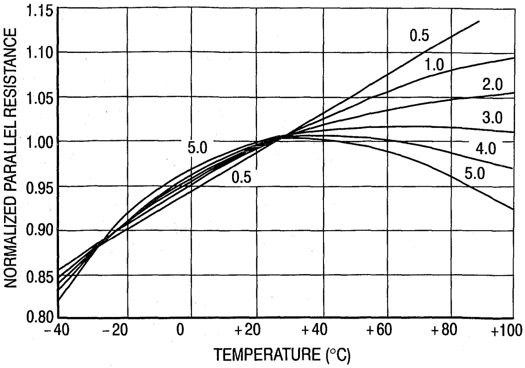


Figure 5. Normalized Series Resistance for "Ideal" Span Temperature Compensation versus Temperature for a Given Resistance Ratio ($R{:}R_X$)

SPAN COMPENSATION USING A PARALLEL RESISTIVE ELEMENT

The temperature compensation of span using a parallel resistive element can only be accomplished if the X-ducer is excited using a constant current source. If constant voltage excitation is required, the use of a parallel resistive element will not work for this application. Where a constant current source can be employed, however, the use of a parallel resistive element can give very good temperature compensation with very simple circuit components.

From Figure 5, it is apparent that for all practical resistance ratios, $R{:}R_X$, of the parallel resistive element to that of the X-ducer, a large and positive TCR is required for the parallel resistor. For resistance ratios less than one, this condition is true even at elevated temperatures. Moreover, the TCR of the parallel resistor for $R{:}R_X$ less than one is a constant to a good approximation for any given resistance ratio $R{:}R_X$. Figure 6 shows how the TCR of the parallel resistor required for *ideal* span temperature compensation must vary with the resistance ratio, $R{:}R_X$. This TCR was determined using a least-square regression analysis to determine the slope of the characteristic curves shown in Figure 5 for $R{:}R_X$ less than one. The magnitude of this TCR is consistent with the use of semiconductor resistors as the parallel resistive element, although it may be necessary to use yet a second zero TCR high value resistor in parallel with the semiconductor resistor to linearize the TCR of this element. Note too that the presence of this linearization resistor will further decrease the effective TCR of the total parallel network and allowance should be made for this effect.

A particularly simple yet effective span temperature compensation can be achieved for temperatures around room temperature by noting in Figure 5 that for resistance ratios, $R{:}R_X$, between 3.0 and 4.0, the behavior of the parallel resistor approximates that of a zero TCR resistor. Figure 7 shows the span compensation error, determined by the percent deviation of the true excitation voltage from that given in Figure 2, realized using zero TCR resistors as the parallel resistive element. As can be seen from this figure, the use of zero TCR parallel resistors in the resistance ratio range of 3.0 to 4.0 can produce temperature compensation sufficient to limit the span compensation error to less than ±1.0% from 0° to +120°C. While the low temperature compensation is not good, this type of span compensation is very well suited to many applications where the X-ducer is not subject to or required to perform accurately at low temperatures. It should be noted, however, that the totally uncompensated X-ducer has a self-temperature compensation characteristic which gives very good low temperature span compensation. This is also shown in Figure 7. A constant current source must be used with the uncompensated X-ducer to achieve this result, just as in the case of the parallel compensation resistor.

While the use of parallel resistor span temperature compensation can be very simple, yet give very good compensation, this technique is not without its limitations. Thus, the X-ducer itself is a low input impedance device with a typical input resistance of 400-550 ohms. While this low impedance minimizes noise problems, it can impose a heavy drain on a current source in order to obtain excitation voltage levels of 3.0 volts or greater. In addition, if the supply voltage is limited (for example, to 5.0 volts maximum), increases in the resistance of the X-ducer with increasing temperature could create a condition where there is not sufficient voltage across the current source to maintain its operation. Because of these problems, the use of the parallel resistive element span compensation technique is not recommended in applications where the current supply is limited or where there are requirements that the X-ducer be operated at low supply voltages and elevated temperatures.

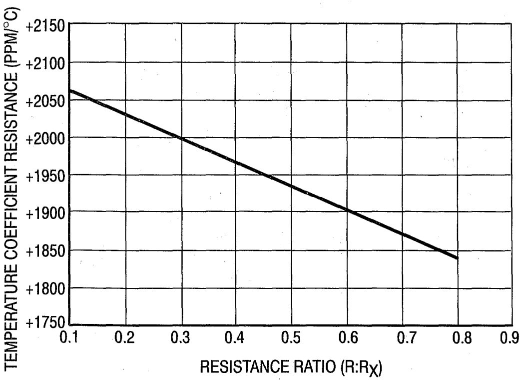


Figure 6. Temperature Coefficient of Resistance for a Parallel Resistance Required for "Ideal" Span Temperature Compensation versus Resistance Ratio ($R{:}R_X$)

SPAN COMPENSATION USING A SERIES RESISTIVE ELEMENT

Span temperature compensation using a series resistive element assumes that a constant supply voltage is employed. The desired excitation voltage, $V_X(T)$, then appears as a result of the voltage divider network formed by the series resistor and the X-ducer piezoresistive pressure sensor element. While this technique is more complex than that of parallel span compensation, it can provide the highest accuracies and cover the widest range of temperatures. The major reason that the use of a series compensation resistor is more complex than the use of a parallel resistor is that, as can be seen from Figure 4, the TCR of the series resistor must be negative for most resistance ratios, $R{:}R_X$, of the series resistors to the X-ducer resistance.

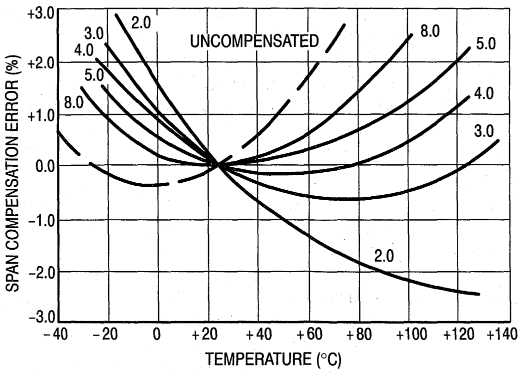


Figure 7. Span Compensation Error versus Temperature for a Given Resistance Ratio ($R{:}R_X$) Using Zero TCR Compensation Resistors

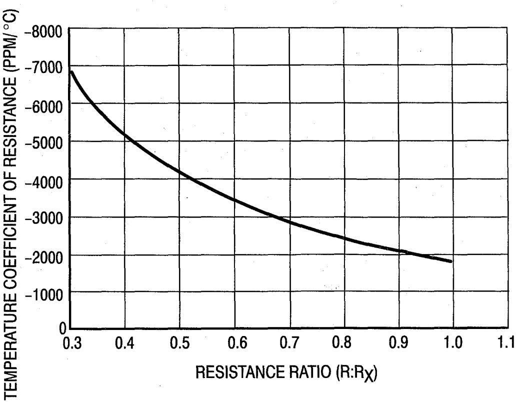


Figure 8. Temperature Coefficient of Resistance for a Series Resistance Required for "Ideal" Span Temperature Compensation versus Resistance Ratio ($R{:}R_X$)

There is one particularly simple case for span temperature compensation using a series resistor, that being where the resistance ratio, $R{:}R_X$, is near 3.0. From Figure 4 again, it is evident that for this case, a zero TCR resistor will provide good span temperature compensation for temperatures around room temperature. In fact, it can be easily shown that the span compensation error resulting from the use of a zero TCR series resistor is identical to that shown in Figure 7 for span compensation using a parallel zero TCR resistor. However, when this resistor is used in series rather than in parallel, the magnitude of the excitation voltage, $V_X(T)$, actually applied to the X-ducer (and hence the magnitude of the output signal) is considerably reduced due to the dividing of the supply voltage across the series resistor. Much lower current drains can be obtained in this manner, however, and this technique can work well where there is sufficient supply voltage to tolerate the loss in excitation voltage applied to the X-ducer.

To minimize the loss in excitation voltage due to the use of a series resistor for span compensation, it is obvious that the resistance ratio, $R:R_X$, of the series resistor to the X-ducer should be kept as small as possible. However, referring to Figure 4, it is evident that as the resistance ratio, $R:R_X$, gets smaller the TCR of the series resistor must become increasingly negative. For values of $R:R_X$ of 0.8 or less, the required TCR of the series resistor closely approximates a constant value, since the characteristic curves shown in Figure 4 are very nearly linear with temperature for ratios of $R:R_X$ less than 0.8. Figure 8 shows the variation in the TCR required for *ideal* span temperature compensation using a series resistor as a function of the resistance ratio, $R:R_X$. This TCR was determined using a least-square linear regression to determine the slope of the characteristic curves shown in Figure 4 for $R:R_X$ less than or equal to 1.0.

The problem with this approach to span temperature compensation is that negative TCR resistors are not common. The closest approximation to a negative TCR resistor is found in thermistors. These are oxide semiconductor materials which show large, nonlinear decreases in resistance with increasing temperature. Empirically, it has been found that the temperature behavior of these thermistors can best be described by an exponential function of the form

$$R(T) = R(25°C) \exp \beta[1/(T + 273) - 1/298] \qquad (8)$$

where the parameter β (which has the units of °K) is equivalent to the TCR for resistors. While a thermistor, itself, is highly nonlinear, a good linear, negative TCR network can be achieved by placing a zero TCR resistor in parallel with the thermistor. The linearity of this parallel network's resistance with temperature and the TCR both depend on the ratio of the parallel resistor to the thermistor as well as the β of the thermistor. Figure 9 shows the effect of different parallel resistance ratios on the temperature dependence of a thermistor with a β of 1250° K. In this case, a linear resistance with a negative TCR is obtained for a resistance ratio of 0.5 or less.

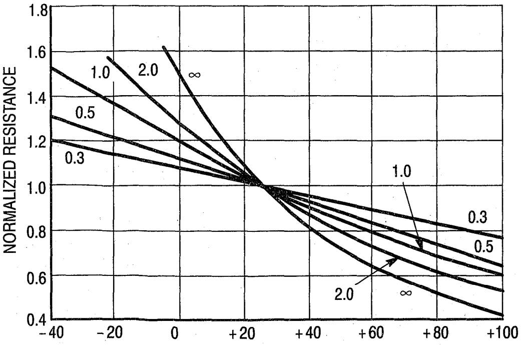


Figure 9. Thermistor:Resistor Parallel Network Normalized Resistance versus Temperature for a Given Resistance Ratio $R_{PARALLEL}:R_{THERMISTOR}$ (β = 1250)

For a thermistor of any given β, an appropriate parallel resistance can be determined which will match the TCR of the thermistor: resistor network to the TCR required for *ideal* span temperature compensation given in Figure 8. This can be done using either a trial-and-error approach or a root solving method. Figure 10 shows the results of this calculation for a given set of thermistor β values ranging from 1000°K to 3000°K. From the set of curves given in this figure, for any given resistance ratio $R_{NETWORK}:R_X$ (which determines from Figure 8 the TCR required for *ideal* span compensation), the ratio $R_{PARALLEL}:R_{THERMISTOR}$ can be found for a particular thermistor β which will make the TCR of the thermistor:resistor parallel network equal to the TCR required for span compensation. Figure 11 is a plot of the same data given in Figure 10, only in this case the ratio $R_{PARALLEL}:R_{THERMISTOR}$ is plotted versus the thermistor β for a given resistance ratio $R_{NETWORK}:R_X$. It should be emphasized that both Figures 10 and 11 are based on approximations of linearity and constant TCR's and, because of this, should be used only as guides to the selection of the thermistor:resistor network required for span temperature compensation.

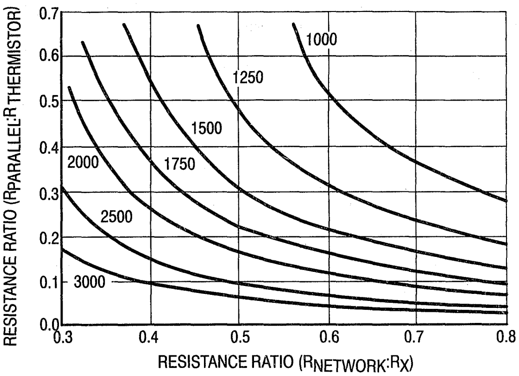


Figure 10. $R_{PARALLEL}:R_{THERMISTOR}$ for Span Temperature Compensation versus $R_{NETWORK}:R_X$ for a Given Thermistor Beta

SAMPLE CALCULATIONS OF SPAN COMPENSATION USING THERMISTORS

Since the results given in Figures 10 and 11 may appear somewhat confusing at first, it is worthwhile to illustrate the use of the figures with some examples. Thus, consider the following problem:

Problem: A MPX100D X-ducer has an input resistance of 450 ohms at 25°C and a temperature coefficient span of –0.21%/°C. It is required that the excitation voltage on the X-ducer be 4.0 volts at 25°C. The supply voltage is 6.0 volts. Select a thermistor:resistor parallel network which will temperature compensate the span of the X-ducer when placed in series with the X-ducer.

Solution: In order for the excitation voltage to be 4.0 volts with a 6.0 volts supply voltage, the resistance ratio

$R_{NETWORK}:R_X$ must be equal to 0.5. Since the X-ducer has a resistance of 450 ohms, this means that the thermistor: resistor parallel network must have a resistance of 225 ohms. Referring to Figure 10, for a resistance ratio of 0.5, it can be seen that there is an infinite number of networks which satisfy the TCR requirement for span compensation, depending on the β of the thermistor. Since the choice of this β is arbitrary, we will select a thermistor with a β of 1250°K. In this case, Figure 10 shows that a resistance ratio of $R_{PARALLEL}:R_{THERMISTOR}$ equal to 0.485 is required to give the TCR required for span temperature compensation.

Figure 12 shows a plot of the span compensation error resulting from this choice of thermistor β and parallel resistance ratio. Also shown in this figure is the span compensation error for resistance ratios, $R_{PARALLEL}:R_{THERMISTOR}$, equal to 0.45 and 0.52. As can be seen from this figure, the value of 0.45 for the parallel resistance ratio gives an even better temperature compensation than does the value of 0.485 selected using Figure 10. Therefore, it can be concluded that a thermistor of β equal to 1250°K and 25°C resistance of 725 ohms in parallel with a 326 ohm resistor will give good span compensation when placed in series with the MPX100D X-ducer.

It is important to note in the above example that although the results of Figure 10 gave a value of 0.485 for the parallel resistance ratio, the span compensation error plot showed that a value of 0.45 gave even better span compensation. This reflects the approximate nature of the results given in Figure 10 and emphasizes the importance of the span compensation error plot. The results of Figure 10 should only be used as a guide to the selection of the approximate values required for span compensation. The actual compensation values should be selected by evaluating the span compensation error for all values in the vicinity of that selected from Figure 10. Figures 13 and 14 show the effect of variations in the ratio $R_{NETWORK}:R_X$ and the β of the thermistor respectively on the span compensation error. While these effects are not large, they can be significant where high accuracy is required.

Problem: A MPX200A X-ducer has a resistance of 480 ohms at 25°C and a temperature coefficient of span of –0.19%/°C. A thermistor is available which has a resistance of 900 ohms at 25°C with a β of 1500°K. It is desired to have an excitation voltage of 3.5 volts on the X-ducer at 25°C when the device is compensated by a series network using this thermistor. The supply voltage is 5.0 volts. Determine the value of the resistor to be placed in parallel with this thermistor to obtain span temperature compensation.

Solution: To obtain an excitation voltage of 3.5 volts at 25°C, the resistance ratio $R_{NETWORK}: R_X$ must be equal to 0.43. Since the X-ducer has a resistance of 480 ohms at 25°C, the network resistance must be equal to 206 ohms. The parallel resistor required to give this value when used with the 900 ohm thermistor is 267 ohms. Therefore, the resistance ratio, $R_{PARALLEL}: R_{THERMISTOR}$, is equal to 0.30. Referring to Figure 10, a problem is immediately obvious, since this figure indicates that for a β of 1500°K, the required resistance ratio, $R_{PARALLEL}: R_{THERMISTOR}$, must be equal to 0.49 for $R_{NETWORK}: R_X$ equal to 0.43. From Figure 11, we can see that the β of the thermistor is too low, a value of approximately 2000°K being indicated by this figure. Therefore, an inconsistent set of values has been selected for this X-ducer. However, note that the temperature coefficient of span of the X-ducer is –1900 ppm/°C, whereas the results given in Figures 10 and 11 assume a value of –2100 ppm/°C. Therefore, we should not be hasty in drawing any firm conclusions at this point. In fact, a span compensation error plot using these values gives a maximum error of +2.11% at –40°C and shows an error of less than ±0.50% from 0°C to +125°C. Thus the available thermistor can give good temperature compensation of span for this X-ducer over a limited range of temperature.

In the example presented above, a situation was encountered where the problem was overdetermined. It was not possible to satisfy the conditions for span compensation required by Figure 10 using the values given in the problem. To avoid situations like this, Figure 10 can be modified to show the interdependence between the two resistance ratios, $R_{NETWORK}:R_X$ and $R_{PARALLEL}:R_{THERMISTOR}$, when both the resistance of the thermistor and the resistance of the X-ducer are given. Figure 15 shows the same data as Figure 10, only with the addition of isocontours for constant resistance ratios $R_{THERMISTOR}:R_X$ (the dashed lines in the figure). To illustrate the use of this figure, consider the following problem:

Problem: An MPX50D X-ducer has a resistance of 470 ohms at 25°C and a temperature coefficient of span of –0.20%/°C. A thermistor is available which has a resistance at 25°C of 1100 ohms and a β of 1250°K. Determine the value of the excitation voltage, V_X, at 25°C and the parallel resistor required to span compensate this device.

Solution: The ratio $R_{THERMISTOR}: R_X$ for this case is equal to 2.3. Referring to Figure 15, for a β of 1250°K, the curve for the ratio $R_{THERMISTOR}:R_X$ equal to 2.3 would cross the compensation curve at the approximate values of $R_{PARALLEL}:R_{THERMISTOR}$ equal to 0.33 and $R_{NETWORK}:R_X$ equal to 0.58. Using a span compensation error plot, it is found that the best span compensation occurs at the values $R_{NETWORK}:R_X$ equal to 0.58 and $R_{PARALLEL}:R_{THERMISTOR}$ equal to 0.31. The resulting compensation error is 1.13% at –40°C and less than ±0.8% between –20°C and +125°C. The excitation voltage on the X-ducer for these values is equal to 63% of the supply voltage and the required parallel resistor is equal to 341 ohms.

As in the first example, the span compensation error plot revealed that the resistance ratios required for *ideal* span temperature compensation as determined from Figure 15 were not the optimal values. In this case, this is probably due to the fact that we had to infer where the isocontour for the ratio $R_{THERMISTOR}: R_X$ equal to 2.3 was located since the nearest value was 2.5. This demonstrates again the value of using the span compensation error plot as the means for determining the proper span compensation conditions.

Summarizing the results of this section, several general features associated with the use of thermistors to span compensate the X-ducer piezoresistive pressure sensor element can be noted.

(1) When both the X-ducer and the thermistor have fixed resistance values, there is only one excitation voltage (as a percent of the supply voltage) and one parallel resistance value which will give the proper span temperature compensation for a given β.

(2) The shape of the compensation curves shown in Figure 10 indicate that the best compensation can be achieved at low values for the resistance ratio $R_{NETWORK}$: R_X, since variations in the resistance ratio $R_{PARALLEL}$:$R_{THERMISTOR}$ result in less deviation from the *ideal* span compensation curve.

(3) As can be seen in Figures 12, 13, and 14, the span compensation error is generally a sigmoidal curve. Increasing either of the required resistance ratios or the β of the thermistor tends to rotate this sigmoidal curve in a counter-clockwise direction about the 25°C point.

(4) The use of low β thermistors tends to give better span temperature compensation. This follows to some degree from the conditions noted in (2) above.

(5) A span compensation error plot should always be used to verify the selected resistance ratios for span compensation, particularly if high accuracy is required.

OFFSET VOLTAGE TEMPERATURE COMPENSATION

One of the primary reasons for the use of the transverse voltage piezoresistive strain gauge found in the X-ducer is that it provides an electrical signal from a single diffused resistive element. Unlike the more conventional piezoresistive pressure sensor devices which employ a Wheatstone bridge, the transverse voltage strain gauge does not have to be matched with other diffused resistors in either its resistance or its temperature coefficient of resistance. Therefore, the zero pressure offset voltage and the temperature coefficient of this offset voltage depend only on the resolution limits of photolithography, which can be very accurately controlled with the technology available within the semiconductor industry.

Indeed the offset voltage of the X-ducer and its temperature coefficient are very well controlled, the offset voltage typically ranging between 0 and 20 millivolts and the temperature coefficient of the offset typically being on the order of ±15 microvolts/°C when the X-ducer is excited at a constant 3.0 volt. Both of these characteristics can vary, however, and provision must be made for the temperature compensation of the offset voltage as well as the span if high accuracy is required over an extended temperature range.

Even in those cases where the temperature coefficient of offset is acceptably small, provision must generally be made for offset temperature compensation for other reasons. Thus, consider Figure 16 which shows schematics for the span temperature compensation methods discussed in the previous sections.

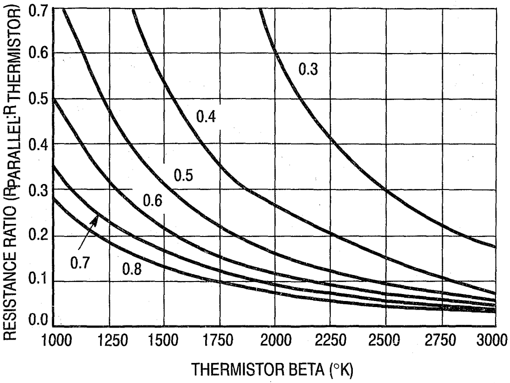


Figure 11. $R_{PARALLEL}$:$R_{THERMISTOR}$ for Span Temperature Compensation versus Thermistor Beta for a Given $R_{NETWORK}$:R_X

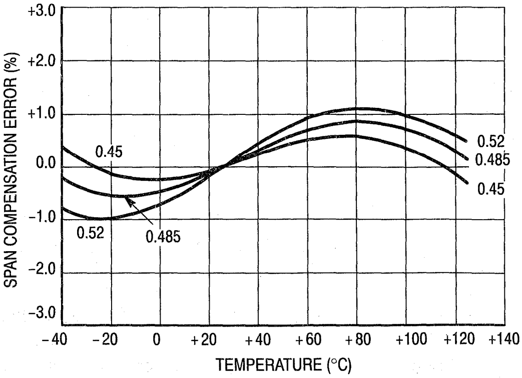


Figure 12. Span Compensation Error versus Temperature ($R_{NETWORK}$:R_X = 0.5, β = 1250) for a Given Resistance Ratio $R_{PARALLEL}$:$R_{THERMISTOR}$

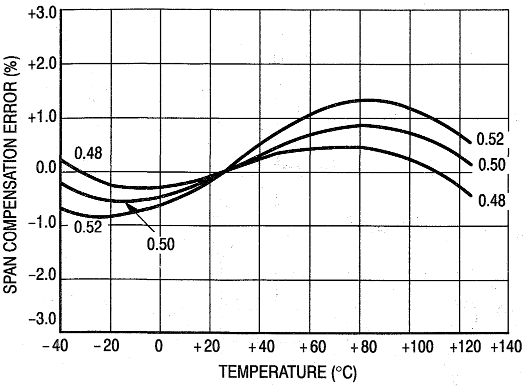


Figure 13. Span Compensation Error versus Temperature $R_{PARALLEL}:R_{THERMISTOR} = 0.485$ $\beta = 1250$ for Given Resistance Ratio $R_{NETWORK}:R_X$

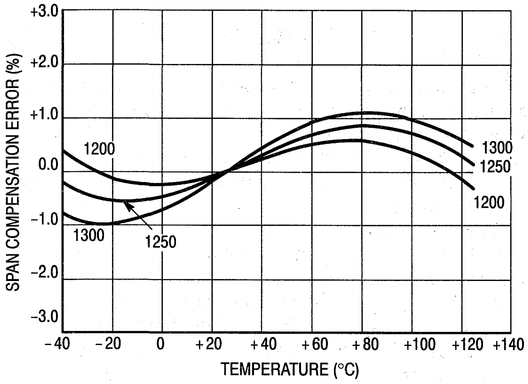


Figure 14. Span Compensation Error versus Temperature ($R_{PARALLEL}:R_{THERMISTOR} = 0.485$) ($R_{NETWORK}:R_X = 0.50$) for a Given Thermistor Beta

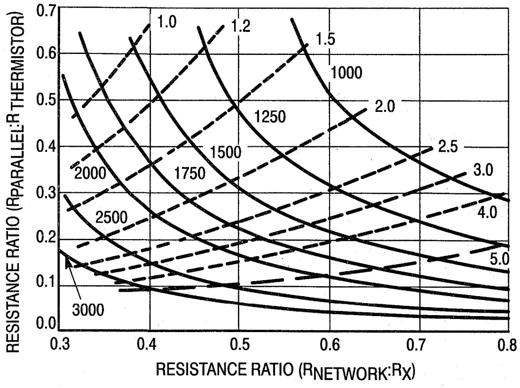


Figure 15. $R_{PARALLEL}:R_{THERMISTOR}$ for Span Temperature Compensation versus $R_{NETWORK}:R_X$ for a Given $R_{THERMISTOR}:R_X$

In all these cases, span temperature compensation is accomplished by introducing a temperature dependent excitation voltage, $V_X(T)$, which increases with increasing temperature to compensate for the decrease in span with increasing temperature. However, the zero pressure offset voltage is proportional to the excitation voltage applied to the X-ducer just as is the span. Therefore, the process of temperature compensating span automatically introduces a positive temperature component into the temperature dependence of the offset voltage.

This problem can be minimized by restoring to a balanced span compensation network such as is shown in Figure 17. In this example, the span compensation is split between the top and the bottom of the X-ducer. This results in the common mode voltage at the output of the X-ducer remaining constant over temperature, since the transverse voltage strain gauge acts as a simple voltage divider in the absence of any applied pressure. However, if amplification of the output signal of the X-ducer is required, additional temperature effects can be introduced in the associated circuitry by, for example, the temperature coefficient of the offset voltage of operational amplifiers. Because of these considerations, the general approach to the temperature compensation of the offset voltage of the X-ducer has been to temperature compensate the system rather than the X-ducer piezoresistive pressure sensor element itself.

The simplest method for accomplishing this system offset voltage temperature compensation is to utilize the temperature dependent voltage, $V_X(T)$, already present in the system as a result of the span temperature compensation process. Figure 18 shows a generalized circuit diagram for the signal conditioning of the X-ducer piezoresistive pressure sensor element which incorporates both span and offset temperature compensation. Both positive and negative temperature coefficients of offset can be accommodated, depending on which input of differential amplifier OA_2 is connected to the temperature dependent excitation voltage, $V_X(T)$. This circuit is quite simple, consisting of a buffer amplifier (OA_1) which amplifies the differential output of the X-ducer and minimizes the loading of these outputs (this is important due to the high output impedance of the X-ducer which is on the order of 1.0 kΩ), and a summing amplifier (OA_2) which provides for the adjustment of both span and offset as well as incorporating temperature compensation of the offset voltage. In general, the major gain stage should be in the buffer amplifier (OA_1), since the temperature coefficient of the amplifier offset voltage will also be amplified and can be compensated for by the summing action of OA_2. The summing amplifier (OA_2) should provide only enough gain to allow for the adjustment of span and offset, since it will amplify its own temperature coefficient of offset as well as any higher order temperature dependent voltages which can not be compensated for by the linearly temperature dependent voltage, $V_X(T)$.

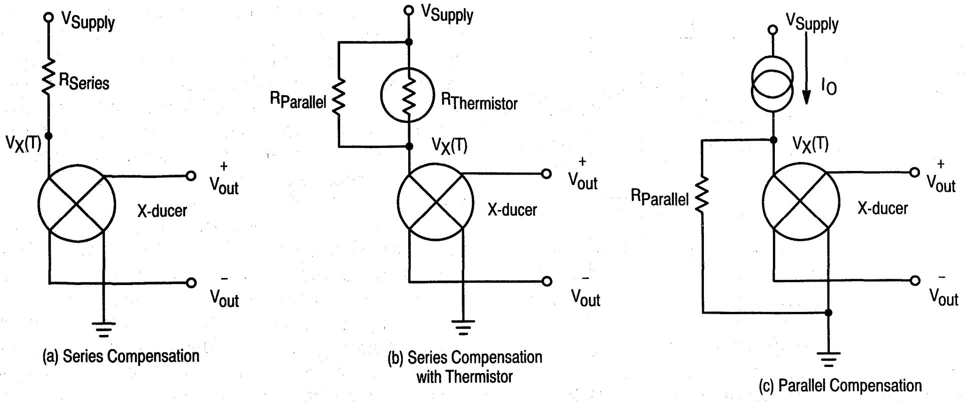


Figure 16. Schematic for Span Temperature Compensation Methods

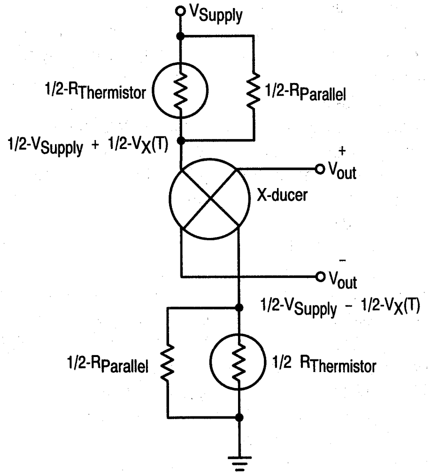
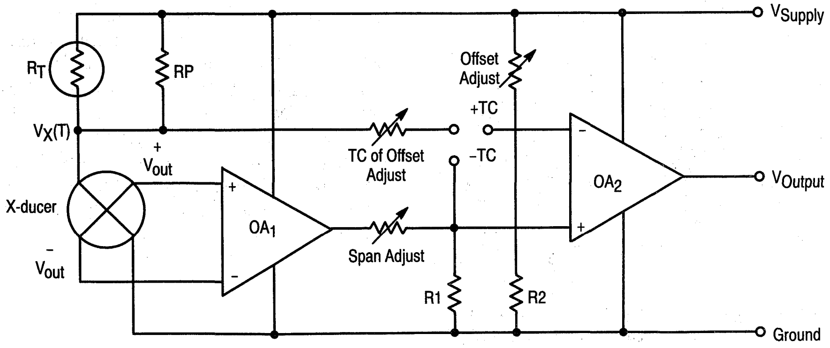


Figure 17. Balanced Series Span Compensation Using Two Thermistor:Resistor Parallel Networks

SUMMARY

Temperature compensation of both span and offset voltage for the X-ducer piezoresistive pressure sensor can be accomplished using relatively simple passive elements to generate temperature dependent voltages which act in a manner counter to the temperature characteristics of the X-ducer. These techniques are capable of providing accuracies of better than ±1% over a temperature range from –40°C to +125°C. Span temperature compensation elements can be selected using design guides presented in the previous sections of this note. The temperature compensation of the offset voltage is less well defined, but should generally be considered from a system viewpoint unless very costly circuits can be accepted.

While the computational methods used in this Application Note may appear laborious, they are well worthwhile. In fact, they are not that difficult. The calculations used in this note have been performed on a programmable hand calculator.



NOTE: OA_1 and OA_2 are generalized differential amplifiers employing negative feedback gain and stabilization.

Figure 18. Generalized Signal Conditioning Circuit for the X-ducer Piezoresistive Pressure Sensor Element, Including Span and Offset Temperature Compensation

AN935

Compensating for Nonlinearity in the MPX10 Series Pressure Transducer

Prepared by: Carl Demington
Design Engineering

INTRODUCTION

This application note describes a technique to improve the linearity of Motorola's MPX10 series pressure transducers when they are interfaced to a microprocessor system. The linearization technique allows the user to obtain both high sensitivity and good linearity in a cost effective system.

The MPX10, MPX11 and MPX12 pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure over the pressure range of 0-10 kPa (0-75 mm Hg). These devices use a unique transverse voltage-diffused silicon strain-gauge which is sensitive to stress produced by pressure applied to a thin silicon diaphragm.

One of the primary considerations when using a pressure transducer is the linearity of the transfer function, since this parameter has a direct effect on the total accuracy of the system, and compensating for nonlinearities with peripheral circuits is extremely complicated and expensive. The purpose of this document is to outline the causes of nonlinearity, the trade-offs that can be made for increased system accuracy, and a relatively simple technique that can be utilized to maintain system performance, as well as system accuracy.

ORIGINS OF NONLINEARITY

Nonlinearity in semiconductor strain-gauges is a topic that has been the target of many experiments and much discussion. Parameters such as resistor size and orientation, surface impurity levels, oxide passivation thickness and growth temperatures, diaphragm size and thickness are all contributors to nonlinear behavior in silicon pressure transducers. The Motorola X-ducer was designed to minimize these effects. This goal was certainly accomplished in the MPX50, MPX100 and MPX200 series which have a maximum nonlinearity of 0.1% FS. However, to obtain the higher sensitivity of the MPX10 series, a maximum nonlinearity of ±1% FS has to be allowed. The primary cause of the additional nonlinearity in the MPX10 series is due to the stress induced in the diaphragm by applied pressure being no longer linear.

One of the basic assumptions in using semiconductor strain-gauges as pressure sensors is that the deflection of the diaphragm when pressure is applied is small compared to the thickness of the diaphragm. With devices that are very sensitive in the low pressure ranges, this assumption is no longer valid. The deflection of the diaphragm is a considerable percentage of the diaphragm thickness, especially in devices with higher sensitivities (thinner diaphragms). The resulting stresses do not vary linearly with applied pressure. This behavior can be reduced somewhat by increasing the area of the diaphragm and consequently thickening the diaphragm. Due to the constraint, the device is required to have high sensitivity over a fairly small pressure range, and the nonlinearity cannot be eliminated. Much care was given in the design of the MPX10 series to minimize the nonlinear behavior. However, for systems which require greater accuracy, external techniques must be used to account for this behavior.

PERFORMANCE OF AN MPX DEVICE

The output versus pressure of a typical MPX12 along with an end-point straight line is shown in Figure 1. All nonlinearity errors are referenced to the end-point straight line (see data sheet). Notice there is an appreciable deviation from the end-point straight line at midscale pressure. This shape of curve is consistent with MPX10 and MPX11, as well as MPX12 devices, with the differences between the parts being the magnitude of the deviation from the end-point line. The major tradeoff that can be made in the total device performance is sensitivity versus linearity.

Figure 2 shows the relationship between full scale span and nonlinearity error for the MPX10 series of devices. The data shows the primary contribution to nonlinearity is nonproportional stress with pressure, while assembly and packaging stress (scatter of the data about the line) is fairly small and well controlled. It can be seen that relatively good accuracies (<0.5% FS) can be achieved at the expense of reduced sensitivity, and for high sensitivity the nonlinearity errors increase rapidly. The data shown in Figure 2 was taken at room temperature with a constant voltage excitation of 3.0 volts.

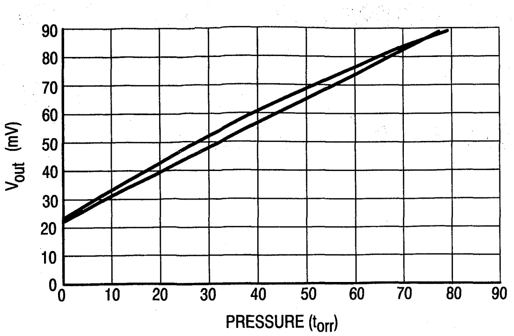


Figure 1. MPX12 Linearity Analysis Raw Data

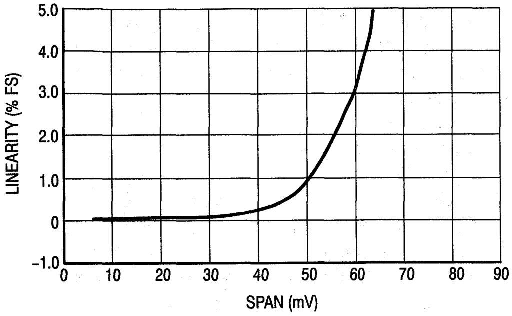


Figure 2. MPX10 Span versus Linearity

COMPENSATION FOR NONLINEARITY

The nonlinearity error shown in Figure 1 arises from the assumption that the output voltage changes with respect to pressure in the following manner:

$$V_{out} = V_{off} + sens*P \qquad [1]$$

where V_{off} = output voltage at zero pressure differential

sens = sensitivity of the device

P = applied pressure

It is obvious that the true output does not follow this simple straight line equation. Therefore, if an expression could be determined with additional higher order terms that more closely described the output behavior, increased accuracies would be possible. The output expression would then become

$$V_{out} = V_{off} + (B_0 + B_1 * P + B_2 * P^2 + B_3 * P^3 + \ldots) \qquad [2]$$

where B_0, B_1, B_2, B_3, etc. are sensitivity coefficients. In order to determine the sensitivity coefficients given in equation [2] for the MPX10 series of pressure transducers, a polynomial regression analysis was performed on data taken from 139 devices with full scale spans ranging from 30 to 730 mV. It was found that second order terms are sufficient to give excellent agreement with experimental data. The calculated regression coefficients were typically 0.999999+ with the worst case being 0.99999. However, these sensitivity coefficients demonstrated a strong correlation with the full scale span of the device for which they were calculated. The correlation of B_0, B_1, and B_2 with full scale span is shown in Figures 3 through 5.

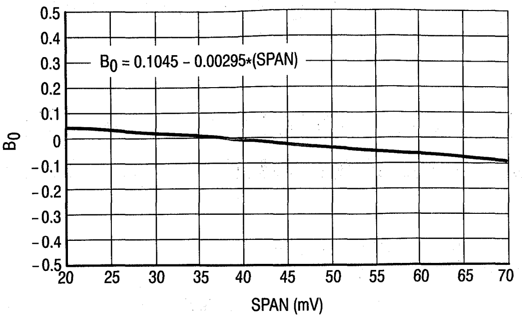


Figure 3. MPX10 Linearity Analysis — Correlation of B_0 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

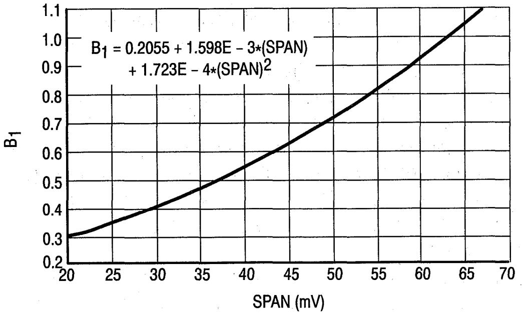


Figure 4. MPX10 Linearity Analysis — Correlation of B_1 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

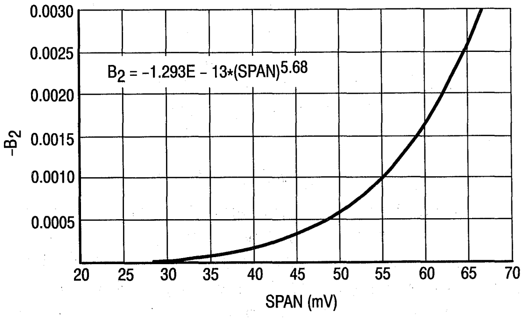


Figure 5. MPX10 Linearity Analysis — Correlation of B_2 $V_{out} = B_0 + B_1 (P) + B_2 (P)^2$

In order to simplify the determination of these coefficients for the user, further regression analysis was performed so that expressions could be given for each coefficient as a function of full scale span. This would then allow the user to do a single pressure measurement, a series of calculations, and analytically arrive at the equation of the line that describes the output behavior of the transducer. Nonlinearity errors were then calculated by comparing experimental data with the values calculated using equation [2] and the sensitivity coefficients given by the regression analysis. The resulting errors are shown in Figures 6 through 9 at various pressure points. While using this technique has been successful in reducing the errors due to nonlinearity, the considerable spread and large number of devices that showed errors >1% indicate this technique was not as successful as desired.

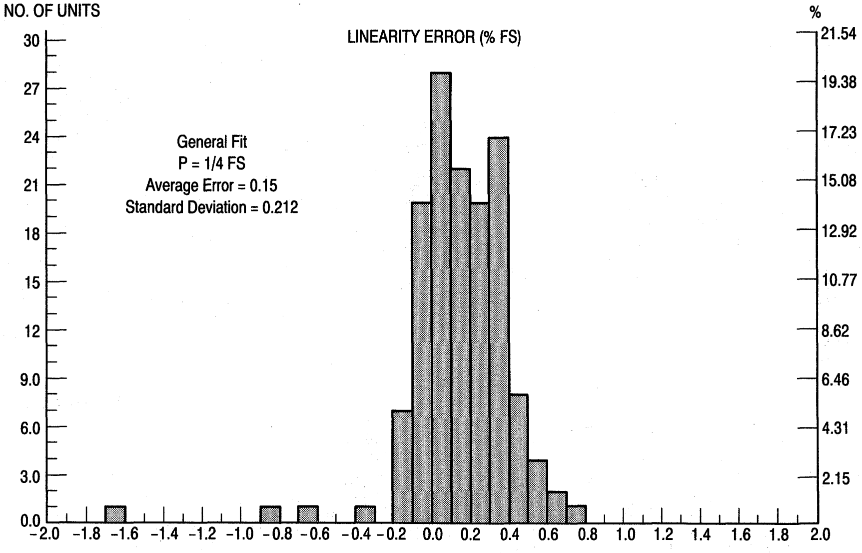


Figure 6. Linearity Error of General Fit Equation at 1/4 FS

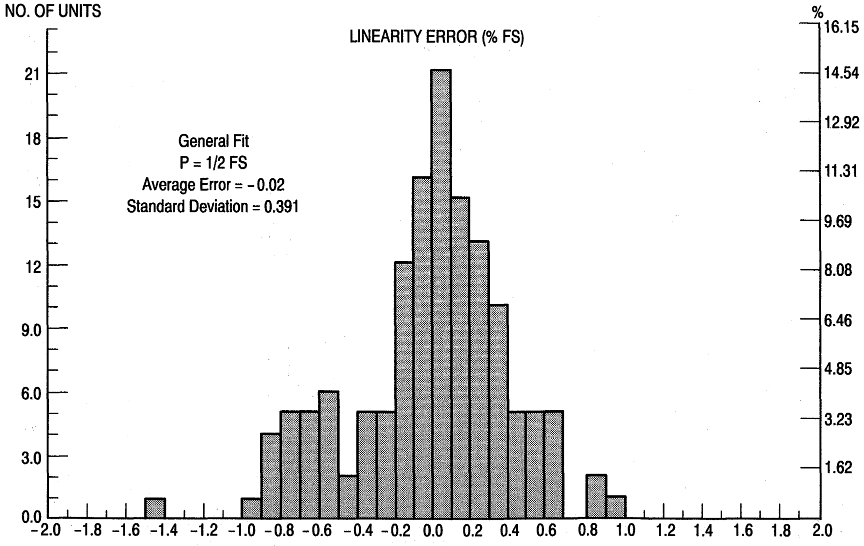


Figure 7. Linearity Error of General Fit Equation at 1/2 FS

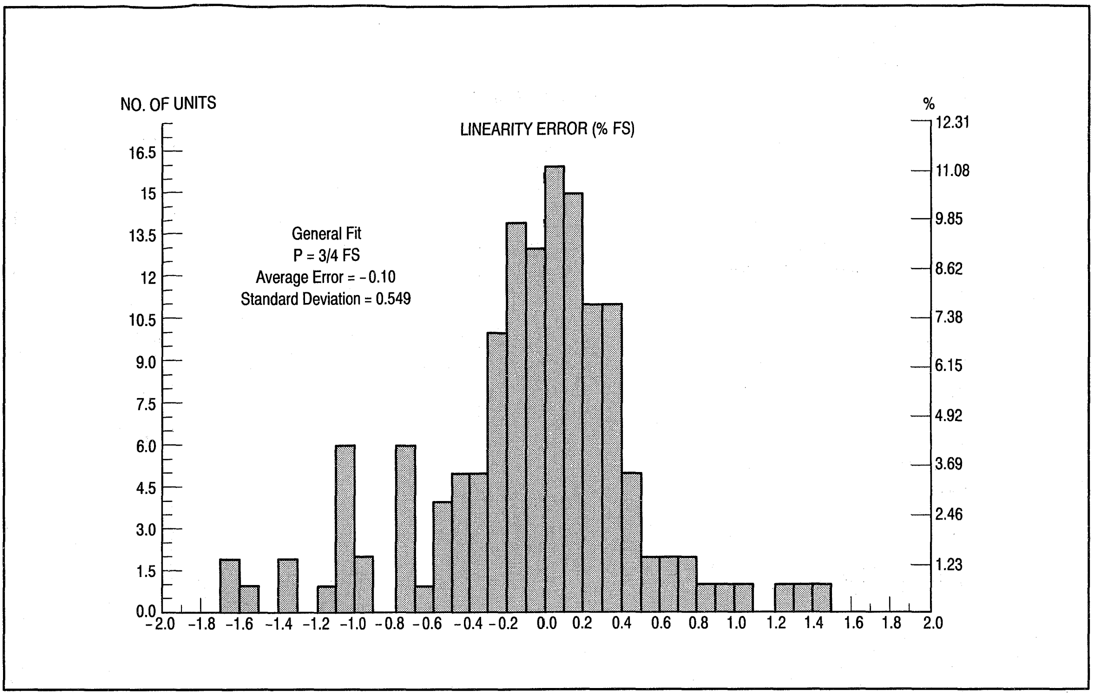


Figure 8. Linearity Error of General Fit Equation at 3/4 FS

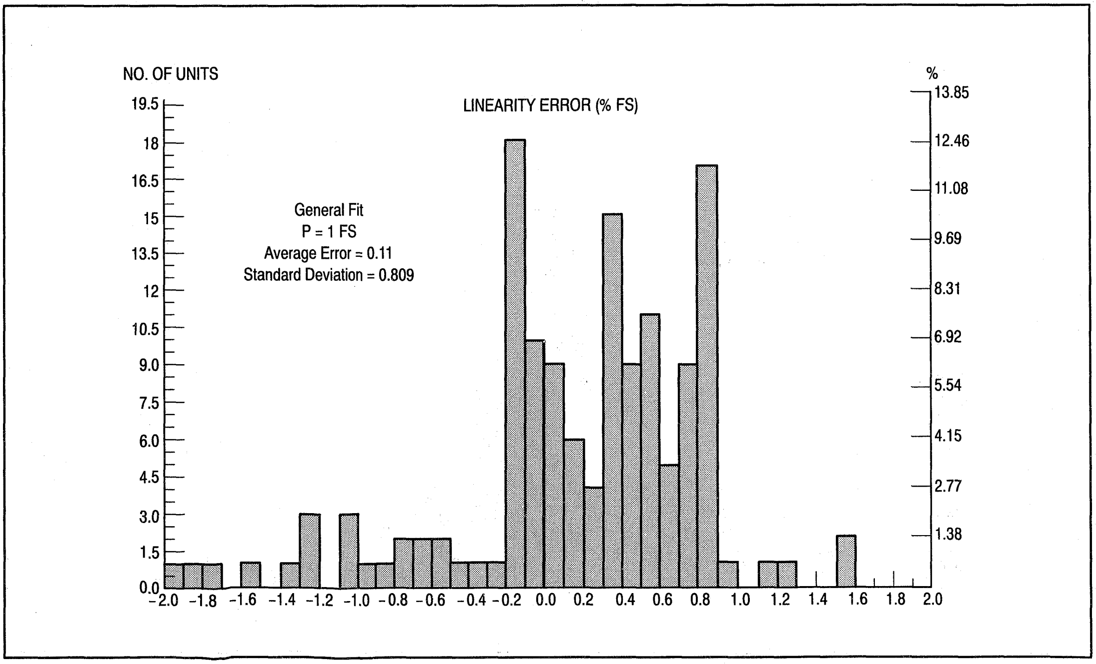


Figure 9. Linearity Error of General Fit Equation at FS

A second technique that still uses a single pressure measurement as the input was investigated. In this method, the sensitivity coefficients are calculated using a piece-wise linearization technique where the total span variation is divided into four windows of 10 mV (i.e., 30–39.99, 40–49.99, etc.) and coefficients calculated for each window. The errors that arise out of using this method are shown in Figures 10 through 13. This method results in a large majority of the devices having errors <0.5%, while only one of the devices was >1%. The sensitivity coefficients that are substituted into equation [2] for the different techniques are given in Table 1. It is important to note that for either technique the only measurement that is required by the user in order to clearly determine the sensitivity coefficients is the determination of the full scale span of the particular pressure transducer.

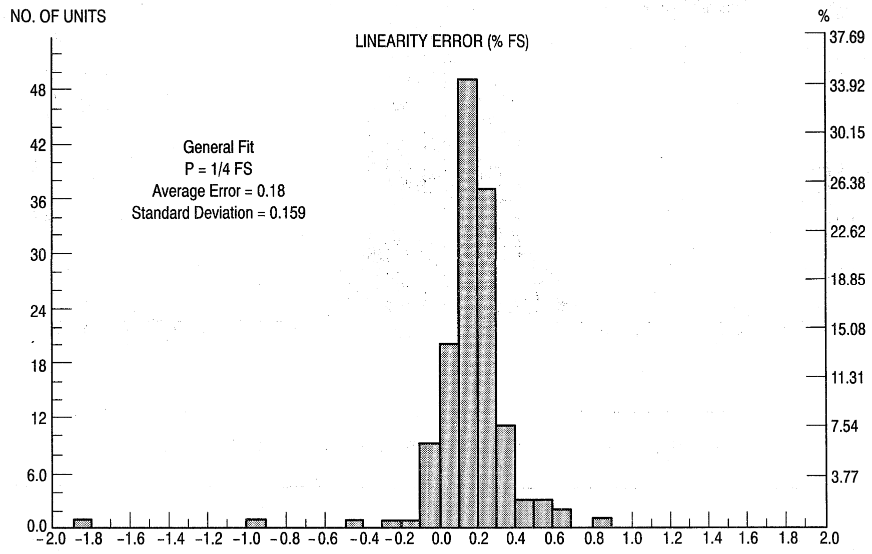


Figure 10. Linearity Error of Piece-Wise Linear Fit at 1/4 FS

Table 1. Comparison of Linearization Methods

SPAN WINDOW	B_0	B_1	B_2
	GENERAL FIT		
	0.1045 + 2.95E – 3X	0.2055 + 1.598E – 3X + 1.723E – $4X^2$	1.293E – $13X^{5.681}$
	PIECE-WISE LINEAR FIT		
30–39.99	0.08209 – 2.246E – 3X	0.02433 = 1.430E – 2X	–1.961E – 4 + 8.816E – 6X
40–49.99	0.1803 – 4.67E – 3X	–0.119 + 1.655E – 2X	–1.572E – 3 + 4.247E – 5X
50–59.99	0.1055 – 3.051E – 3X	–0.355 + 2.126E – 2X	–5.0813 – 3 + 1.116E – 4X
60–69.99	–0.288 + 3.473E – 3X	–0.361 + 2.145E – 2X	–5.928E – 3 + 1.259E – 4X

X = Full Scale Span

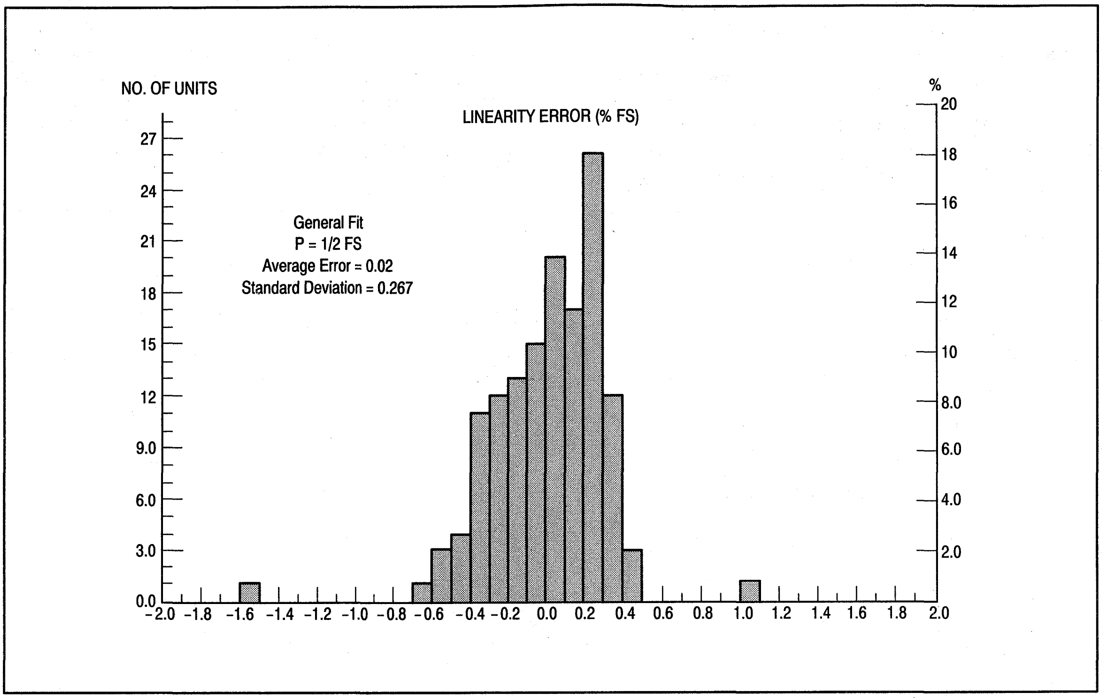


Figure 11. Linearity Error of Piece-Wise Linear Fit at 1/2 FS

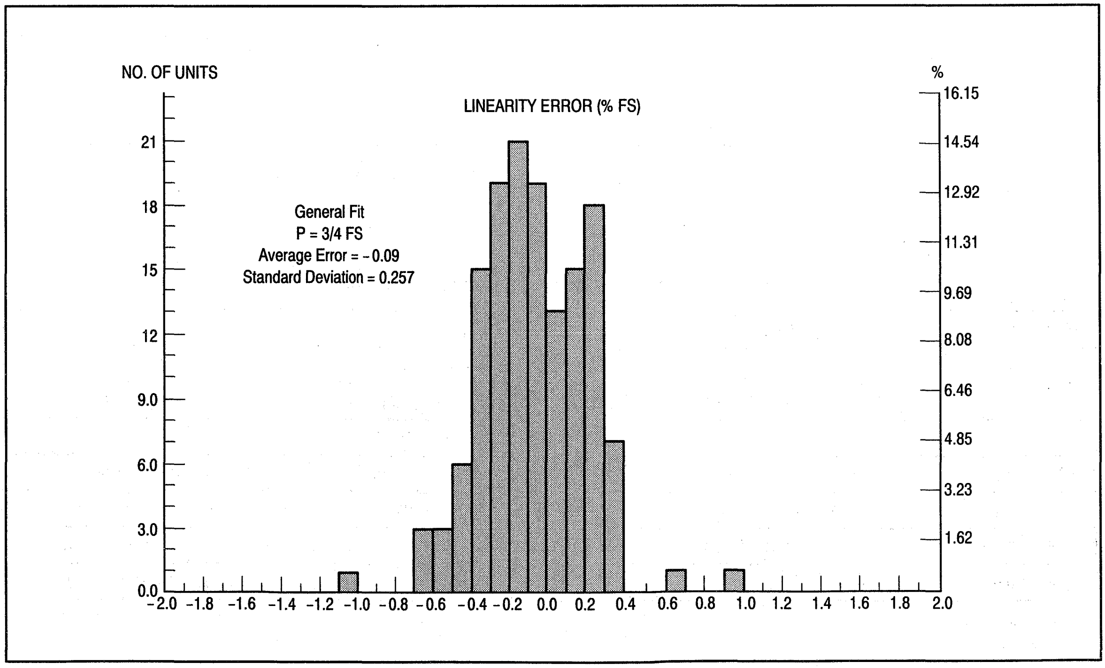


Figure 12. Linearity Error of Piece-Wise Linear Fit at 3/4 PS

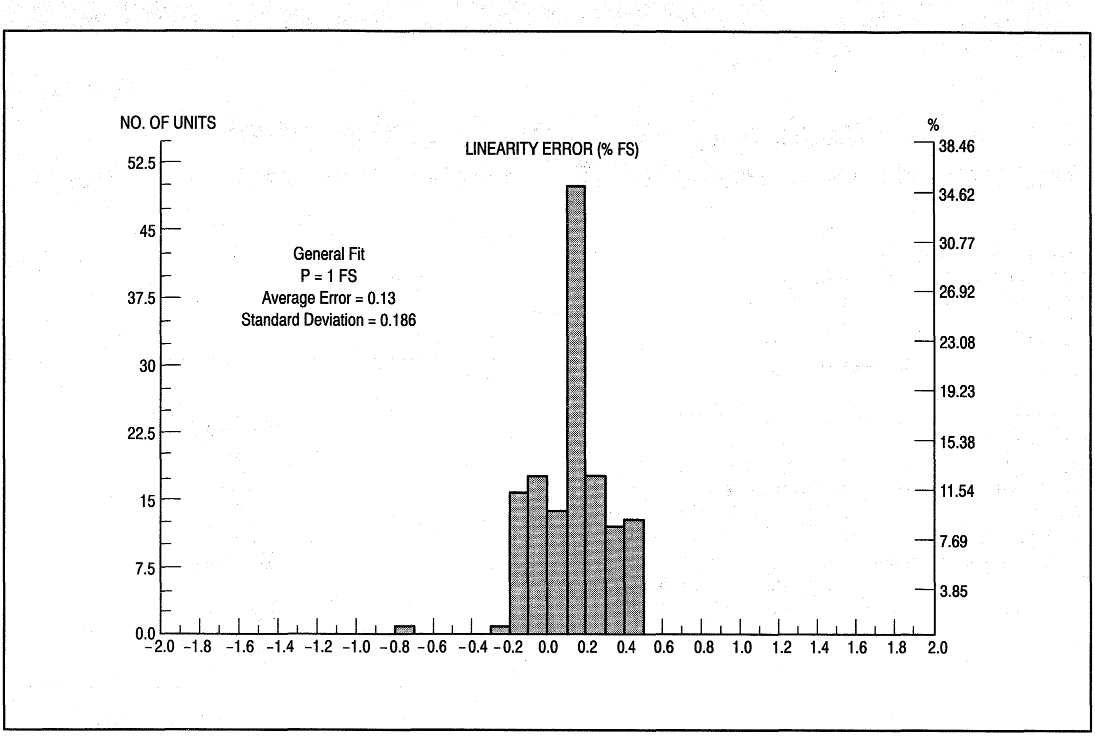


Figure 13. Linearity Error of Piece-Wise Linear Fit at FS

Once the sensitivity coefficients have been determined, a system can then be built that provides an accurate output function with pressure. The system shown in Figure 14 consists of a pressure transducer, a temperature compensation and amplification stage, an A/D converter, a microprocessor, and a display. The display block can be replaced with a control function if required. Further details on the temperature compensation and amplification block may be obtained by consulting Application Note AN840. The A/D converter simply transforms the voltage signal to an input signal for the microprocessor, in which resides the look-up table of the transfer function generated from the previously determined sensitivity coefficients. The microprocessor can then drive a display or control circuit using standard techniques.

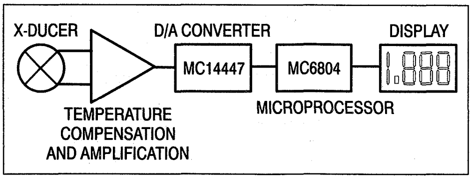


Figure 14. Linearization System Block Diagram

SUMMARY

While at first glance this technique appears to be fairly complicated, it can be a very cost effective method of building a high-accuracy, high-sensitivity pressure-monitoring system for low-pressure ranges.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN936

Mounting Techniques, Lead Forming and Testing of Motorola's MPX Series Pressure Sensors

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Phoenix, Arizona

INTRODUCTION

Motorola's MPX series pressure sensors are silicon piezoresistive strain-gauges offered in a chip-carrier package (see Figure 1). The exclusive chip-carrier package was developed to realize the advantages of high-speed, automated assembly and testing. In addition to high volume availability and low cost, the chip-carrier package offers users a number of packaging options. This Application Note describes several mounting techniques, offers lead forming recommendations, and suggests means of testing the MPX series of pressure sensors.

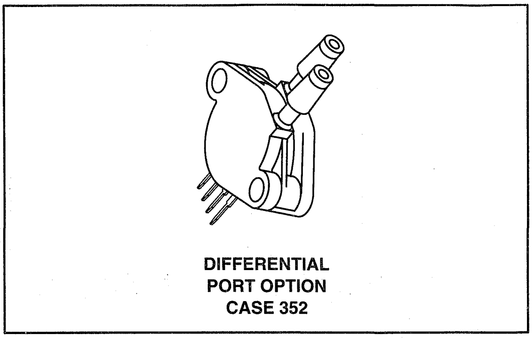


Figure 1. MPX Pressure Sensor In Chip Carrier Package Shown with Port Options

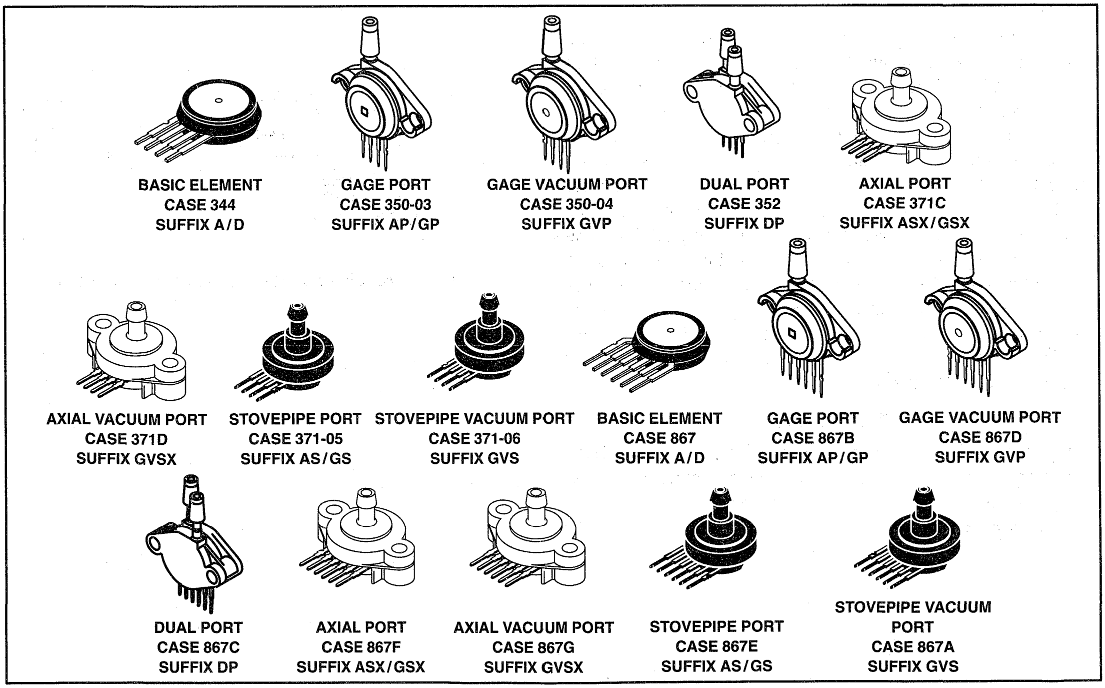


Figure 2. Chip Carrier and Available Ported Packages

PORT ADAPTERS

Available Packages

Motorola's chip-carrier package and available ports for attachment of 1/8″ I.D. hose are made from a high temperature thermoplastic that can withstand temperature extremes from –50 to 150°C (see Figure 2). The port adapters were designed for rivet or 5/32″ screw attachment to panels, printed circuit boards or chassis mounting.

Custom Port Adaptor Installation Techniques

The Motorola MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 3 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, 30% glass reinforced polyester resin plastic or Union Carbide's Udel® polysulfone (MPX2040D only). Motorola recommends using *Thermoset* EP530 epoxy or an equivalent. The epoxy should be dispensed in a continuous bead around the cell-to-port interface shoulder. Refer to Figure 4. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. The recommended cure conditions for *Thermoset* EP539 are 15 minutes at 150°C. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for 5 seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication.

TESTING MPX SERIES PRESSURE SENSORS

Pressure Connection

Testing of pressure sensing elements in the chip carrier package can be performed easily by using a clamping fixture which has an O-ring seal to attach to the beveled surface. Figure 8 shows a diagram of the fixture that Motorola uses to apply pressure or vacuum to unported elements.

When performing tests on packages with ports, a high durometer tubing is necessary to minimize leaks, especially in higher pressure range sensors. Removal of tubing must be parallel to the port since large forces can be generated to the pressure port which can break the nozzle if applied at an angle. Whether sensors are tested with or without ports, care must be exercised so that force is not applied to the back metal cap or offset errors can result.

Standard Port Attach Connection

Motorola also offers standard port options designed to accept readily available silicone, vinyl, nylon or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Dimensions of the ports may be found in the case outline drawings found in section six. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Motorola's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

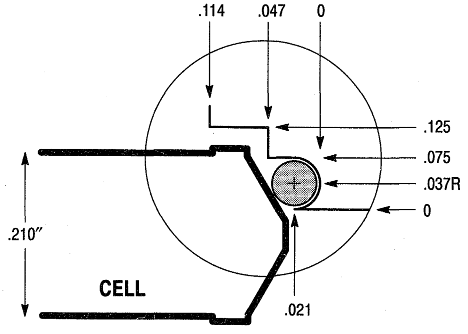


Figure 3. Examples of Motorola Sensors in Custom Housings

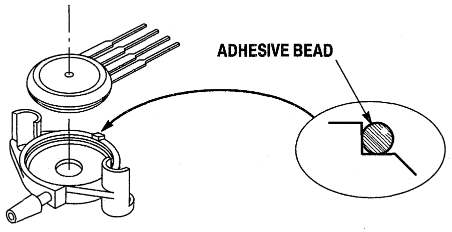


Figure 4. Port Adapter Dimensions

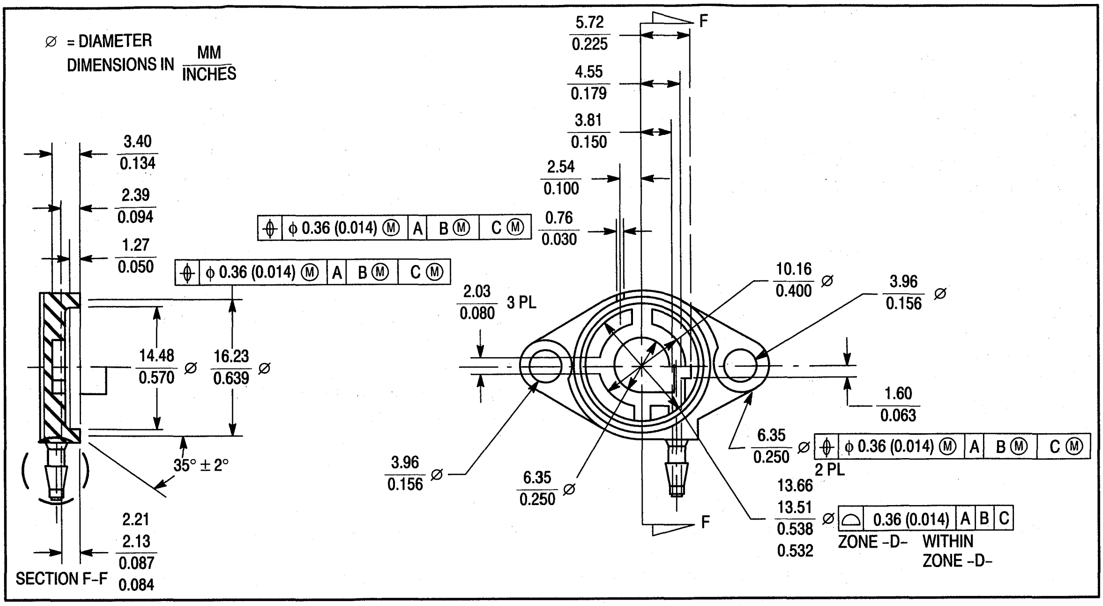
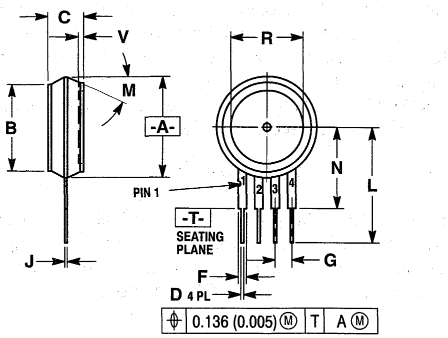


Figure 5. Port Adapter Dimensions



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. 344-01 THRU -04 OBSOLETE.
4. 344-05 THRU -07 OBSOLETE, NEW STANDARD 344-08.

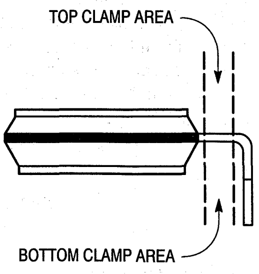
STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

DIM	MILLIMETERS		INCHES	
	MIN	MAX	MIN	MAX
A	14.99	15.62	0.590	0.615
B	12.83	13.34	0.505	0.525
C	4.95	5.72	0.195	0.225
D	0.41	0.51	0.016	0.020
F	1.22	1.32	0.048	0.052
G	2.54 BSC		0.100 BSC	
J	0.36	0.40	0.014	0.016
L	17.40	18.16	0.685	0.715
M	30° NOM		30° NOM	
N	12.19	12.70	0.480	0.500
R	10.67	11.43	0.420	0.450

CASE 344-08

All seals to be made on pressure sealing surface.

Figure 6. Chip-Carrier Package



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 7. Leadforming

Electrical Connection

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or "needlenose" pliers should never be used for leadforming unless they are specifically designed for that purpose. Industrial leadform tooling is available from various companies including *Janesville Tool & Manufacturing* (608-868-4925). Refer to Figure 7 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL. The part numbers for the housing and pins are listed below.

CONCLUSION

Motorola's MPX series pressure sensors in the chip carrier package provide the design engineer several packaging alternatives. They can easily be tested with or without pressure ports using the information provided.

CONNECTORS FOR CHIP CARRIER PACKAGES

MFG./ADDRESS/PHONE	CONNECTOR	PIN
J.S. Terminal Corp. 1200 Business Center Dr. Mount Prospect, IL 60056 (800) 292-4243	4 Pin Housing: SMP-04V-BC 6 Pin Housing: SMP-06V-BC Hand crimper YC-12 recommended	SHF-001T-0.8SS SHF-01T-0.8SS
Methode Electronics, Inc. Rolling Meadows, IL 60008 (312) 392-3500	1300-004 Requires hand crimper	1400-213 1402-213 1402-214 Reel

TERMINAL BLOCKS

MFG./ADDRESS/PHONE	TERMINAL BLOCKS
Molex 2222 Wellington Court Lisle, IL 60532 (312) 969-4550	22-18-2043 22-16-2041
Samtec P.O. Box 1147 New Albany, IN 47150 (812) 944-6733	SSW-104-02-G-S-RA SSW-104-02-G-S

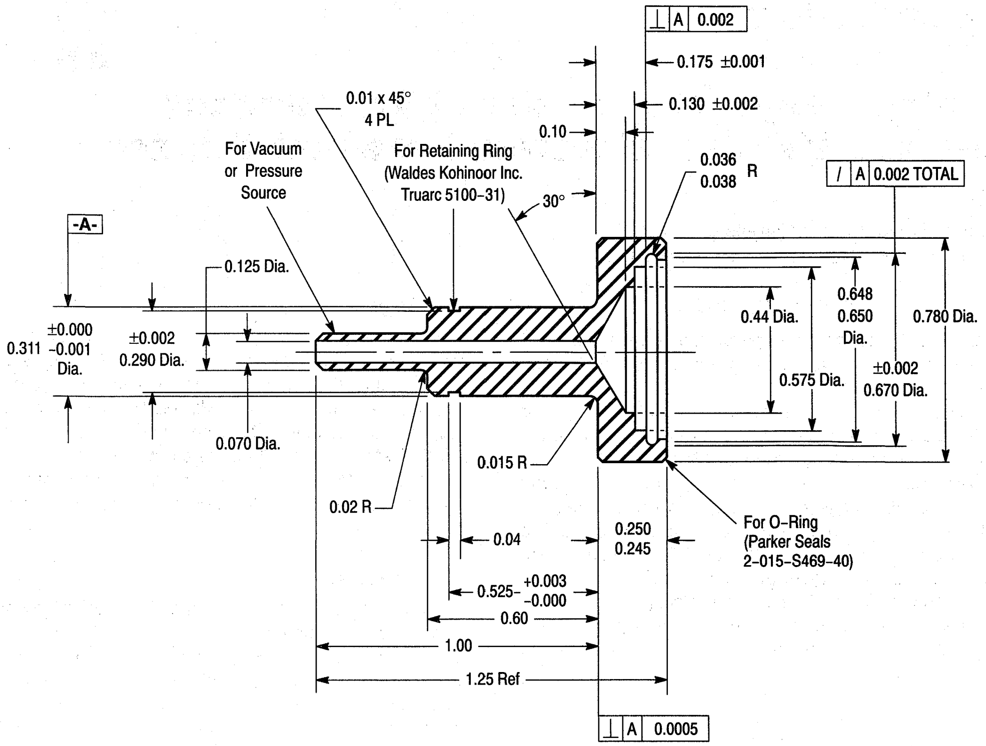


Figure 8. O-Ring Test Fixture

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1082

Simple Design for a 4-20 mA Transmitter Interface Using a Motorola Pressure Sensor

Prepared by: Jean Claude Hamelain
Motorola Toulouse Application Lab Manager

INTRODUCTION

Pressure is a very important parameter in most industrial applications such as air conditioning, liquid level sensing and flow control.

In most cases, the sensor is located close to the measured source in a very noisy environment, far away from the receiver (recorder, computer, automatic controller, etc.)

The transmission line can be as long as a few hundred meters and is subject to electromagnetic noise when the signal is transmitted as voltage. If the signal is transmitted as a current it is easier to recover at the receiving end and is less affected by the length of the transmission line.

The purpose of this note is to describe a simple circuit which can achieve high performance, using standard Motorola pressure sensors, operational amplifiers and discrete devices.

PERFORMANCES

The following performances have been achieved using an MPX2100DP Motorola pressure sensor and an MC33079 quad operational amplifier. The MPX2100DP is a 100 kPa temperature compensated differential pressure sensor. The load is a 150 ohm resistor at the end of a 50 meter telephone line. The 15 volt power supply is connected at the receiver end.

Power Supply	+15 Vdc, 30 mA
Connecting Line	3 wire telephone cable
Load Resistance	150 to 400 Ohms
Temperature Range	−40 to +85°C (up to +125°C with special hardware)
Pressure Range	0 to 100 kPa
Total Maximum Error	Better than 2% full scale

Basic Circuit

The Motorola MPX2100DP pressure sensor is a very high performance piezoresistive pressure sensor. Manufacturing technologies include standard bipolar processing techniques with state of the art metallization and on-chip laser trim for offset and temperature compensation.

This unique design, coupled with computer laser trimming, gives this device excellent performance at competitive cost for demanding applications such as automotive, industrial or medical.

MC33078, 79 operational amplifiers are specially designed for very low input voltage, a high output voltage swing and very good stability versus temperature changes.

First Stage

The Motorola MPX2100 and the operational amplifier are directly powered by the 15 Vdc source. The first stage is a simple true differential amplifier made with both of the operational amplifiers in the MC33078. The potentiometer, R_G, provides adjustment for the output.

This first stage is available as a pressure sensor kit, SEK-1 (refer to EB130/D). If using the kit, the resistors must be changed according to the schematic below to provide a full 4–20 mA output.

Current Generator

The voltage to current conversion is made with a unity gain differential amplifier, one of the four operational amplifiers in an MC33079. The two output connections from the first stage are connected to the input of this amplifier through R3 and R5. Good linearity is achieved by the matching between R3, R4, R5 and R6, providing a good common mode rejection. For the same reason, a good match between resistors R8 and R9 is needed.

The MC33078 or MC33079 has a limited current output, therefore a 2N2222 general purpose transistor is connected as the actual output current source to provide a 20 mA output.

To achieve good performance with a very long transmission line it may be necessary to place some capacitors (C1, C2) between the power supply and output to prevent oscillations.

Calibration

The circuit is electrically connected to the 15 Vdc power supply and to the load resistor (receiver).

The high pressure is connected to the pressure port and the low pressure (if using a differential pressure sensor), is connected to the vacuum port.

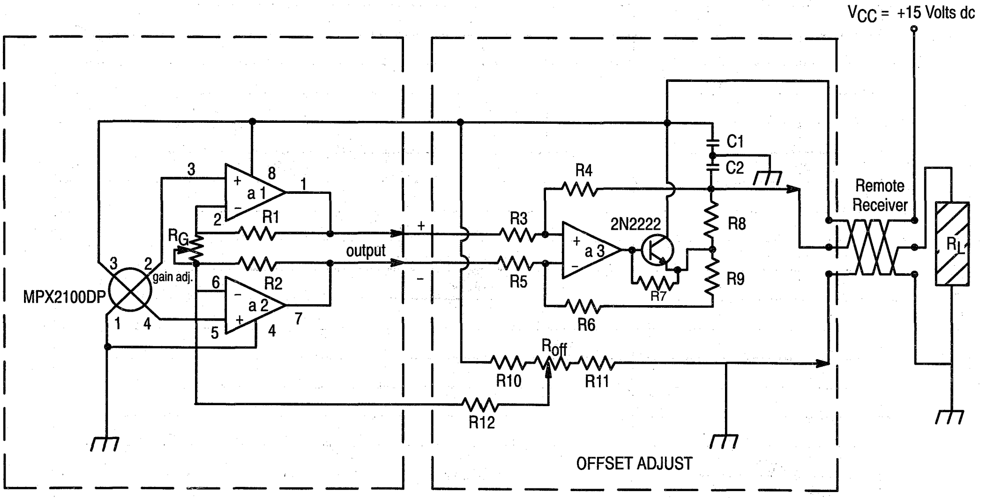
It is important to perform the calibration with the actual transmission line connected.

The circuit needs only two adjustments to achieve the 4–20 mA output current.

1. With no pressure (zero differential pressure), adjust R_{off} to read exactly 4 mA on the receiver.
2. Under the full scale pressure, adjust R_G to exactly read 20 mA on the receiver. The calibration is now complete.

The output is ratiometric to the power supply voltage. For example, if the receiver reads 18 mA at 80 kPa and 15 V power supply, the receiver should read 16.8 mA under the same pressure with 14 V power supply.

For best results it is mandatory to use a regulated power supply. If that is not possible, the circuit must be modified by inserting a 12 V regulator to provide a constant supply to the pressure sensor.



Basic Circuit of SEK-1
(See EB130)

Additional Circuit for 4 to 20 mA current loop
(Receiver Load Resistance : R_L = 150 to 400 Ohms)

R_G = 47 K Pot.
R_{off} = 1 M Pot.
* R1 = R2 = 330 K
* R3 = R4 = 27 K
* R5 = R6 = 27 K
* R8 = R9 = 150

R7 = 1 K
R10 = 110 K
R11 = 1 M
R12 = 330 K
C1 = C2 = 0.1 µF
a1, a2, a3 = 1/4 MC33079

* All resistor pairs must be matched at better than 0.5%

Note A: If using SEK-1 a1, a2, a3 = 1/2 MC33078
R_G from 20 K to 47 K
R1 and R2 from 1M to 330 K

NOTICE: THE PRESSURE SENSOR OUTPUT IS RATIOMETRIC TO THE POWER SUPPLY VOLTAGE. THE OUTPUT WILL CHANGE WITH THE SAME RATIO AS VOLTAGE CHANGE.

Figure 1. Demo Kit with 4–20 mA Current Loop

When using a Motorola MC78L12AC voltage regulator the circuit can be used with power voltage variation form 14 to 30 volts.

The following results have been achieved using an MPX2100DP and two MC33078s. The resistors were regular carbon resistors, but pairs were matched at ±0.3% and capacitors were 0.1 µF. The load was 150 ohms and the transmission line was a two pair telephone line with the +15 Vdc power supply connected on the remote receiver side.

Note: Best performances in temperature can be achieved using metal film resistors. The two potentiometers must be chosen for high temperatures up to 125°C.

The complete circuit with pressure sensor is available under reference TZA120 and can be ordered as a regular Motorola product for evaluation.

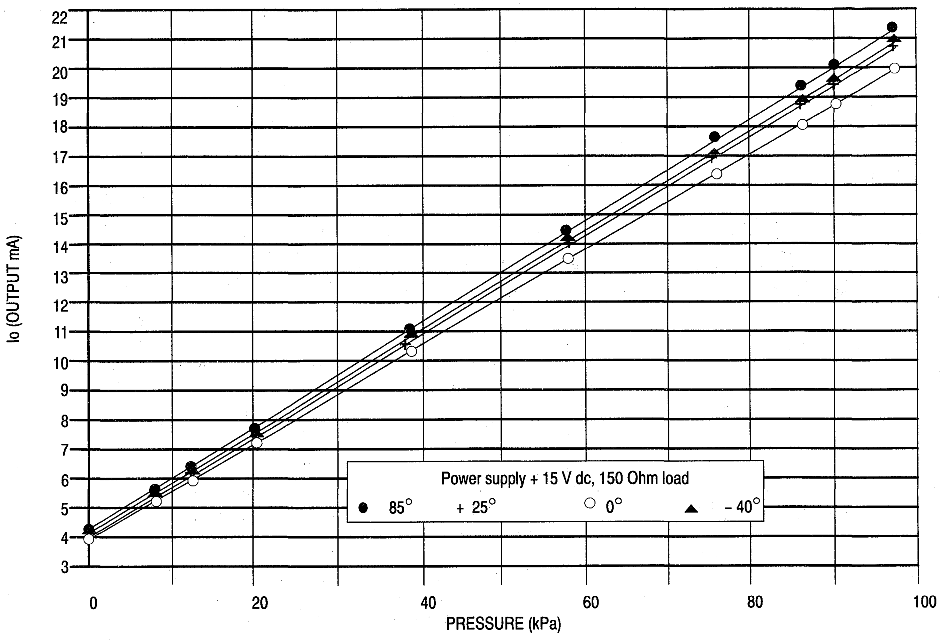
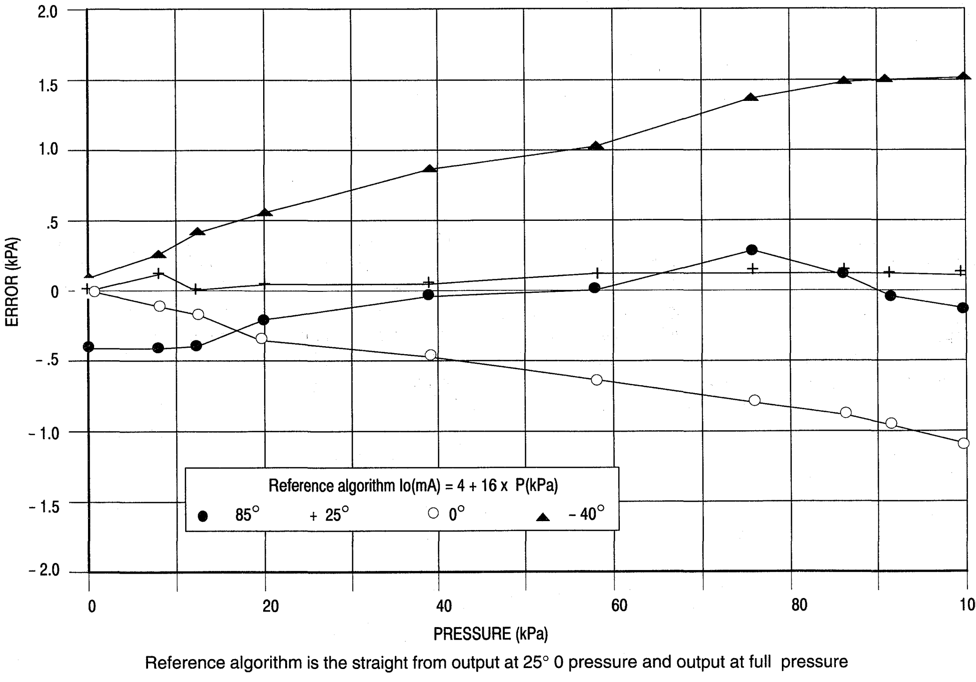


Figure 2. Output versus Pressure



Reference algorithm is the straight from output at 25° 0 pressure and output at full pressure

Figure 3. Absolute Error Reference to Algorithm

MOTOROLA
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APPLICATION NOTE

AN1097

Calibration-Free Pressure Sensor System

Prepared by: Michel Burri, Senior System Engineer
Geneva, Switzerland

INTRODUCTION

The MPX2000 series pressure transducers are semiconductor devices which give an electrical output signal proportional to the applied pressure. The sensors are a single monolithic silicon diaphragm with strain gauge and thin-film resistor networks on the chip. Each chip is laser trimmed for full scale output, offset, and temperature compensation.

The purpose of this document is to describe another method of measurement which should facilitate the life of the designer. The MPX2000 series sensors are available both as unported elements and as ported assemblies suitable for pressure, vacuum and differential pressure measurements in the range of 10 kPa through 200 kPa.

The use of the on-chip A/D converter of Motorola's MC68HC05B6 HCMOS MCU makes possible the design of an accurate and reliable pressure measurement system.

SYSTEM ANALYSIS

The measurement system is made up of the pressure sensor, the amplifiers, and the MCU. Each element in the chain has its own device-to-device variations and temperature effects which should be analyzed separately. For instance, the 8-bit A/D converter has a quantization error of about ±0.2%. This error should be subtracted from the maximum error specified for the system to find the available error for the rest of elements in the chain. The MPX2000 series pressure sensors are designed to provide an output sensitivity of 4.0 mV/V excitation voltage with full-scale pressure applied or 20 mV at the excitation voltage of 5.0 Vdc.

An interesting property must be considered to define the configuration of the system: the ratiometric function of both the A/D converter and the pressure sensor device. The ratiometric function of these elements makes all voltage variations from the power supply rejected by the system. With this advantage, it is possible to design a chain of amplification where the signal is conditioned in a different way.

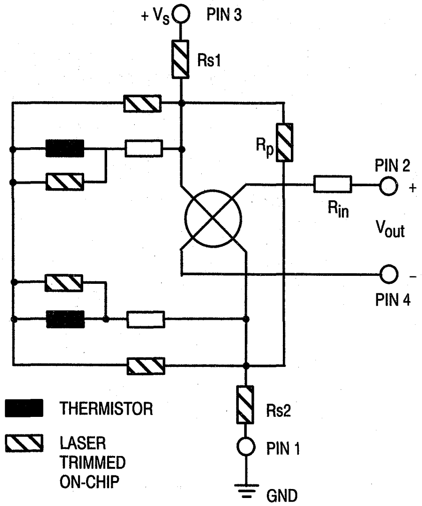


Figure 1. Seven Laser-Trimmed Resistors and Two Thermistors Calibrate the Sensor for Offset, Span, Symmetry and Temperature Compensation

The op amp configuration should have a good common-mode rejection ratio to cancel the DC component voltage of the pressure sensor element which is about half the excitation voltage value V_S. Also, the op amp configuration is important when the designer's objective is to minimize the calibration procedures which cost time and money and often don't allow the unit-to-unit replacement of devices or modules.

One other aspect is that most of the applications are not affected by inaccuracy in the region 0 kPa thru 40 kPa. Therefore, the goal is to obtain an acceptable tolerance of the system from 40 kPa through 100 kPa, thus minimizing the inherent offset voltage of the pressure sensor.

PRESSURE SENSOR CHARACTERISTICS

Figure 2 shows the differential output voltage of the MPX2100 series at +25°C. The dispersion of the output voltage determines the best tolerance that the system may achieve without undertaking a calibration procedure, if any other elements or parameters in the chain do not introduce additional errors.

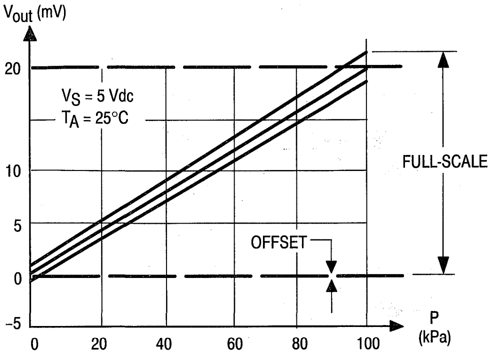


Figure 2. Spread of the Output Voltage versus the Applied Pressure at 25°C

The effects of temperature on the full scale output and offset are shown in Figure 3. It is interesting to notice that the offset variation is greater than the full scale output and both have a positive temperature coefficient respectively of +8.0 µV/degree and +5.0 µV excitation voltage. That means that the full scale variation may be compensated by modifying the gain somewhere in the chain amplifier by components arranged to produce a negative T_C of 250 PPM/°C. The dark area of Figure 3 shows the trend of the compensation which improves the full scale value over the temperature range. In the area of 40 kPa, the compensation acts in the ratio of 40/100 of the value of the offset temperature coefficient.

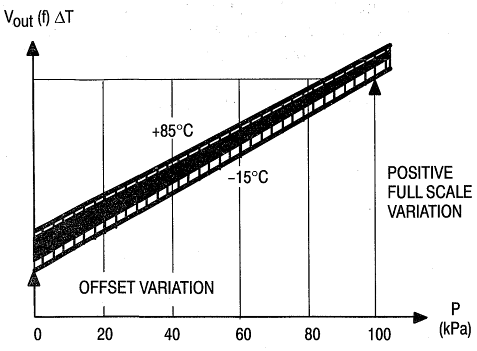


Figure 3. Output Voltage versus Temperature. The Dark Area Shows the Trend of the Compensation

OP AMP CHARACTERISTICS

For systems with only one power supply, the instrument amplifier configuration shown in Figure 4 is a good solution to monitor the output of a resistive transducer bridge.

The instrument amplifier does provide an excellent CMRR and a symmetrical buffered high input impedance at both non-inverting and inverting terminals. It minimizes the number of the external passive components used to set the gain of the amplifier. Also, it is easy to compensate the temperature variation of the Full Scale Output of the Pressure Sensor by implementing resistors "R_f" having a negative coefficient temperature of –250 PPM/°C.

The differential-mode voltage gain of the instrument amplifier is:

$$\text{Avd} = \frac{\text{V1-V2}}{\text{Vs2-Vs4}} = \left(1 + \frac{2\,R_f}{R_g}\right) \qquad (1)$$

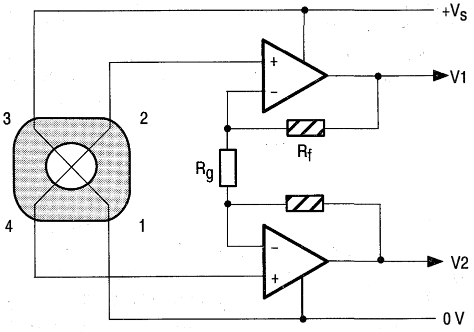


Figure 4. One Power Supply to Excite the Bridge and to Develop a Differential Output Voltage

The major source of errors introduced by the op amp is offset voltages which may be positive or negative, and the input bias current which develops a drop voltage ΔV through the feedback resistance R_f. When the op amp input is composed of PNP transistors, the whole characteristic of the transfer function is shifted below the DC component voltage value set by the Pressure Sensor as shown in Figure 5.

The gain of the instrument amplifier is calculated carefully to avoid a saturation of the output voltage, and to provide the maximum of differential output voltage available for the A/D Converter. The maximum output swing voltage of the amplifiers is also dependent on the bias current which creates a ΔV voltage on the feedback resistance R_f and on the Full Scale output voltage of the pressure sensor.

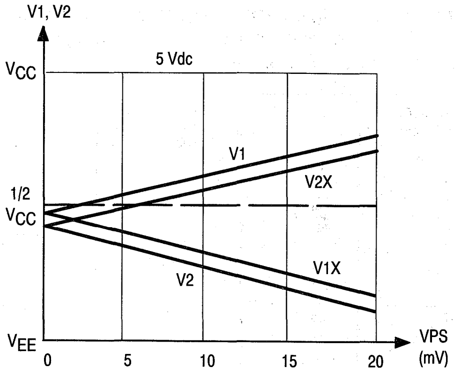


Figure 5. Instrument Amplifier Transfer Function with Spread of the Device to Device Offset Variation

Figure 5 shows the transfer function of different instrument amplifiers used in the same application. The same sort of random errors are generated by crossing the inputs of the instrument amplifier. The spread of the differential output voltage (V1-V2) and (V2x-V1x) is due to the unsigned voltage offset and its absolute value. Figures 6 and 7 show the unit-to-unit variations of both the offset and the bias current of the dual op amp MC33078.

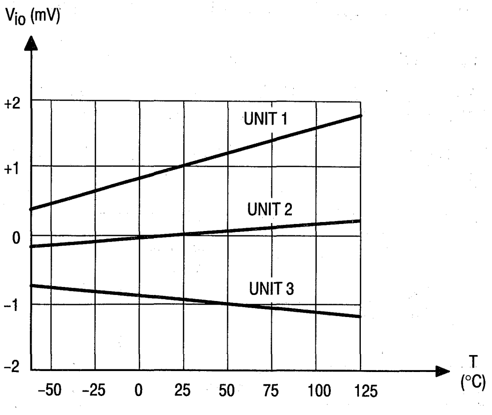


Figure 6. Input Offset Voltage versus Temperature

To realize such a system, the designer must provide a calibration procedure which is very time consuming. Some extra potentiometers must be implemented for setting both the offset and the Full Scale Output with a complex temperature compensation network circuit.

The new proposed solution will reduce or eliminate any calibration procedure.

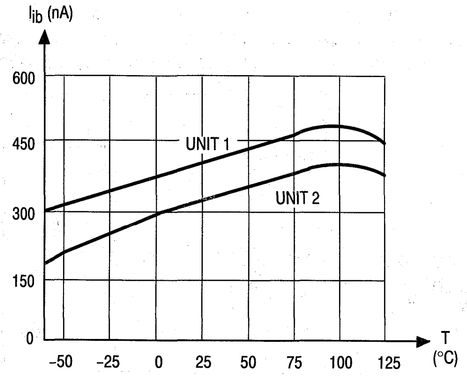


Figure 7. Input Bias Current versus Temperature

MCU CONTRIBUTION

As shown in Figure 5, crossing the instrument amplifier inputs generated their mutual differences which can be computed by the MCU.

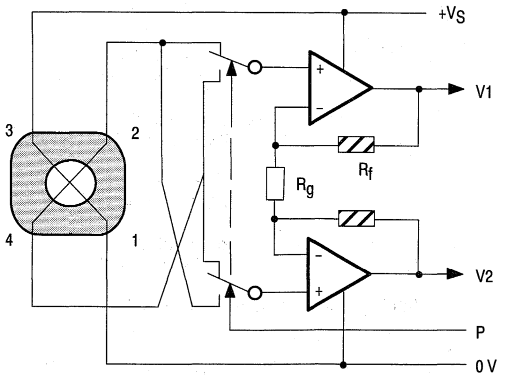


Figure 8. Crossing of the Instrument Amplifier Input Using a Port of the MCU

Figure 8 shows the analog switches on the front of the instrument amplifier and the total symmetry of the chain. The residual resistance $R_{DS(on)}$ of the switches does not introduce errors due to the high input impedance of the instrument amplifier.

With the aid of two analog switch, the MCU successively converts the output signals V1, V2.

Four conversions are necessary to compute the final result. First, two conversions of V1 and V2 are executed and stored in the registers R1, R2. Then, the analog switches are commuted in the opposite position and the two last conversions of $V2_X$ and V1x are executed and stored in the registers $R2_X$ and R1x. Then, the MCU computes the following equation:

$$\text{RESULT} = (R1-R2) + (R2x-R1x) \qquad (2)$$

The result is twice a differential conversion. As demonstrated below, all errors from the instrument amplifier are cancelled. Other averaging techniques may be used to improve the result, but the appropriated algorithm is always determined by the maximum bandwidth of the input signal and the required accuracy of the system.

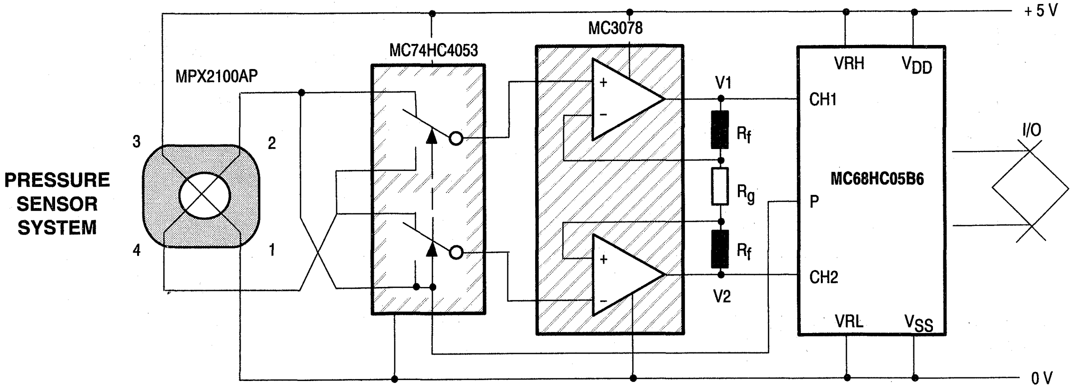


Figure 9. Two Channel Input and One Output Port Are Used by the MCU

SYSTEM CALCULATION

Sensor out 2
$Vs2 = a\,(P) + of2$

Sensor out 4
$Vs4 = b\,(P) + of4$

Amplifier out 1
$V1 = Avd\,(Vs2 + OF1)$

Amplifier out 2
$V2 = Avd\,(Vs4 + OF2)$

Inverting of the amplifier input
$V1x = Avd\,(Vs4 + OF1)$ $V2x = Avd\,(Vs2 + OF2)$

$$\begin{aligned} Delta &= V1\text{-}V2 \quad \text{1st differential result}\\ &= Avd * (Vs2 \text{ of } OF1) - Avd * (Vs4 + OF2)\end{aligned}$$

$$\begin{aligned} Deltax &= V2x - V1x \quad \text{2nd differential result}\\ &= Avd * (Vs2 + OF2) - Vdc * (Vs4 + OF1)\end{aligned}$$

Adding of the two differential results

$$\begin{aligned} VoutV &= Delta + Deltax\\ &= Avd{*}Vs2 + Avd{*}OF2 + Avd{*}OF2 - Avd{*}OF1\\ &\quad + Avd{*}OF1 - Avd{*}OF2 + Avd{*}OF2 - Avd{*}OF1\\ &= 2 * Avd * (Vs2 - Vs4)\\ &= 2 * Avd * [(a\,(P) + of2) - (b\,(P) + of4)]\\ &= 2 * Avd * [V(P) + Voffset]\end{aligned}$$

There is a full cancellation of the amplifier offset OF1 and OF2. The addition of the two differential results V1-V2 and V2x-V1X produce a virtual output voltage VoutV which becomes the applied input voltage to the A/D converter. The result of the conversion is expressed in the number of counts or bits by the ratiometric formula shows below:

$$count = VoutV * \frac{255}{VRH - VRL}$$

255 is the maximum number of counts provided by the A/D converter and VRH-VRL is the reference voltage of the ratiometric A/D converter which is commonly tied to the 5.0 V supply voltage of the MCU.

When the tolerance of the full scale pressure has to be in the range of ± 2.5%, the offset of the pressure sensor may be neglected. That means the system does not require any calibration procedure.

The equation of the system transfer is then:

$count = 2 * Avd * V(P) * 51/V$ where:

Avd is the differential-mode gain of the instrument amplifier which is calculated using the equation (1). Then with $R_f = 510$ kΩ and $R_g = 9.1$ kΩ Avd = <u>113</u>.

The maximum counts available in the MCU register at the Full Scale Pressure is:

count (Full Scale) = $2 * 113 * 0.02\ V * 51/V = \underline{230}$

knowing that the MPX2100AP pressure sensor provides 20 mV at 5.0 excitation voltage and 100 kPa full scale pressure.

The system resolution is 100 kPa/230 that give 0.43 kPa per count.

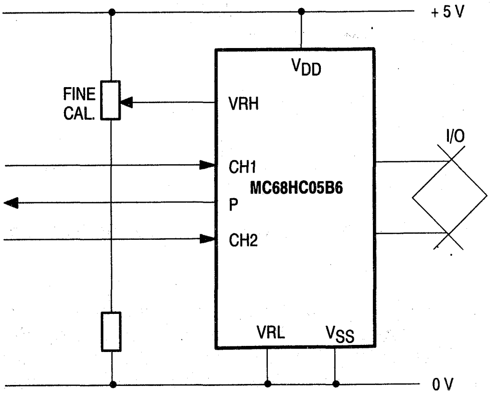


Figure 10. Full Scale Output Calibration Using the Reference Voltage VRH-VRL

When the tolerance of the system has to be in the range of ±1%, the designer should provide only one calibration procedure which sets the Full Scale Output (counts) at 25°C 100 kPa or under the local atmospheric pressure conditions.

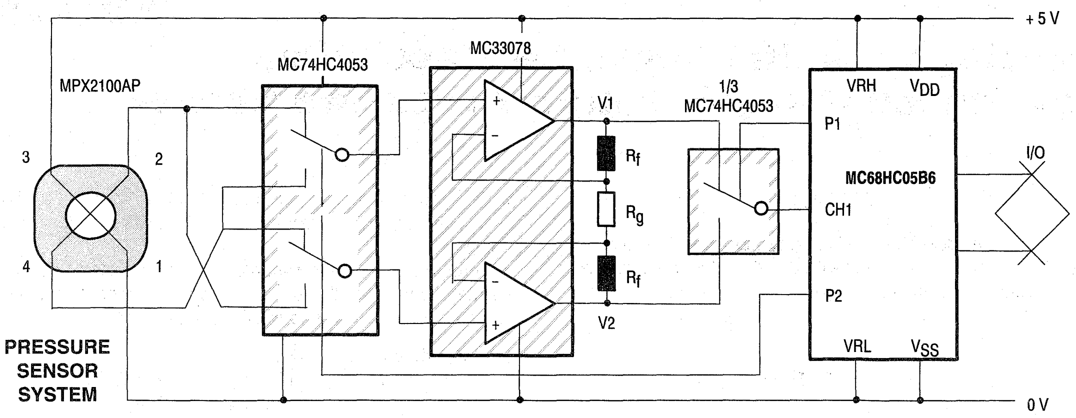


Figure 11. One Channel Input and Two Output Ports are used by the MCU

Due to the high impedance input of the A/D converter of the MC68HC05B6 MCU, another configuration may be implemented which uses only one channel input as shown in Figure 11. It is interesting to notice that practically any dual op amp may be used to do the job but a global consideration must be made to optimize the total cost of the system according the the requested specification.

When the Full Scale Pressure has to be sent with accuracy, the calibration procedure may be executed in different ways. For instance, the module may be calibrated directly using Up/Down push buttons.

The gain of the chain is set by changing the VRH voltage of the ratiometric A/D converter with the R/2R ladder network circuit which is directly drived by the ports of the MCU. (See Figure 12.)

Using a communication bus, the calibration procedure may be executed from a host computer. In both cases, the setting value is stored in the EEROM of the MCU.

The gain may be also set using a potentiometer in place of the resistor R_f. But, this component is expensive, taking into account that it must be stable over the temperature range at long term.

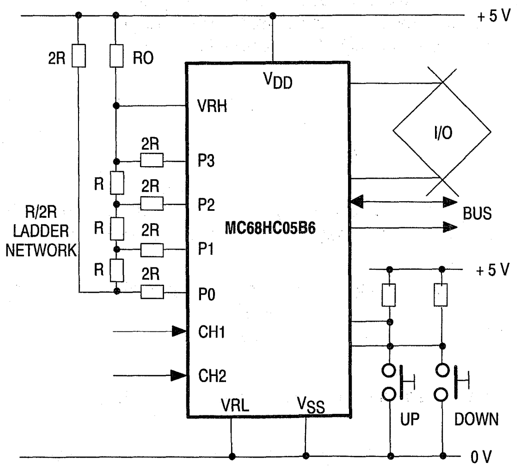


Figure 12.

Table 1. Pressure Conversion Table

Unity	Pa	mbar	Torr	atm	at=kp/cm^2	mWS	psi
1 N/m^2 = 1 Pascal	1	0.01	7.5 10^{-3}	—	—	—	—
1 mbar	100	1	0.75	—	—	0.0102	0.014
1 Torr = 1 mmHg	133.32	1.333	.1	—	—	—	0.019
1 atm (1)	101325	1013.2	760	1	1.033	10.33	14.69
1 at = 1 kp/cm^2 (2)	98066.5	981	735.6	0.97	1	10	14.22
1 m of water	9806.65	98.1	73.56	0.097	0.1	1	1.422
1 lb/sqin = 1 psi	6894.8	68.95	51.71	0.068	—	—	1

(1) Normal atmosphere (2) Technical atmosphere

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1100

Analog to Digital Converter Resolution Extension Using A Motorola Pressure Sensor

PURPOSE

This paper describes a simple method to gain more than 8-bits of resolution with an 8-bit A/D. The electronic design is relatively simple and uses standard components.

PRINCIPLE

Consider a requirement to measure pressure up to 200 kPa. Using a pressure sensor and an amplifier, this pressure can be converted to an analog voltage output. This analog voltage can then be converted to a digital value and used by the microprocessor as shown in Figure 1.

If we assume for this circuit that 200 kPa results in a +4.5 V output, the sensitivity of our system is:

$$\begin{aligned} S &= 4.5\ \text{V} / 200\ \text{kPa} \\ &= 0.0225\ \text{V/kPa} \\ \text{or}\quad S &= 22.5\ \text{mV/kPa} \end{aligned} \tag{1}$$

If an 8-bit A/D is used with 0 and 5 Volt low and high references, respectively, then the resolution would be:

$$\begin{aligned} R_V &= 5\text{V} / (2^8 - 1) = 5\text{V}/255 \\ &= 0.01961\ \text{V} \\ \text{or}\quad R_V &= 19.60\ \text{mV per bit} \end{aligned} \tag{2}$$

This corresponds to a pressure resolution of:

$$\begin{aligned} R_P &= (19.60\ \text{mV/bit}) / (22.5\ \text{mV/kPa}) \\ &= 0.871\ \text{kPa per bit} \end{aligned} \tag{3}$$

Assume a resolution of at least 0.1 kPa/bit is needed. This would require an A/D with at least 12 bits ($2^{12} = 4096$ steps).

One can artificially increase the A/D resolution as described below.

Refer to Figure 1 and assume a pressure of 124 kPa is to be measured. With this system, the input signal to the A/D should read (assuming no offset voltage error):

$$\begin{aligned} V_m\ (\text{measured}) &= (\text{Papp}) \times (S) \\ &= (124\ \text{kPa}) \times (22.5\ \text{mV/kPa}) \\ &= 2790\ \text{mV}, \end{aligned} \tag{4}$$

where Papp is the pressure applied to the sensor.

Due to the resolution of the A/D, the microprocessor receives the following conversion:

$$\begin{aligned} M &= (2790\ \text{mV}) / (19.60\ \text{mV/bit}) \\ &= 142.35 \\ &= 142\ (\text{truncated to integer}) \end{aligned} \tag{5}$$

The calculated voltage for this stored value is:

$$\begin{aligned} V_C\ (\text{calculated}) &= (142\ \text{counts}) \times (19.60\text{mV/}\ \text{count}) \\ &= 2783\ \text{mV} \end{aligned} \tag{6}$$

The microprocessor will output the stored value M to the D/A. The corresponding voltage at the analog output of the D/A, for an 8-bit D/A with same references, will be 2783 mV.

The calculated pressure corresponding to this voltage would be:

$$\begin{aligned} P_C\ (\text{calculated}) &= (2783\ \text{mV}) / (22.5\ \text{mV/kPa}) \\ &= 123.7\ \text{kPa} \end{aligned} \tag{7}$$

Thus, the error would be:

$$\begin{aligned} E &= \text{Papp} - \text{Pc} \\ &= 124\ \text{kPa} - 123.7\ \text{kPa} \\ &= 0.3\ \text{kPa} \end{aligned} \tag{8}$$

This is greater than the 0.1 kPa resolution requirement.

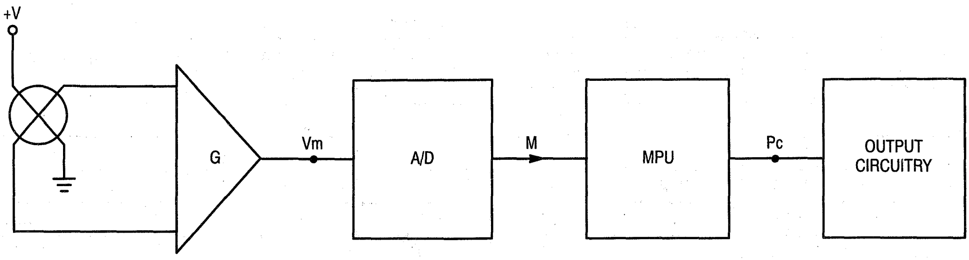


Figure 1. Block Diagram

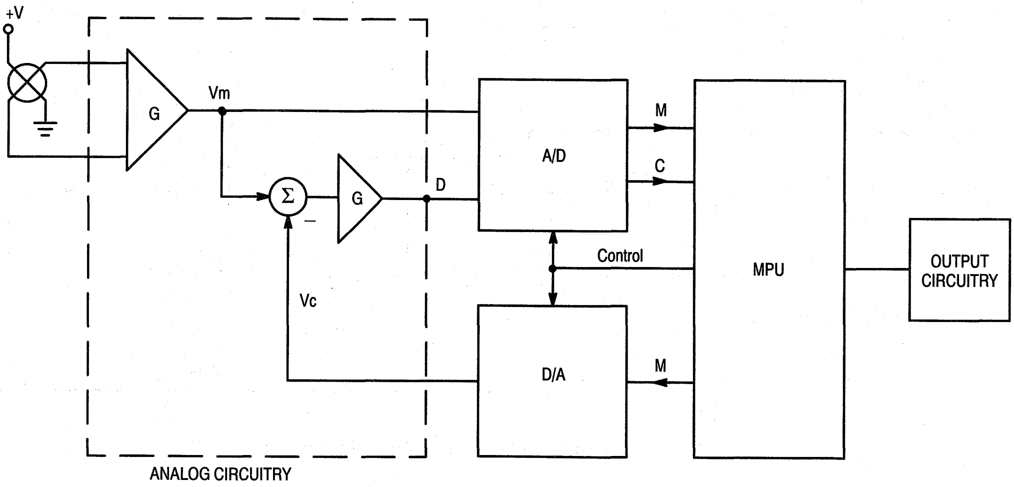


Figure 2. Expanded Block Diagram

Figure 2 shows the block diagram of a system that can be used to reduce the inaccuracies caused by the limited A/D resolution. The microprocessor would use the stored value M, as described above, to cause a D/A to output the corresponding voltage, Vc. Vc is subtracted from the measured voltage, Vm, using a differential amplifier, and the resulting voltage is amplified. Assuming a gain, G, of 10 for the amplifier, the output would be:

$$\begin{aligned} D &= (Vm - Vc) \times G \\ &= (2790\ \text{mV} - 2783\ \text{mV}) \times 10 \\ &= 70\ \text{mV} \end{aligned} \tag{9}$$

The microprocessor will receive the following count from the A/D:

$$\begin{aligned} C &= 70\ \text{mV} / (19.60\ \text{mV/count}) \\ &= 3.6 \\ &= 3\ \text{full counts} \end{aligned} \tag{10}$$

The microprocessor then computes the actual pressure with the following equations:

$$\begin{aligned} \text{Expanded Voltage} &= Vc + ((C \times R) / G) \\ &= 2783 + ((3 \times 19.60) / 10) \\ &= 2789\ \text{mV} \end{aligned} \tag{11}$$

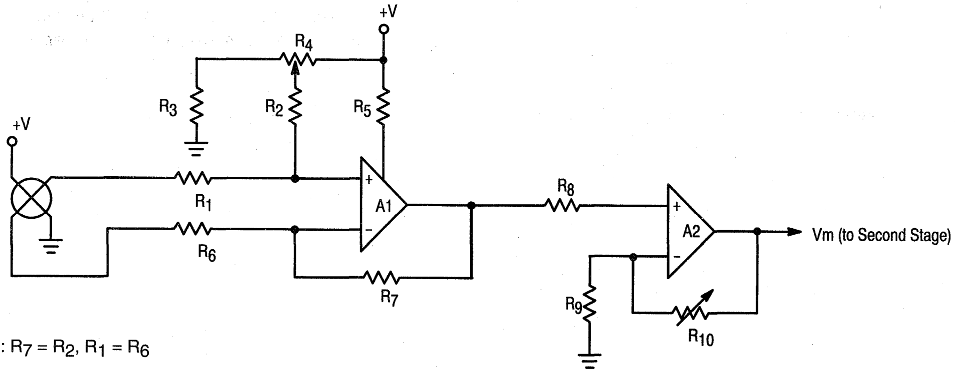
NOTE: R is resolution of 8-bit D/A

$$\begin{aligned} \text{Corresponding Pressure} &= 2789\ \text{mV} / (22.5\ \text{mV/kPa}) \\ &= 123.9\ \text{kPa} \end{aligned} \tag{12}$$

Thus the error is:

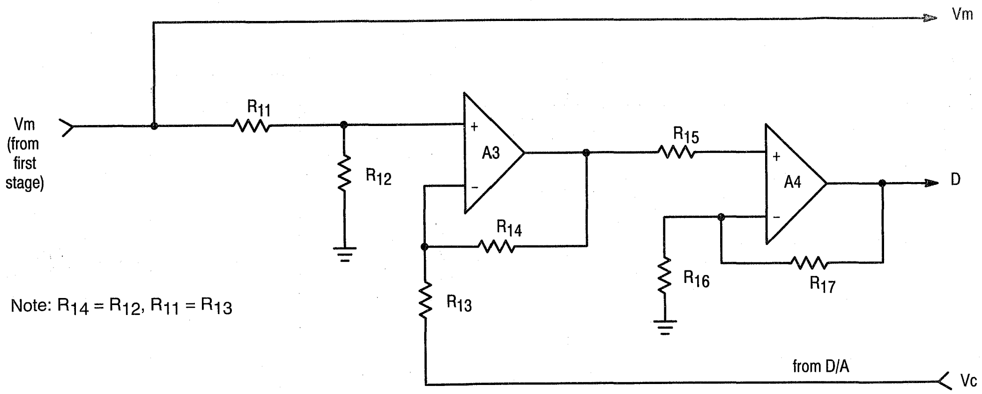
$$\begin{aligned} \text{Pressure Error} &= \text{Actual} - \text{Measured} \\ &= 124\ \text{kPa} - 123.9\ \text{kPa} \\ &= 0.1\ \text{kPa} \end{aligned} \tag{13}$$

Figures 3 and 4 together provide a more detailed description of the analog portion of this system.



Note: $R_7 = R_2$, $R_1 = R_6$

Figure 3. First Stage – Differential Amplifier, Offset Adjust and Gain Adjust



Note: $R_{14} = R_{12}$, $R_{11} = R_{13}$

Figure 4. Second Stage — Difference Amplifier and Gain

FIRST STAGE (Figure 3)

The first stage consists of the Motorola pressure sensor; in this case the MPX2200 is used. This sensor typically gives a full scale span output of 40 mV at 200 kPa. The sensor output (V_S) is connected to the inputs of amplifier A1 (1/4 of the Motorola MC33079, a Quad Operational Amplifier). The gain, G1, of this amplifier is R7/R6. The sensor has a typical zero pressure offset voltage of 1 mV. Figure 3 shows offset compensation circuitry if it is needed. A1 output is fed to the non-inverting input of A2 amplifier (1/4 of a Motorola MC33079) whose gain, G2, is $1+R_{10}/R_9$. G2 should be set to yield 4.5 volts out with full-rated pressure.

THE SECOND STAGE (Figure 4)

The output from A2 (Vm = G1 x G2 x Vs) is connected to the non-inverting input of amplifier A3 (1/4 of a Motorola MC33079) and to the A/D where its corresponding (digital) value is stored by the microprocessor. The output of A3 is the amplified difference between Vm, and the digitized/calculated voltage Vc. Amplifier A4 (1/4 of a Motorola MC33079) provides additional gain for an amplified difference output for the desired resolution. This difference output, D, is given by:

$$D = (Vm - V_C) \times G3$$
$$G3 = (R14/R13)\ (1 + \tfrac{R17}{R16})$$

where G3 is the gain associated with amplifiers A3 and A4.

The theoretical resolution is limited only by the accuracy of the programmable power supply. The Motorola microprocessor used has an integrated A/D. The accuracy of this A/D is directly related to the reference voltage source stability, which can be self-calibrated by the microprocessor. Vexpanded is the system output that is the sum of the voltage due to the count and the voltage due to the difference between the count voltage and the measured voltage. This is given by the following relation:

$$V_{expanded} = V_c + D / G3$$

therefore, $P_{expanded}$ = Vexpanded / S.

$P_{expanded}$ is the value of pressure (in units of kPa) that results from this improved-resolution system. This value can be output to a display or used for further processing in a control system.

CONCLUSION

This circuit provides an easy way to have high resolution using inexpensive microprocessors and converters.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1105

A Digital Pressure Gauge Using the Motorola MPX700 Series Differential Pressure Sensor

Prepared by: Anthony J. Caristi

INTRODUCTION

This application note describes a solid state digital pressure gauge which is composed of the Motorola MPX series transducer, instrumentation amplifier, A/D converter, and LCD readout. Differential, gauge, and vacuum pressure readings from 0 to 100 PSI with resolution of 1 PSI are possible using the MPX700 sensor. The circuit is also capable of measuring and displaying pressures as low as 1 PSI full scale, and resolution as fine as of 0.01 PSI, by using a more sensitive MPX series pressure transducer and full display capability of the A/D converter.

The Motorola MPX series of pressure transducers is a family of piezoresistive transducers which exhibits a very linear and accurate output voltage relationship that is directly proportional to the applied pressure. The sensor consists of an etched silicon diaphragm upon which a single piezoresistive element is implanted. The resistor senses the stress placed upon the silicon diaphragm by external pressure, and produces a linear output voltage which is proportional to the applied pressure. The output voltage/pressure relationship is ratiometric with the supply voltage feeding the sensor.

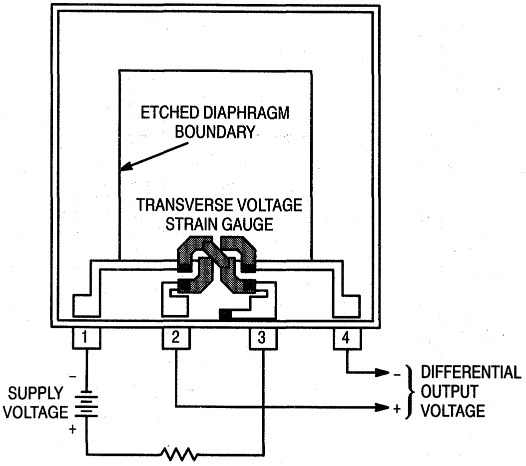


Figure 1. Sensor Construction Showing Electrical Connections

The pressure sensor is available as a differential gauge device in a pressure side ported, vacuum side ported, or differential configuration. The following describes an application using the MPX700DP differential sensor to measure and display gauge pressure, vacuum (negative pressure), or differential pressure.

BASIC STRUCTURE

Figure 1 illustrates the top view of the pressure sensor silicon chip, showing the strain-gauge resistor diagonally placed on the edge of the diaphragm. Voltage is applied across pins 1 and 3, while the taps that sense the voltage differential transversely across the pressure sensitive resistor are connected to terminals 2 and 4. An external series resistor is used to provide temperature compensation while reducing the voltage impressed upon the sensor to within its rated value.

OPERATION

Recommended voltage drive is 3 Vdc, and should not exceed 6 volts under any operating condition. The differential voltage output of the sensor, appearing between terminals 2 and 4, will be positive when the pressure applied to the "pressure" side of the sensor is greater than the pressure applied to the "vacuum" side. Nominal full scale span of the transducer is 60 millivolts when driven by a 3 volt constant voltage source.

When zero pressure is applied to the sensor there will be some output voltage, called zero pressure offset. For the MPX700 sensor this voltage is guaranteed to be within the range of zero to 35 millivolts. The zero pressure offset output voltage is easily nulled out by a suitable instrumentation amplifier. The output voltage of the sensor will vary in a linear manner with applied pressure. Figure 2 illustrates output voltage versus pressure differential applied to the sensor, when driven by a 3 volt source.

TEMPERATURE COMPENSATION

As illustrated in Figure 2, the output voltage of the sensor will be affected by the temperature of the device. Temperature compensation may easily be accomplished by one of several methods. A full discussion of these methods is covered in Motorola application note AN840.

The simplest method of temperature compensation, placing a resistance (R19 and R20) in series with the sensor driving voltage, is utilized in the schematic diagram illustrated in Figure 3. This provides good results over a temperature span of 0 to 80°C, yielding a 0.5% full scale span compensated device. Since the desired bridge driving voltage is about 3 volts, placing the temperature compensating resistor in series with the bridge circuit has the additional

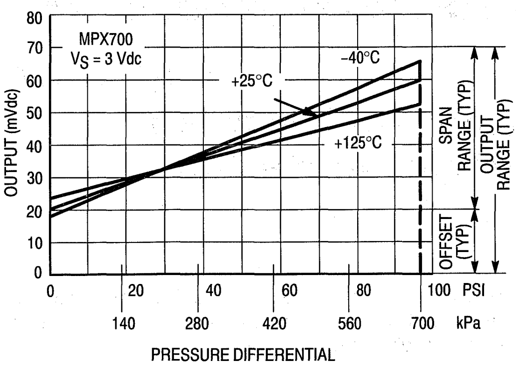


Figure 2. Output versus Pressure Differential

advantage of reducing the power supply voltage, 15 volts, to the desired 3 volt level.

Note that the 15 volt power source must be held to within a tight tolerance, since the output voltage of the transducer is ratiometric with the the supply voltage. In most applications an ordinary fixed 15 volt regulator chip can be used to provide the required stable supply voltage.

The series method of compensation requires a series resistor which is equal to 3.577 times the bridge input resistance at 25 degrees Celsius. The range of transducer resistance is between 400 and 550 ohms, so the compensating network will be 1431 to 1967 ohms. If a temperature compensated span of greater than plus or minus 0.5% is satisfactory or the operating temperature range of the circuit is less than 80 degrees Celsius, one value of compensating resistance can be used for any sensor resistance over the range of 400 and 550 ohms.

In the circuit of Figure 3 the temperature compensating network is composed of two resistors to allow the quiescent voltage of the sensor at pins 2 and 4 to be near the center level (2.5 volts) of the analog and digital circuit that follows.

SENSOR AMPLIFIER

An amplifier is used to convert the low level differential output of the transducer, 60 millivolts at 100 PSI, to a useful level that can drive subsequent circuitry. Additionally, the amplifier must provide means to null out the DC offset output voltage of the transducer when zero pressure is applied. The circuit illustrated in Figure 3 uses three sections of a common op-amp chip, LM324N, for this purpose. The high input impedance of operational amplifiers IC1A and IC1B ensures that the circuit does not load the basic transducer.

The gain of the instrumentation amplifier is adjusted by means of potentiometer R6 to allow full scale calibration at 100 PSI applied pressure. Using the circuit constants indicated in Figure 3, the gain of the amplifier can be expressed as

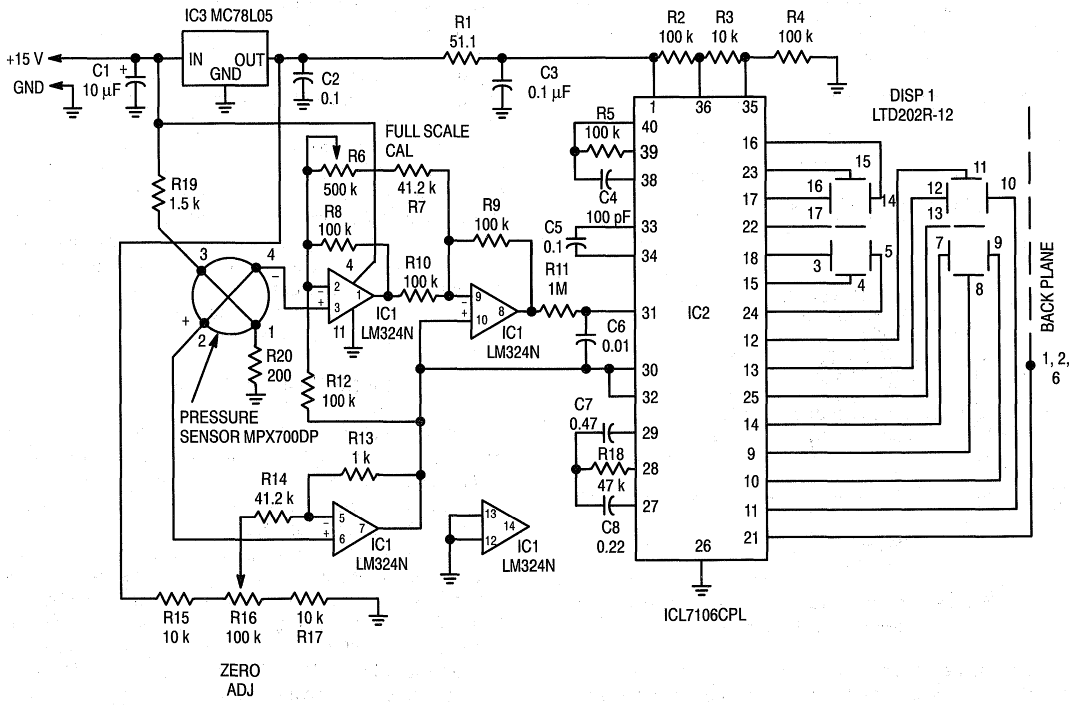


Figure 3. Schematic Diagram of Digital Pressure Gauge

A = 2(1 + 100K/R)
where A = circuit gain
R = the total resistance composed of R6 plus R7
100K = the circuit value represented by R8, R9, R10 and R12.

As can be seen by the gain equation, the minimum value of gain is 2 when R is infinite. The amplifier is capable of providing a gain of 100 or more by adjustment of R6, and R7, but in this application the required gain is within the range of about 2.6 to 5.3 to accommodate the tolerance of the full scale span of the sensor.

A voltage divider composed of R15, R16, and R17 provides an adjustable voltage which is fed to the inverting input of IC1B. This voltage, attenuated by the gain of less than 1 of IC1B, is fed to the analog to digital converter chip to negate the effect of the offset voltage produced by the sensor and allows the display of the circuit to read 00 when no pressure is applied. The differential output of the instrumentation amplifier appears between pins 7 and 8 of IC1. This is fed to the analog to digital converter, IC2, to provide a digital readout of the pressure difference impressed upon the transducer.

A/D CONVERTER

The circuit employs a high performance 3 1/2 digit A/D converter chip (IC2) which contains all the necessary active devices to convert the differential analog output voltage of the instrumentation amplifier to digital form. A pair of LCD digits is directly driven without multiplexing.

Included in IC2 are seven segment decoders, display drivers, backplane frequency generator, reference, and clock. The chip is capable of driving a 3 1/2 digit LCD non-multiplexed display. In this application the least and most significant digits are not used, but if greater range and/or resolution is desired the unused output terminals of the chip can be wired to drive 1 1/2 additional digits.

Full scale output of IC2 (2000 counts) is attained when the analog differential input voltage fed to pins 30 and 31 is equal to twice the reference voltage applied to pins 35 and 36, the differential reference input terminals. In this application the voltage divider composed of R2, R3, and R4, driven by the on-board 5 volt regulator, provides an arbitrary reference voltage of 238 millivolts. Since the maximum desired digital display occurs at 1000 counts (half of A/D converter full scale capability) for a display of 00 at 100 PSI, the maximum analog input voltage to IC2 will be 238 millivolts. Thus, nominal amplifier circuit gain must be 238/60, or about 4. The two least significant digits of input pressures exceeding 100 PSI will be displayed by the readout.

IC2 responds to both positive and negative analog input voltages, and generates a polarity bit at pin 20. If desired, the circuit can be used to measure both positive and negative differential pressures, with the polarity output bit at pin 20 used to activate a minus sign indicator for negative pressures.

The circuit of Figure 4 employs only two digits of the possible 3 1/2 digit capability of IC2. By substituting a 3 1/2 digit LCD display, the resolution of the pressure reading is increased by a factor of ten. Additionally, any input pressure of 100 PSI or greater will result in the most significant digit, "1", being displayed. Figure 4 illustrates the connections between the A/D converter and the optional 3 1/2 digit LCD display.

CIRCUIT ASSEMBLY

The terminals of the pressure sensor should be carefully formed to allow insertion into the PC board. Observe the location of pin 1 of the sensor, which is identified by a small notch. Use suitable hardware to mount the unit, being careful not to over tighten the screws and damage the plastic housing. To ensure circuit stability, use metal film resistors throughout the amplifier circuit. The only exception to this are the resistors associated with the A/D converter, R5, R11, and R18, which can be ordinary carbon types.

It is recommended to use sockets for IC1 and IC2.

A small identifier notch is located on the front of the display to identify the location of pin 1, similar to that of a DIP IC chip. This component is constructed of glass and must be handled carefully to avoid breakage.

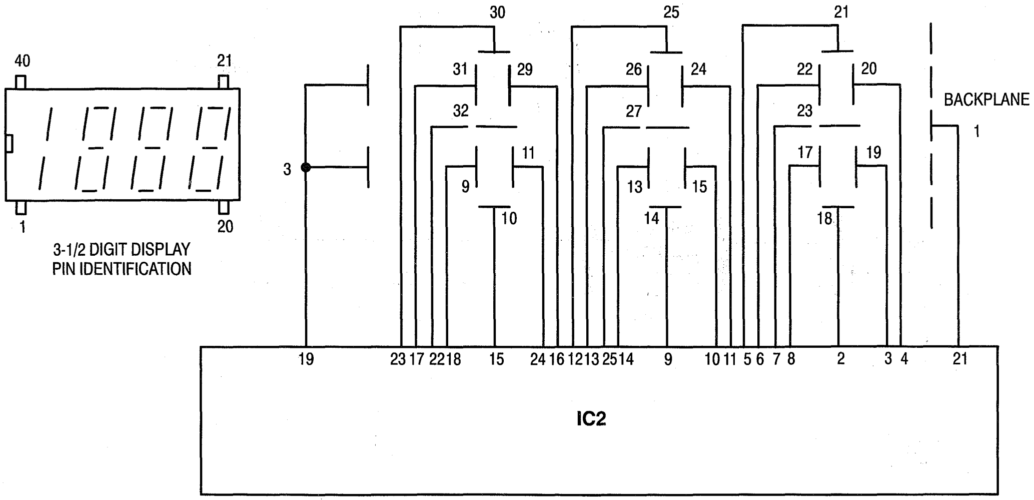


Figure 4. IC2 Driving Optional 3-1/2 Digit LCD Display

PRESSURE CONNECTIONS

For gauge pressure measurements, the port which is closest to pin 4 of the sensor (identified as P1 in Figure 5) is to be used, with the other port left open to the atmosphere. For vacuum measurements, use port P2, with the opposite port open to the atmosphere.

When the unit is to be used for differential pressure measurements, both ports are used. Positive pressure readings will be obtained when the pressure applied to the high pressure side, P1, is greater than that applied to the low pressure side P2. Should the pressures be opposite the display will still read the difference in pressure, and the A/D converter will output a polarity bit at pin 20 of the chip.

Hoses should be attached to the sensor using a suitable clamp. 100 PSI is a substantial pressure and any hose which is not secured properly can suddenly disconnect.

CALIBRATION

Calibration of the circuit consists of adjustment of the zero set and span adjust potentiometers, R16 and R6 respectively. A pressure source of up to 100 PSI and accurate pressure gauge is required. Figure 6 illustrates the test setup. Since the output voltage of the sensor is dependent upon the magnitude of the power supply voltage, calibration of the circuit must be performed with the circuit being driven by a regulated 15 volt supply. Any variation in the supply voltage will cause a proportional error in calibration. With the circuit operating and no pressure applied to the sensor, adjust R16 for a display of 00. Note that the display will read upscale when R16 is set to either side of zero.

Connect the sensor to the pressure source as indicated in Figure 6. Use a reference pressure gauge of known accuracy, and adjust the pressure to 100 PSI. The pressure sensor is capable of withstanding pressures up to 300 PSI without damage.

Adjust R6 for a display of 00, indicating 100 PSI. Since the A/D converter is capable of displaying readings greater than 100, adjustment of R6 is easily set between a display of 99 and 01.

Remove the pressure from the sensor and recheck the setting of the zero set potentiometer. Readjust if necessary for a display of 00. Check the pressure display at 100 PSI. This completes calibration of the circuit.

The digital pressure gauge may be checked over its range by applying any pressure between 0 and 100 PSI and comparing the display to the reference gauge. Note that pressures above 100 PSI will be indicated, but with reduced accuracy.

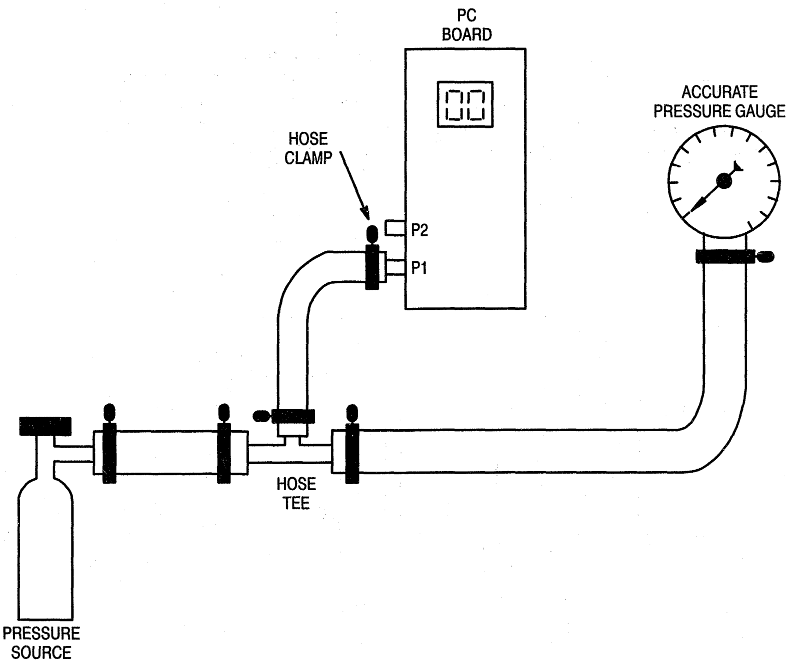


Figure 5. Setup to Calibrate Circuit Against a Known Accurate Pressure Gauge

Table 1. Parts List By Component Values and Part Numbers

Designators	Quantity	Description	Rating	Tolerance	Manufact.	Part Number
C1	1	25 volt electrolytic capacitor	10 µFd			
C2, C3, C5	3	50 volt ceramic disc capacitor	0.1 µFd			
C4	1	50 volt ceramic disc capacitor	100 pF			
C6	1	50 volt ceramic disc capacitor	0.01 µFd			
C7	1	50 volt ceramic disc capacitor	0.47 µFd			
C8	1	50 volt ceramic disc capacitor	0.22 µF			
DISP	1	2 digit LCD readout			Amperex	LTD202R-12
(optional) DISP	1	3 1/2 digit LCD readout			Amperex	LTD221R-12
IC1	1	Quad operational amplifier			Harris Teledyne	ICL7106CPL
IC2		A/D converter				
IC3	1	100 mA fixed regulator	5 volt		Motorola	MC78L05
R1	1	1/4 watt metal film resistor	51.1 Ω	1%		
R2, R4, R8, R9, R10, R12	6	1/4 watt metal film resistor	100 K	1%		
R3, R15, R17	3	1/4 watt metal film resistor	10 K	1%		
R7, R14	2	1/4 watt metal film resistor	41.2 K	1%		
R13	1	1/4 watt metal film resistor	1 K	1%		
R19	1	1/4 watt metal film resistor	1.5 K	1%		
R20	1	1/4 watt metal film resistor	200 Ω	%		
R5	1	1/4 watt carbon resistor	100 K	5%		
R11	1	1/4 watt carbon resistor	1 meg Ω	5%		
R18	1	1/4 watt carbon resistor	47 K	5%		
R6	1	0.3 watt cermet potentiometer, PC mount	500 K			
R16	1	0.3 watt cermet potentiometer, PC mount	100 K			
Sensor	1	0–100 psi, uncompensated pressure sensor			Motorola	MPX700DP

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1302

Motorola Pressure Sensors — Recommended Housing For Very Low Absolute Pressure Measurements

Prepared by: Motorola Toulouse Pressure Sensor Laboratory

INTRODUCTION

This application note describes the problems of measuring absolute pressure under 30 kPa and a description of a housing to solve these problems.

PROBLEM

When measuring absolute pressure under 30 kPa, very small leaks may introduce small offset and/or linearity errors.

CAUSE

Micro leaks are due to a very small gap between the metal leadframe and the plastic molded housing which surrounds the pressure sensor die.

When the sensor is measuring a very low pressure, the ambient pressure may be large enough to force some bubbles into the protective gel which may introduce stress on the sensor die.

SOLUTION

One way to avoid the problem is to place the sensor element in an external encapsulation. This can easily be achieved as shown in Figures 1, 2 and 3. These figures show the use of epoxy molding or equivalent compound in the solution of the problem.

The hermeticity must be very well done at the interface with the electrical connection to prevent any error; nevertheless if the leak is small enough the error may be negligible. The pressure around the sensor in this case is the same inside and outside of its housing.

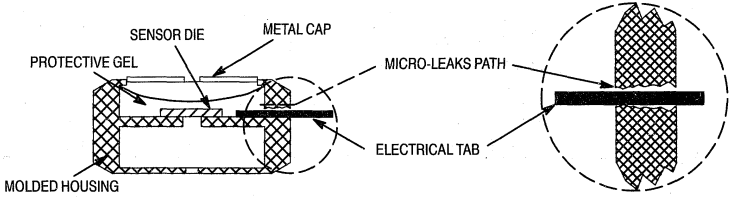


Figure 1. Basic Element

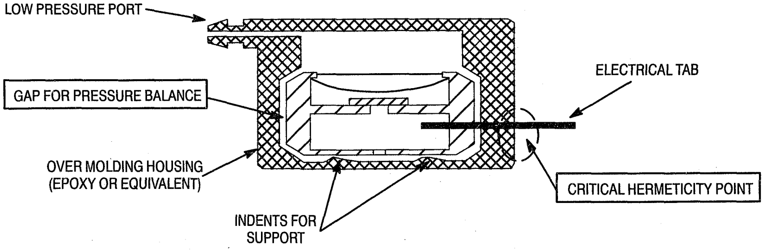


Figure 2. Single Element Mounting

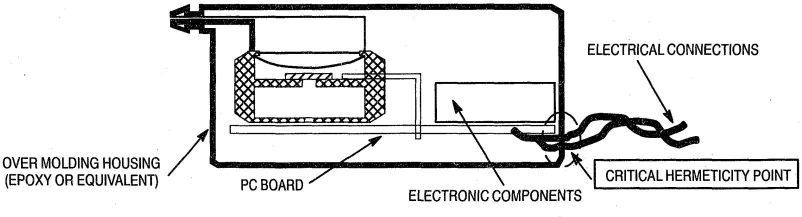


Figure 3. Complete Module Mounting

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APPLICATION NOTE

AN1303

A Simple 4-20 mA Pressure Transducer Evaluation Board

Prepared by: Denise Williams
Discrete Applications Engineering

INTRODUCTION

The two wire 4–20 mA current loop is one of the most widely utilized transmission signals for use with transducers in industrial applications. A two wire transmitter allows signal and power to be supplied on a single wire-pair. Because the information is transmitted as current, the signal is relatively immune to voltage drops from long runs and noise from motors, relays, switches and industrial equipment. The use of additional power sources is not desirable because the usefulness of this system is greatest when a signal has to be transmitted over a long distance with the sensor at a remote location. Therefore, the 4 mA minimum current in the loop is the maximum usable current to power the entire control circuitry. An evaluation board designed to meet these requirements is shown in Figure 1. A description of this 4–20 mA Pressure Transducer Evaluation Board, as well as a summary of the information required to use it, are presented here.

Figure 2 is a block diagram of a typical 4–20 mA current loop system which illustrates a simple two chip solution to converting pressure to a 4–20 mA signal. This system is designed to be powered with a 24 Vdc supply. Pressure is converted to a differential voltage by the Motorola MPX7100 pressure sensor. The voltage signal proportional to the monitored pressure is then converted to the 4–20 mA current signal with the Burr-Brown XTR101 Precision Two-Wire Transmitter. The current signal can be monitored by a meter in series with the supply or by measuring the voltage drop across R_L. A key advantage to this system is that circuit performance is not affected by a long transmission line.

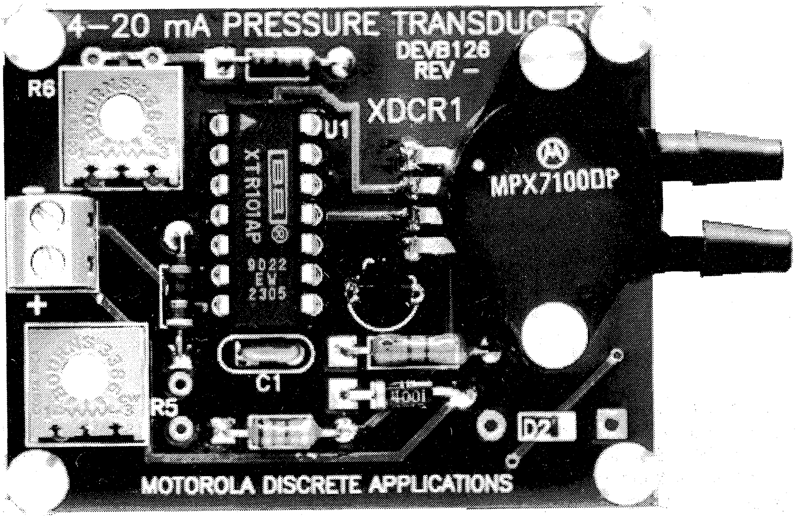


Figure 1. 4–20 mA Pressure Transducer Evaluation Board

REV 1

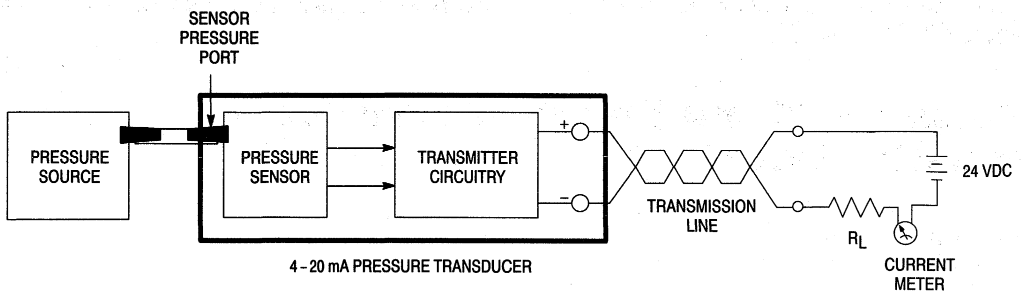


Figure 2. System Block Diagram

INPUT TERMINALS

A schematic of the 4–20 mA Pressure Transducer Evaluation Board is shown in Figure 3. Connections to this evaluation board are made at the terminals labeled (+) and (–). Because this system utilizes a current signal, the power supply, the load and any current meter must be put in series with the (+) to (–) terminals as indicated in the block diagram.

The load for this type of system is typically a few hundred ohms. As described above, a typical use of a 4–20 mA current transmission signal is the transfer of information over long distances. Therefore, a long transmission line can be connected between the (+) and (–) terminals on the evaluation board and the power supply/load.

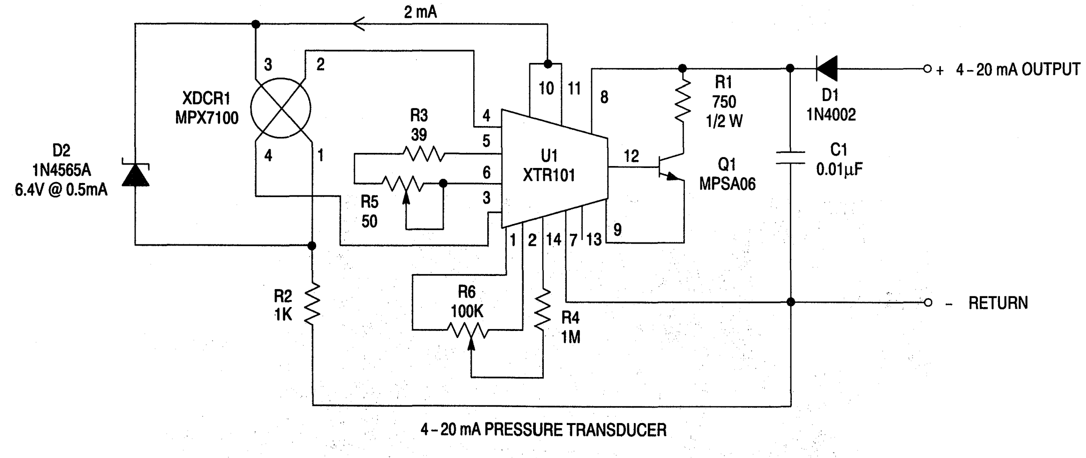


Figure 3. Schematic Diagram

PRESSURE INPUT

The device supplied on this evaluation board is an MPX7100DP, a high impedance (10 kΩ typ) 15 PSI sensor which provides two ports. P1, the positive pressure port, is on top of the sensor and P2, the vacuum port, is on the bottom of the sensor. The system can be supplied up to 15 PSI of positive pressure to P1 or up to 15 PSI of vacuum to P2 or a differential pressure up to 15 PSI between P1 and P2. Any of these pressure applications will create the same results at the sensor output.

CIRCUIT DESCRIPTION

The XTR101 current transmitter provides two one-milliamp current sources for sensor excitation when its bias voltage is between 12 V and 40 V. The MPX7100 series sensors are constant voltage devices, so a zener, D2, is placed in parallel with the sensor input terminals. Because the MPX7100 series parts have a high input impedance the zener and sensor combination can be biased with just the two milliamps available from the XTR101.

The offset adjustment is composed of R4 and R6. They are used to remove the offset voltage at the differential inputs to the XTR101. R6 is set so a zero input pressure will result in the desired output of 4 mA.

R3 and R5 are used to provide the full scale current span of 16 mA. R5 is set such that a 15 PSI input pressure results in the desired output of 20 mA. Thus the current signal will span 16 mA from the zero pressure output of 4 mA to the full scale output of 20 mA. To calculate the resistor required to set the full scale output span, the input voltage span must be defined. The full scale output span of the sensor is 24.8 mV and is ΔV_{IN} to the XTR101. Burr-Brown specifies the following equation for R_{span}. The 40 and 16 mΩ values are parameters of the XTR101.

$$R_{span} = 40 / [(16\text{ mA} / \Delta V\text{in}) - 0.016\text{ mhos}]$$
$$= 64\ \Omega$$

The XTR101 requires that the differential input voltage at pins 3 and 4, V2 - V1 be less than 1V and that V2 (pin 4) always be greater than V1 (pin 3). Furthermore, this differential voltage is required to have a common mode of 4-6 volts above the reference (pin 7). The sensor produces the differential output with a common mode of approximately 3.1 volts above its reference pin 1. Because the current of both 1 mA sources will go through R2, a total common mode voltage of about 5.1 volts (1 kΩ x 2 mA + 3.1 volts = 5.1 volts) is provided.

The printed circuit layout and the component layout for the evaluation board are shown in Figures 4a–4c. Table 1 is the parts list for the evaluation board. Some extra pads and the labels R7 and R8 were provided on the board to allow replacement of the variable resistors with fixed resistors R5 and R6 and select-in-test resistors R7 and R8 for particular applications.

OTHER CONSIDERATIONS

The 4–20 mA Pressure Transducer Evaluation Board has been designed to demonstrate the performance of the Motorola MPX7100 pressure sensor in conjunction with a 4–20 mA current transmitter. Several design considerations should be considered when actually optimizing for an application.

1. The optional external transistor, Q1, is recommended by Burr-Brown to increase accuracy by reducing temperature change inside the XTR101 package as the output current spans from 4 mA to 20 mA. Also for power supply voltages above 24 V, the 750 Ω 1/2W resistor, R1, is recommended to limit the power dissipation in the MPSA06 to below its 625 mW rating.
2. Keeping lead lengths short in the portion of the circuit where the span adjust and zero adjust resistors connect to the XTR101 is recommended to reduce noise pick-up and parasitic resistance.
3. C1 is a bypass capacitor and, therefore, should be connected across pins 7 and 8 of the XTR101 as close to the device as possible.

CALIBRATION

1. Connect the evaluation board as shown in the block diagram of Figure 2.
2. With no pressure connections to the sensor, adjust R6 so that I_{out} is 4 mA.
3. Supply 15 PSI to the sensor, (either positive pressure to the pressure port or vacuum to the vacuum port) and adjust R5 so that I_{out} is 20 mA.
4. You may need to repeat steps 2 and 3 to ensure proper calibration.

CONCLUSION

This circuit is an example of how the higher impedance MPX7000 series sensors can be utilized in an industrial application. It provides a simple design alternative where remote pressure sensing is required.

Table 1. Parts List for 4–20 mA Pressure Transducer Evaluation Board

Designator	Quantity	Description	Rating	Manufacturer	Part Number
	1 1 4 4 2 2	PC Board (see Figure 3) Input/Output Terminals 1/2″ standoffs, Nylon threaded 1/2″ screws, Nylon 5/8″ screws, Nylon 4-40 nuts, Nylon		Motorola PHX CONT	DEVB126 #1727010
C1	1	**Capacitor** 0.01 µF	50 V		
D1 D2	1 1	**Diodes** 100 V Diode 6.4 V Zener	1 A		1N4002 1N4565A
Q1	1	**Transistor** NPN Bipolar		Motorola	MPSA06
R1 R2 R3 R4	1 1 1 1	**Resistors, Fixed** 750 Ω 1 kΩ 39 Ω 1 MΩ	1/2 W		
R5 R6	1 1	**Resistors, Variable** 50 Ω, one turn 100 KΩ, one turn		Bourns Bourns	#3386P-1-500 #3386P-1-104
U1	1	**Integrated Circuit** Two wire current transmitter		Burr-Brown	XTR101
XDCR1	1	**Sensor** High Impedance	15 PSI	Motorola	MPX7100DP

NOTE: All resistors are 1/4 W with a tolerance of 5% unless otherwise noted. All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

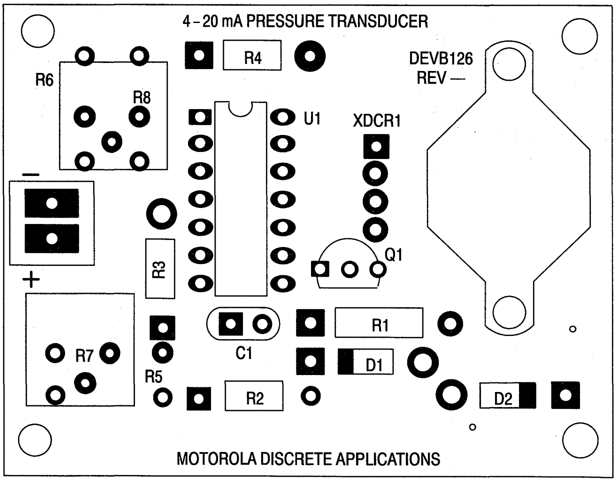


Figure 4a. Component Layout

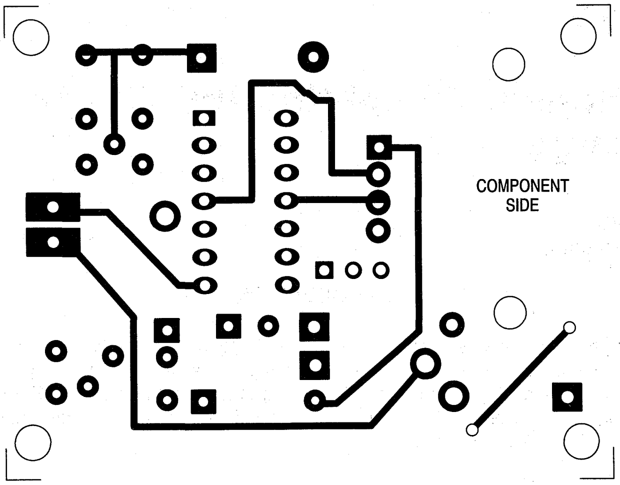


Figure 4b. Board Layout Component Side

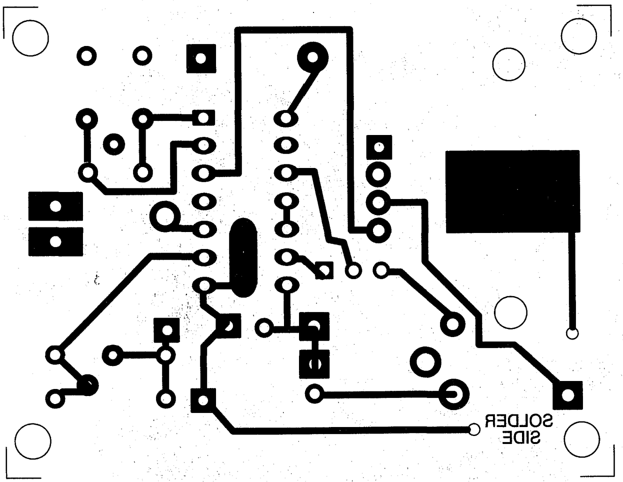


Figure 4c. Board Layout Solder Side

(With traces reversed for easy comparison to front side)

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1304

Integrated Sensor Simplifies Bar Graph Pressure Gauge

Prepared by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

Integrated semiconductor pressure sensors such as the MPX5100 greatly simplify electronic measurement of pressure. These devices translate pressure into a 0.5 to 4.5 volt output range that is designed to be directly compatible with microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with ICs such as the LM3914, making Bar Graph Pressure Gauges relatively simple. A description of a Bar Graph Pressure Sensor Evaluation Board and its design considerations are presented here.

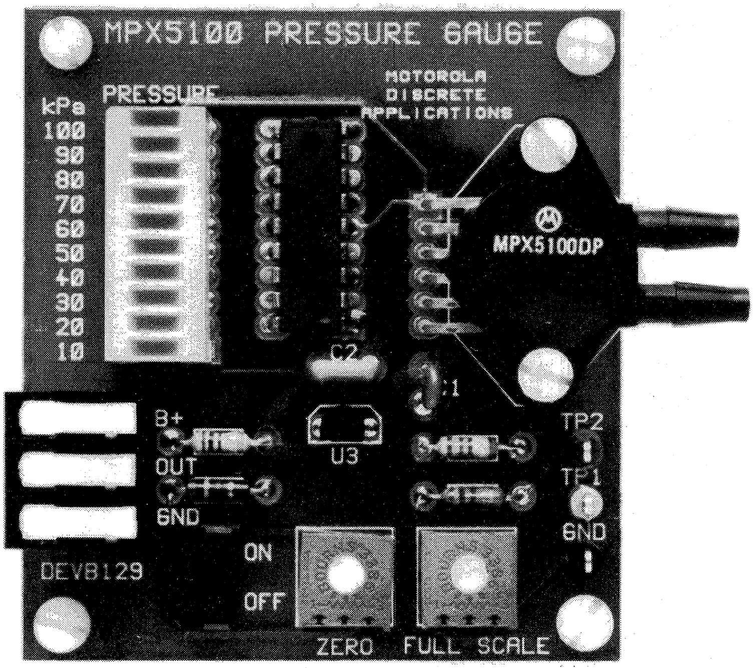


Figure 1. DEVB129 MPX5100 Bar Graph Pressure Gauge

EVALUATION BOARD DESCRIPTION

A summary of the information required to use evaluation board number DEVB129 is presented as follows. A discussion of the design appears under the heading Design Considerations.

FUNCTION

The evaluation board shown in Figure 1 is designed to provide a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port is on the top side of the MPX5100 sensor, and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi)* of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10 kPa. If full scale pressure is adjusted for a value other than 100 kPa the bar graph may be read as a percent of full scale. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at 100 kPa. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of each other.

ELECTRICAL CHARACTERISTICS

The following electrical characteristics are included to describe evaluation board operation. They are not specifications in the usual sense and are intended only as a guide to operation.

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	Volts
Full Scale Pressure	P_{FS}	—	—	100	kPa
Overpressure	P_{MAX}	—	—	700	kPa
Analog Full Scale	V_{FS}	—	4.5	—	Volts
Analog Zero Pressure Offset	V_{OFF}	—	0.5	—	Volts
Analog Sensitivity	S_{AOUT}	—	40	—	mV/kPa
Quiescent Current	I_{CC}	—	20	—	mA
Full Scale Current	I_{FS}	—	140	—	mA

CONTENT

Board contents are described in the following parts list, schematic, and silk screen plot. A pin by pin circuit description follows in the next section.

PIN-BY-PIN DESCRIPTION

B+:

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that power dissipation in the LM3914 does not exceed 1.3 watts.

OUT:

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at 100 kPa. This output is capable of sourcing 100 µA at full scale output.

GND:

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board, one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1:

Test point 1 is connected to the zero pressure reference voltage and can be used for zero pressure calibration. To calibrate for zero pressure, this voltage is adjusted with R6 to match the zero pressure voltage that is measured at the analog output (OUT) terminal.

TP2:

Test point 2 performs a similar function at full scale. It is connected to the LM3914's reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R5 to set full scale pressure.

P1, P2:

Pressure and Vacuum ports P1 & P2 protrude from the MPX5100 sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither is labeled. Either one or a differential pressure applied to both can be used to obtain full scale readings up to 100 kPa (15 psi). Maximum safe pressure is 700 kPa.

---

* 100 kPa = 14.7 psi., 15 psi is used throughout the text for convenience.

DESIGN CONSIDERATIONS

In this type of an application the design challenge is how to interface a sensor with the bar graph output. MPX5100 Sensors and LM3914 Bar Graph Display drivers fit together so cleanly that having selected these two devices the rest of the design is quite straight forward.

A block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the MPX5100's zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5 volt regulator's output voltage through R1, R4, and adjustment pot R6. The voltage generated at the wiper of R6 is then fed into R_{LO} which matches the sensor's zero pressure voltage and zeros the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R5 that are shown in Figure 2.

The MPX5100 requires 5 volt regulated power that is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R2, R5, and R3 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 85°C temperature range accuracy for both the sensor and driver IC are ±2.5%, totaling ±5%. Given a 10 segment display total accuracy is approximately ±(10 kPa +5%).

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is how easy it is to design. The interface between an MPX5100 sensor, LM3914 display driver, and bar graph output is direct and straight forward. The result is a simple circuit that is capable of measuring pressure, vacuum, or differential pressure; and will also send an analog signal to other control circuitry.

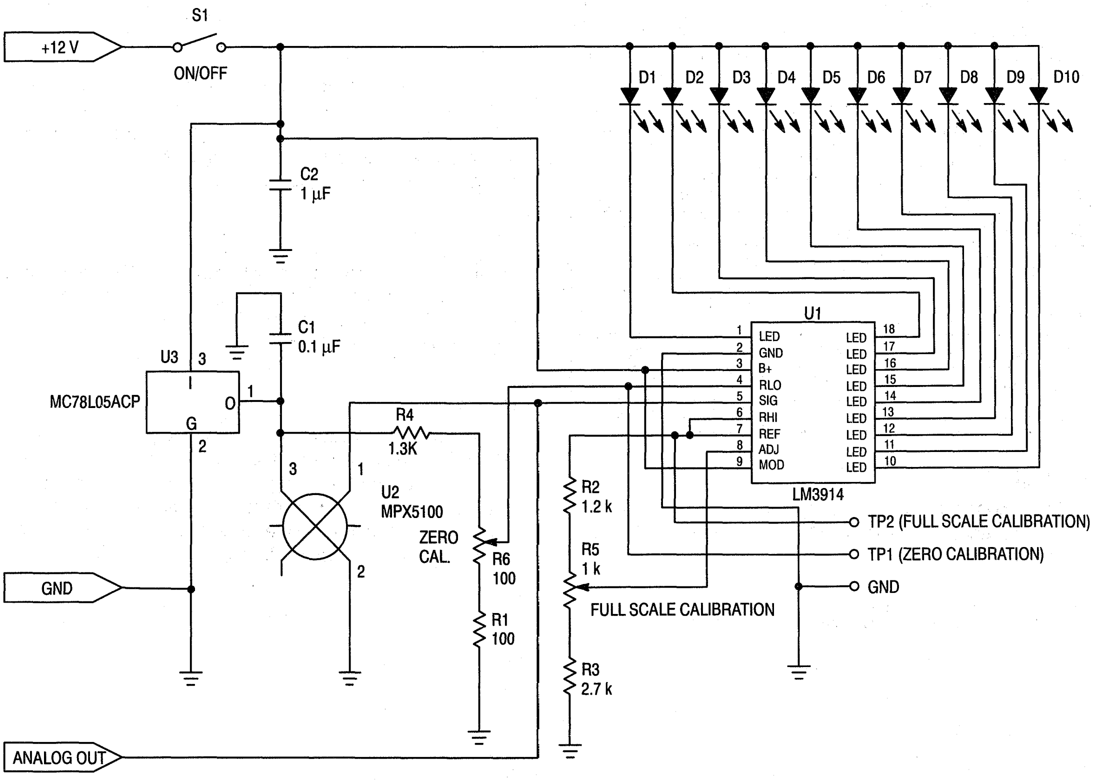


Figure 2. MPX5100 Pressure Gauge

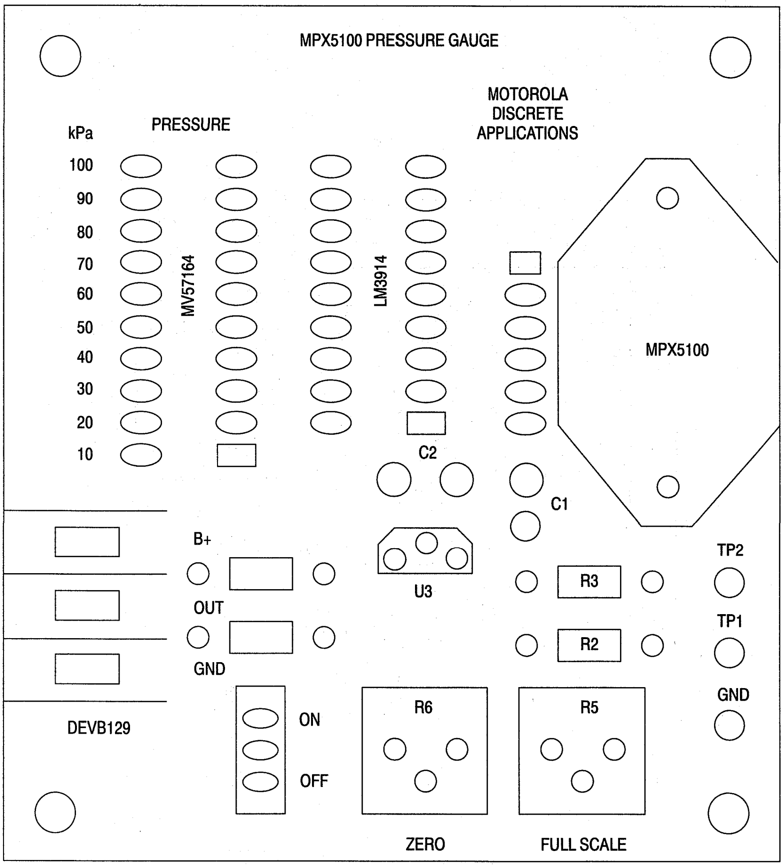


Figure 3. Silk Screen 2X

Table 1. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1 C2	1 1	Ceramic Cap Ceramic Cap	0.1 µF 1 µF		
D1-D10	1	Bar Graph LED		GI	MV57164
R1 R2 R3 R4 R5 R6	1 1 1 1 1 1	1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor 1/4 W Film Resistor Trimpot Trimpot	100 1.2K 2.7K 1.3K 1K 100	 Bourns Bourns	
S1	1	On/Off Switch		NKK	12SDP2
U1 U2 U3	1 1 1	Bar Graph IC Pressure Sensor Voltage Regulator		National Motorola Motorola	LM3914 MPX5100 MC78L05ACP
— — — —	1 3 4 4	Terminal Block Test Point Terminal Nylon Spacer 4-40 Nylon Screw	 3/8″ 1/4″	Augat Components Corp.	25V03 TP1040104

Note: All resistors have a tolerance of 5% unless otherwise noted.
All capacitors are 50 volt ceramic capacitors with a tolerance of 10% unless otherwise noted.

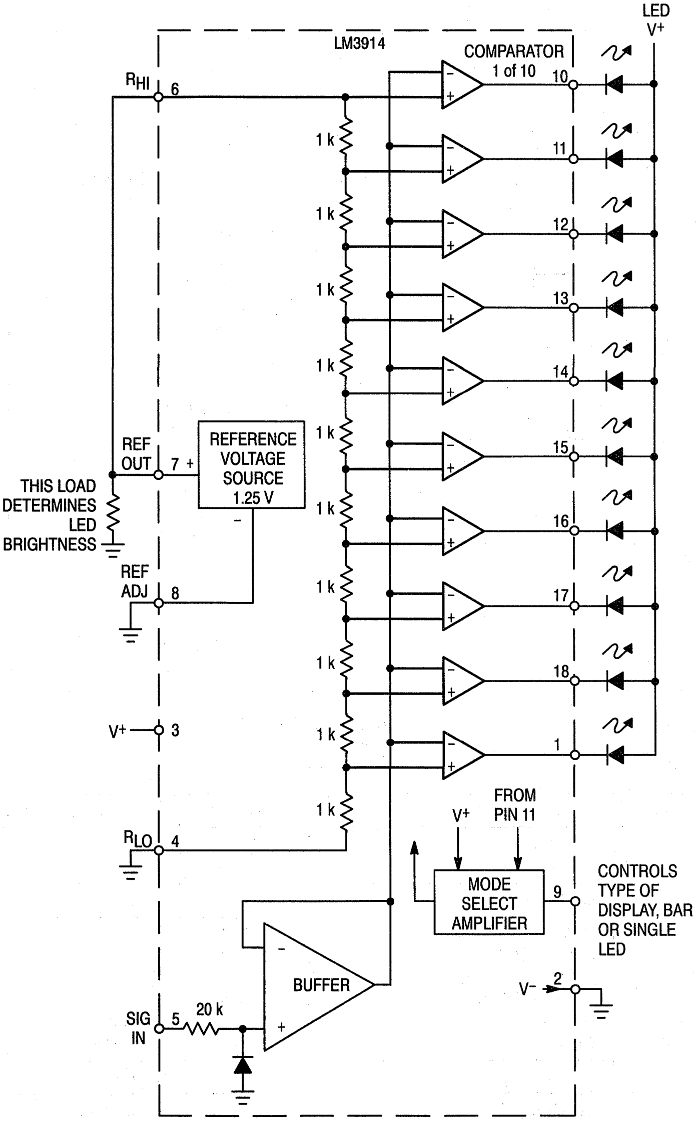


Figure 4. LM3914 Block Diagram

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1305

An Evaluation System for Direct Interface of the MPX5100 Pressure Sensor with a Microprocessor

Prepared by: Bill Lucas
Discrete Applications Engineering

INTRODUCTION

Interfacing pressure sensors to analog-to-digital converters or microprocessors with on-chip A/D converters has been a challenge that most engineers do not enjoy accepting. Recent design advances in pressure sensing technology have allowed the engineer to directly interface a pressure sensor to an A/D converter with no additional active components. This has been made possible by integrating a temperature compensated pressure sensor element and active linear circuitry on the same die. A description of an evaluation board that shows the ease of interfacing a signal conditioned pressure sensor to an A/D converter is presented here.

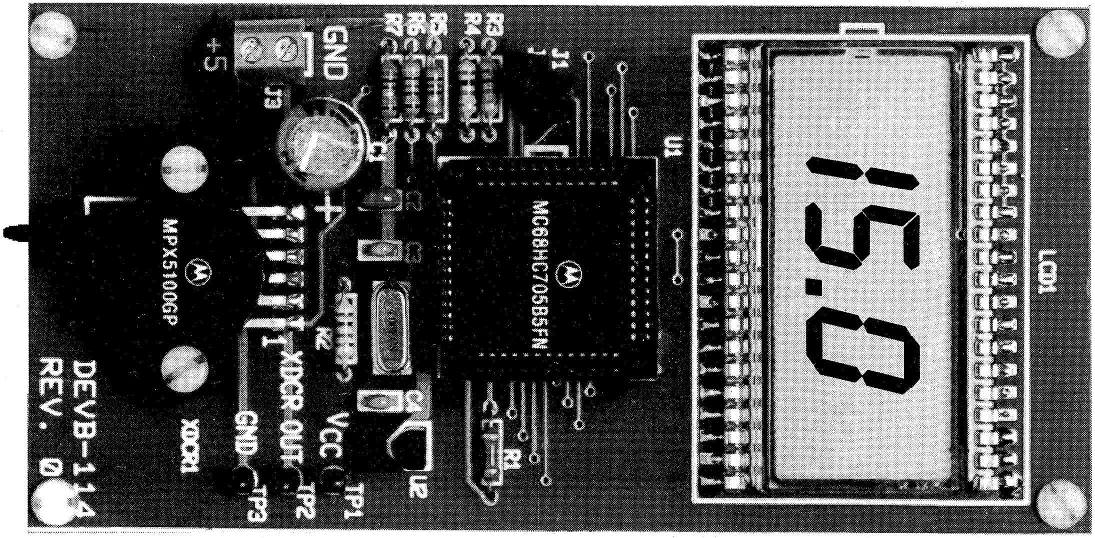


Figure 1. DEVB-114 MPX5100 Evaluation Module

PURPOSE

This evaluation system, shown in Figure 1, demonstrates the ease of operation and interfacing of the Motorola MPX5100 series pressure sensors with on-chip temperature compensation, calibration and amplification. The board may be used to evaluate the sensor's suitability for a specific application.

DESCRIPTION

The DEVB-114 evaluation board is constructed on a small printed circuit board. It is powered from a single +5 Vdc regulated power supply. The system will display the pressure applied to the MPX5100 sensor in pounds per square inch. The range is 0 PSI through 15 PSI, resolved to 0.1 PSI. No potentiometers are used in the system to adjust the span and offset. The sensor's zero offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX5100 is repeatable from unit to unit. There is a facility for a small "rubbering" of the slope constant built into the program. It is accomplished with jumpers J1 and J2, and is explained in the Operation section. The board contents are further described in the schematic, silk screen plot, and parts list that appear in Figures 2, 3 and Table 1.

BASIC CIRCUIT

The evaluation board consists of three basic subsystems: an MPX5100GP pressure sensor, a four digit liquid crystal display (only three digits and a decimal are used) and a programmed microprocessor with the necessary external circuitry to support the operation of the microprocessor.

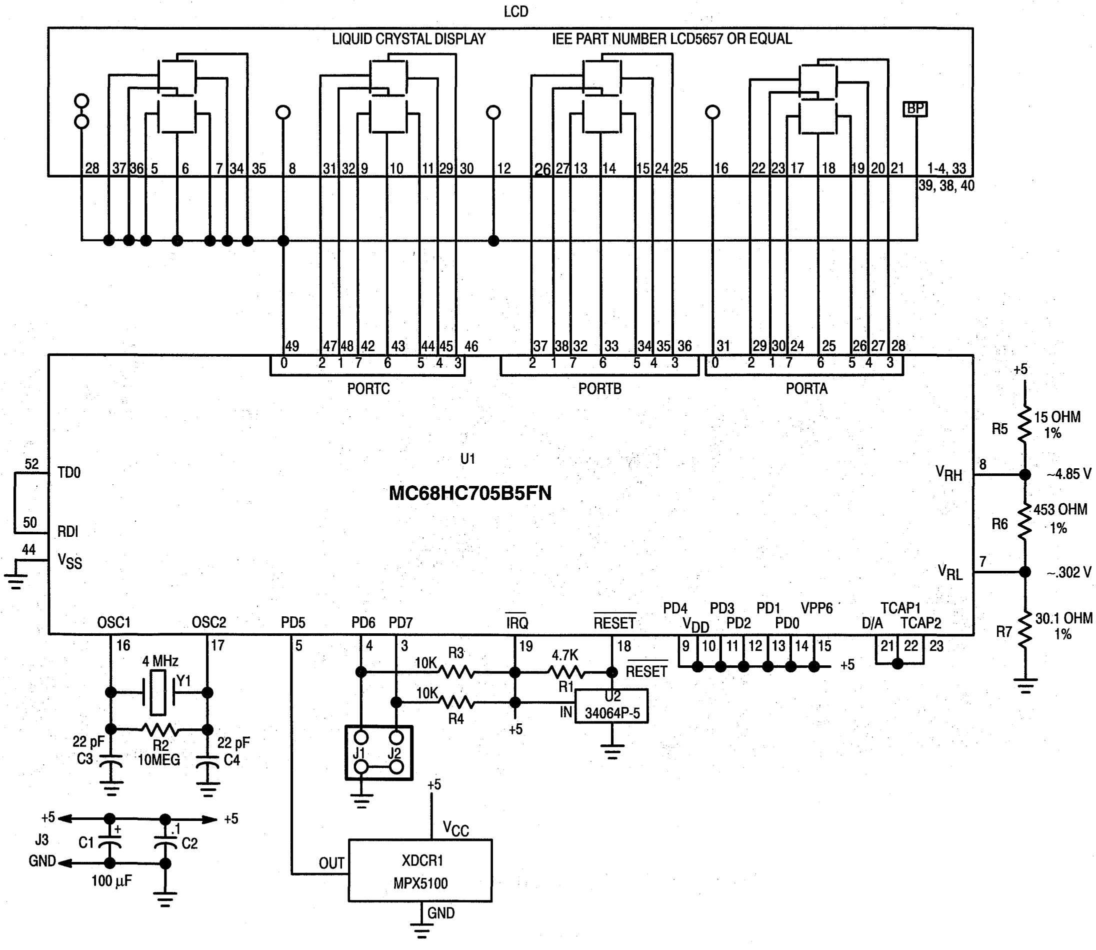


Figure 2. DEVB-114 System Schematic

Table 1. DEVB-114 Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C1	1	100 µF Electrolytic Capacitor	25 Vdc	Sprague	513D107M025BB4
C2	1	0.1 µF Ceramic Capacitor	50 Vdc	Sprague	1C105Z5U104M050B
C3, C4	2	22 pF Ceramic Capacitor	100 Vdc	Mepco/Centralab	CN15A220K
J1, J2	1	Dual Row Straight .025 Pins Arranged On .1″ Grid		Molex	10-89-1043
LCD	1	Liquid Crystal Display		AMPEREX	LTD226R-12
R1	1	4.7 k Ohm Resistor			
R2	1	10 Meg Ohm Resistor			
R3, R4	2	10 k Ohm Resistor			
R5	1	15 Ohm 1% 1/4 W Resistor			
R6	1	453 Ohm 1% 1/4 W Resistor			
R7	1	30.1 Ohm 1% 1/4 W Resistor			
XDCR1	1	Pressure Sensor		Motorola	MPX5100GP
U1	1	Microprocessor		Motorola Motorola	MC68HC705B5FN or XC68HC705B5FN
U2	1	Under Voltage Detector		Motorola	MC34064P-5
Y1	1	Crystal (Low Profile)	4.0 MHz	ECS	ECS-40-S-4
No Designator	1	52 Pin PLCC Socket		AMP	821-575-1
No Designator	2	Jumpers For J1 and J2		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			

Note: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

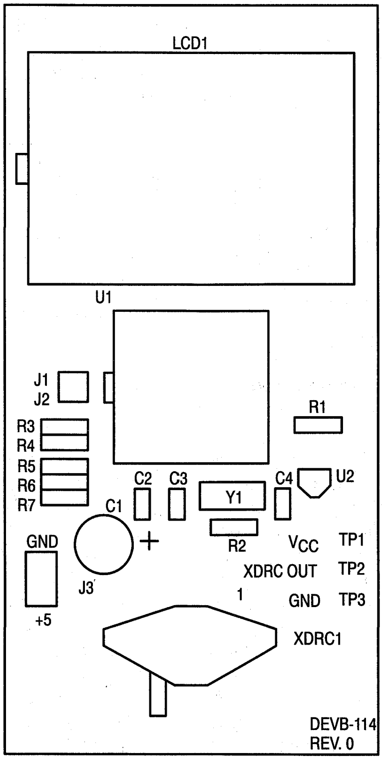


Figure 3. Silk Screen

Theory of Operation

Referring to the schematic, Figure 2, the MPX5100 pressure sensor is connected to PORT D bit 5 of the microprocessor. This port is an input to the on-chip 8 bit analog to digital converter. The pressure sensor provides a signal output to the microprocessor of approximately 0.5 Vdc at 0 psi to 4.5 Vdc at 15 psi of applied pressure as shown in Figure 4. The input range of the A to D converter is set at approximately 0.3 Vdc to 4.85 Vdc. This compresses the range of the A to D converter around the output range of the sensor to maximize the A to D converter resolution; 0 to 255 counts is the range of the A to D converter. V_{RH} and V_{RL} are the reference voltage inputs to the A to D converter. The resolution is defined by the following:

Analog-to-digital converter count =

$$[(V_{xdcr} - V_{RL})/(V_{RH} - V_{RL})] \bullet 255$$

The count at 0 psi = $[(.5 - .302)/(4.85 - .302)] \bullet 255 \approx 11$
The count at 15 psi = $[(4.5 - .302)/(4.85 - .302)] \bullet 255 \approx 235$
Therefore the resolution = count @ 15 psi – count @ 0 psi or the resolution is (235 – 11) = 224 counts. This translates to a system that will resolve to 0.1 psi.

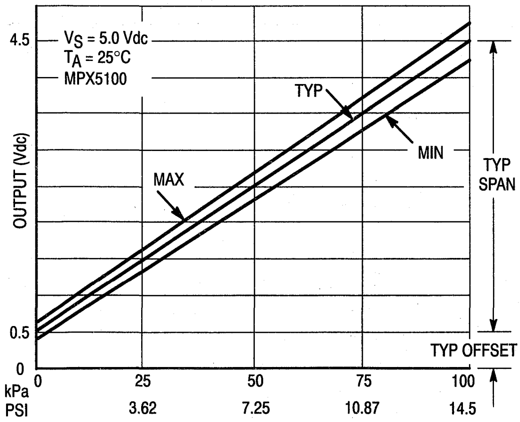


Figure 4. MPX5100 Output versus Pressure Input

The voltage divider consisting of R5 through R7 is connected to the +5 volts powering the system. The output of the pressure sensor is ratiometric to the voltage applied to it. The pressure sensor and the voltage divider are connected to a common supply; this yields a system that is ratiometric. By nature of this ratiometric system, variations in the voltage of the power supplied to the system will have no effect on the system accuracy.

The liquid crystal display is directly driven from I/O ports A, B, and C on the microprocessor. The operation of a liquid crystal display requires that the data and backplane pins must be driven by an alternating signal. This function is provided by a software routine that toggles the data and backplane at approximately a 30 Hz rate.

The microprocessor section of the system requires certain support hardware to allow it to function. The MC34064P-5 (U2) provides an under voltage sense function which is used to reset the microprocessor at system power-up. The 4 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and provides a stable base for time based functions. Jumpers J1 and J2 are examined by the software and are used to "rubber" the slope constant.

OPERATION

The system must be connected to a 5 Vdc regulated power supply. Note the polarity marked on the power terminal J3. Jumpers J1 and J2 must either both be installed or both be removed for the normal slope constant to be used. The pressure port on the MPX5100 sensor must be left open to atmosphere anytime the board is powered-up. As previously stated, the sensor's voltage offset with zero pressure applied is computed at power-up.

You will need to apply power to the system. The LCD will display CAL for approximately 5 seconds. After that time, the LCD will then start displaying pressure.

To improve upon the accuracy of the system, you can change the constant used by the program that constitutes the span of the sensor. You will need an accurate test gauge to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation (after CAL is no longer displayed), apply 15.0 PSI to the sensor. Make sure that jumpers J1 and J2 are either both installed or both removed. Referring to Table 2, you can increase the displayed value by installing J1 and removing J2. Conversely, you can decrease the displayed value by installing J2 and removing J1.

J1	J2	Action
IN	IN	USE NORMAL SPAN CONSTANT
OUT	OUT	USE NORMAL SPAN CONSTANT
OUT	IN	DECREASE SPAN CONSTANT APPROXIMATELY 1.5%
IN	OUT	INCREASE SPAN CONSTANT APPROXIMATELY 1.5%

Table 2

SOFTWARE

The source code, compiler listing, and S-record output for the software used in this system are available on the Motorola Freeware Bulletin Board Service in the MCU directory under the filename DEVB-114.ARC. To access the bulletin board you must have a telephone line, a 300, 1200 or 2400 baud modem and a terminal or personal computer. The modem must be compatible with the Bell 212A standard. Call 1-512-891-3733 to access the Bulletin Board Service.

The software for the system consists of several modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX5100 transducer.

Figure 5 is a flowchart for the program that controls the system.

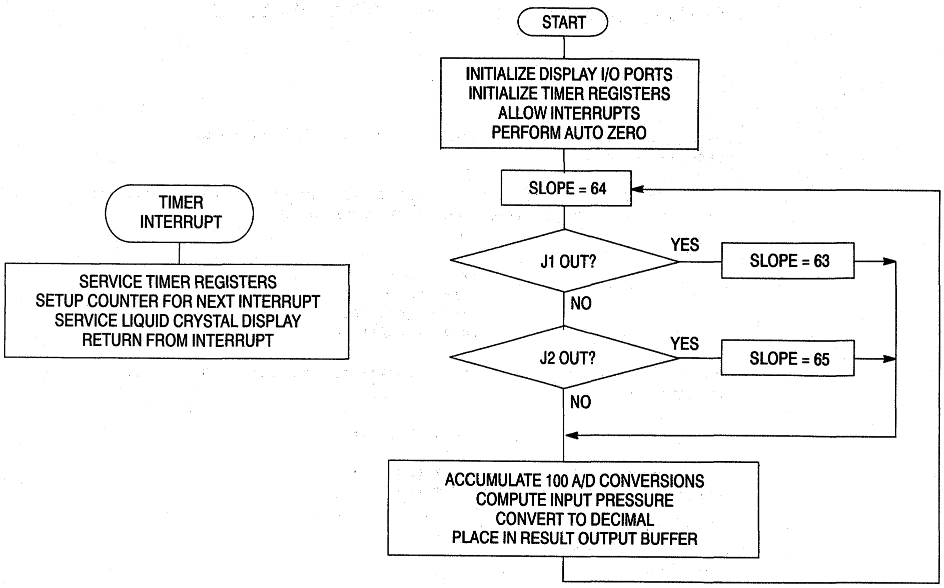


Figure 5. DEVB-114 Software Flowchart

The compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide approximately a 20 ms loop.

read_a2d() Performs one hundred reads on the analog to digital converter on multiplexer channel 5 and returns the accumulation.

fixcompare() Services the internal timer for 30 ms timer compare interrupts.

TIMERCMP() Alternates the data and backplane for the liquid crystal display.

initio() Sets up the microcomputer's I/O ports, timer, allows processor interrupts, and calls adzero().

adzero() This routine is necessary at power-up time because it delays the power supply and allows the transducer to stabilize. It then calls 'read_atod()' and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg) This routine converts the unsigned binary argument passed in 'arg' to a five digit decimal number in an array called 'digit'. It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. It is then output to the display.

display_psi() This routine is called from 'main()'. The analog to digital converter routine is called, the pressure is calculated, and the pressure applied to the sensor is displayed. The loop then repeats.

main() This is the main routine called from reset. It calls 'initio()' to set up the system's I/O. 'display_psi()' is called to compute and display the pressure applied to the sensor.

SOFTWARE SOURCE/ASSEMBLY PROGRAM CODE

```
                              #pragma option v ;
                              /*

                              rev 1.1 code rewritten to use the MC68HC705B5 instead of the
                              MC68HC805B6. WLL 6/17/91

                              THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB-114 DEMONSTRATION
                              BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                          BYTE CRAFT LTD.
                                                          421 KING ST.
                                                          WATERLOO, ONTARIO
                                                          CANADA  N2J 4E4
                                                          (519)888-6911

                              SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                              COMPILERS.
                                                           BILL LUCAS 8/5/90
                                                           MOTOROLA, SPS            */

0800 1700                     #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096                     #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                              /*      Vector assignments    */
1FFE                          #pragma vector __RESET   @ 0x1ffe ;
1FFC                          #pragma vector __SWI     @ 0x1ffc ;
1FFA                          #pragma vector IRQ       @ 0x1ffa ;
1FF8                          #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                          #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                          #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                          #pragma vector SCI       @ 0x1ff2 ;

                              #pragma has STOP ;
                              #pragma has WAIT ;
                              #pragma has MUL ;

                              /*      Register assignments for the 68HC705B5 microcontroller     */
0000                          #pragma portrw porta   @ 0x00;  /*                                      */
0001                          #pragma portrw portb   @ 0x01;  /*                                      */
0002                          #pragma portrw portc   @ 0x02;  /*                                      */
0003                          #pragma portrw portd   @ 0x03;  /* in  ,-  ,SS  ,SCK  ,MOSI,MISO,TxD,RxD */
0004                          #pragma portrw ddra    @ 0x04;  /* Data direction, Port A               */
0005                          #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B               */
0006                          #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)   */
0007                          #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                          #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                          #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                          #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                          #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                          #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                          #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                          #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                          #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                          #pragma portrw scistat @ 0x10;  /* sci status reg */
```

```
0011                            #pragma portrw scidata  @ 0x11;  /* SCI Data  */
0012                            #pragma portrw tcr      @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL       */
0013                            #pragma portrw tsr      @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0               */
0014                            #pragma portrw icaphi1  @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0015                            #pragma portrw icaplo1  @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15) */
0016                            #pragma portrw ocmphi1  @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0017                            #pragma portrw ocmplo1  @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)*/
0018                            #pragma portrw tcnthi   @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
0019                            #pragma portrw tcntlo   @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)   */
001A                            #pragma portrw acnthi   @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001B                            #pragma portrw acntlo   @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B) */
001C                            #pragma portrw icaphi2  @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001D                            #pragma portrw icaplo2  @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d) */
001E                            #pragma portrw ocmphi2  @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/
001F                            #pragma portrw ocmplo2  @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)*/

                                   /* put constants and variables here...they must be global */

                                /************************************************************************/
1EFE 74                         #pragma mor @ 0x1EFE = 0x74; /* this disables the watchdog counter and does not
                                                                add pull-down resistors on ports B and C */

0800 FC 30 DA 7A 36 6E E6 38 FE   const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                  /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */
080A 27 10 03 E8 00 64 00 0A      const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                         unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec functio */

0000                              registera ac;      /* processor's A register */

0055                              long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */


0059                              long slope;        /* multiplier for adc to engineering units conversion */

005B                              int adcnt;         /* a/d converter loop counter */

005C                              long xdcr_offset;  /* initial xdcr offset */

005E 0060                         unsigned long i,j; /* counter for loops */

0062                              int k;             /* misc variable */

                                  struct bothbytes
                                     {  int hi;
                                        int lo;
                                     };

                                     union isboth
                                          {  long  l;
                                          struct bothbytes b;
                                          };

0063 0002                            union isboth q;  /* used for timer set-up */
```

```
                                  /****************************************************************************/
                                                        /* code starts here */
                                  /****************************************************************************/
                                  /* these interrupts are not used...give them a graceful return if for
                                     some reason one occurs */

1FFC 08 12                        __SWI(){}
0812 80       RTI
1FFA 08 13                        IRQ(){}
0813 80       RTI
1FF8 08 14                        TIMERCAP(){}
0814 80       RTI
1FF4 08 15                        TIMEROV(){}
0815 80       RTI
1FF2 08 16                        SCI(){}
0816 80       RTI

                                  /****************************************************************************/

                                  void delay(void)  /* just hang around for a while */
                                  {
0817 4F      CLRA                 for (i=0; i<20000; ++i);
0818 3F 57    CLR    $57
081A B7 58    STA    $58
081C B6 57    LDA    $57
081E B7 5E    STA    $5E
0820 B6 58    LDA    $58
0822 B7 5F    STA    $5F
0824 B6 5F    LDA    $5F
0826 A0 20    SUB    #$20
0828 B6 5E    LDA    $5E
082A A2 4E    SBC    #$4E
082C 24 08    BCC    $0836
082E 3C 5F    INC    $5F
0830 26 02    BNE    $0834
0832 3C 5E    INC    $5E
0834 20 EE    BRA    $0824
0836 81       RTS                 }
                                  /****************************************************************************/

                                  read_a2d(void)
                                  {
                                  /* read the a/d converter on channel 5 and accumulate the result
                                     in atodtemp */

0837 3F 56    CLR    $56          atodtemp=0;   /* zero for accumulation */
0839 3F 55    CLR    $55
083B 4F       CLRA                   for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
083C B7 5B    STA    $5B
083E B6 5B    LDA    $5B
0840 A8 80    EOR    #$80
0842 A1 E4    CMP    #$E4
0844 24 21    BCC    $0867
```

```
                                      {
0846 A6 25    LDA    #$25               adstat = 0x25;  /* convert on channel 5 */
0848 B7 09    STA    $09
084A 0F 09 FD BRCLR 7,$09,$084A         while (!(adstat & 0x80));  /* wait for a/d to complete */
084D B6 08    LDA    $08                atodtemp = addata + atodtemp;
084F 3F 57    CLR    $57
0851 B7 58    STA    $58
0853 BB 56    ADD    $56
0855 B7 58    STA    $58
0857 B6 57    LDA    $57
0859 B9 55    ADC    $55
085B B7 57    STA    $57
085D B7 55    STA    $55
085F B6 58    LDA    $58
0861 B7 56    STA    $56
                                      }
0863 3C 5B    INC    $5B
0865 20 D7    BRA    $083E
0867 B6 56    LDA    $56            atodtemp = atodtemp/100;
0869 B7 58    STA    $58
086B B6 55    LDA    $55
086D B7 57    STA    $57
086F 3F 66    CLR    $66
0871 A6 64    LDA    #$64
0873 B7 67    STA    $67
0875 CD 0A 5E JSR    $0A5E
0878 CD 0A 8F JSR    $0A8F
087B BF 55    STX    $55
087D B7 56    STA    $56
087F 81       RTS                   return atodtemp;
                                  }

                                  /***********************************************************************/

                                  void fixcompare (void) /* sets-up the timer compare for the next interrup */
                                     {
0880 B6 18    LDA    $18              q.b.hi =tcnthi;
0882 B7 63    STA    $63
0884 B6 19    LDA    $19              q.b.lo = tcntlo;
0886 B7 64    STA    $64
0888 AB 4C    ADD    #$4C             q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms.*/
088A B7 64    STA    $64
088C B6 63    LDA    $63
088E A9 1D    ADC    #$1D
0890 B7 63    STA    $63
0892 B7 16    STA    $16              ocmphi1 = q.b.hi;
0894 B6 13    LDA    $13              ac=tsr;
0896 B6 64    LDA    $64              ocmplo1 = q.b.lo;
0898 B7 17    STA    $17
089A 81       RTS                     }


                                   /**********************************************************************/
                                   void TIMERCMP (void)              /* timer service module */
1FF6 08 9B                            {
```

```
089B 33 02      COM     $02              portc =~ portc;        /* service the lcd */
089D 33 01      COM     $01              portb =~ portb;
089F 33 00      COM     $00              porta =~ porta;
08A1 AD DD      BSR     $0880            fixcompare();
08A3 80         RTI                  }

                                   /*************************************************************************/

                                   void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                              pressure offset voltage output */
                                   {

08A4 4F          CLRA                for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
08A5 3F 57       CLR     $57
08A7 B7 58       STA     $58
08A9 B6 57       LDA     $57
08AB B7 60       STA     $60
08AD B6 58       LDA     $58
08AF B7 61       STA     $61
08B1 B6 61       LDA     $61
08B3 A0 14       SUB     #$14
08B5 B6 60       LDA     $60
08B7 A2 00       SBC     #$00
08B9 24 0B       BCC     $08C6
                                                            power supply time to settle down */
                                      {
08BB CD 08 17    JSR     $0817          delay();
                                      }

08BE 3C 61       INC     $61
08C0 26 02       BNE     $08C4
08C2 3C 60       INC     $60
08C4 20 EB       BRA     $08B1
08C6 CD 08 37    JSR     $0837          xdcr_offset =  read_a2d();
08C9 3F 5C       CLR     $5C
08CB B7 5D       STA     $5D
08CD 81          RTS               }

                                   /**************************************************************************/

                                   void initio (void)      /*  setup the I/O */
                                     {
08CE A6 20       LDA     #$20          adstat = 0x20; /* power-up the A/D */
08D0 B7 09       STA     $09
08D2 3F 02       CLR     $02           porta = portb = portc = 0;
08D4 3F 01       CLR     $01
08D6 3F 00       CLR     $00
08D8 A6 FF       LDA     #$FF          ddra = ddrb = ddrc = 0xff;
08DA B7 06       STA     $06
08DC B7 05       STA     $05
08DE B7 04       STA     $04
08E0 B6 13       LDA     $13           ac=tsr;  /* dummy read */
08E2 3F 1E       CLR     $1E           ocmphi1 = ocmphi2 = 0;
08E4 3F 16       CLR     $16
08E6 B6 1F       LDA     $1F           ac = ocmplo2; /* clear out output compare 2 if it happens to be set */
08E8 AD 96       BSR     $0880         fixcompare(); /* set-up for the first timer interrupt */
```

```
08EA A6 40     LDA    #$40         tcr = 0x40;
08EC B7 12     STA    $12
08EE 9A        CLI                 CLI;  /* let the interrupts begin !  */
                                 /* write CAL to the display */
08EF A6 CC     LDA    #$CC         portc = 0xcc; /* C */
08F1 B7 02     STA    $02
08F3 A6 BE     LDA    #$BE         portb = 0xbe; /* A */
08F5 B7 01     STA    $01
08F7 A6 C4     LDA    #$C4         porta = 0xc4; /* L */
08F9 B7 00     STA    $00
08FB AD A7     BSR    $08A4        adzero();
08FD 81        RTS                }

                                  /***************************************************************************/
                                  void cvt_bin_dec(unsigned long arg)

                                  /* First converts the argument to a five digit decimal value. The msd is in
                                  the lowest address. Then leading zero suppresses the value and writes it to
                                  the display ports.
                                     The argument value range is 0..65535 decimal. */

0069                              {
08FE BF 69     STX    $69
0900 B7 6A     STA    $6A
006B                              char i;
006C                              unsigned long l;
0902 4F        CLRA                 for ( i=0; i < 5; ++i )
0903 B7 6B     STA    $6B
0905 B6 6B     LDA    $6B
0907 A1 05     CMP    #$05
0909 24 07     BCC    $0912
                                    {
090B 97        TAX                    digit[i] = 0x0;  /* put blanks in all digit positions */
090C 6F 50     CLR    $50,X
                                    }
090E 3C 6B     INC    $6B
0910 20 F3     BRA    $0905
0912 4F        CLRA                    for ( i=0; i < 4; ++i )
0913 B7 6B     STA    $6B
0915 B6 6B     LDA    $6B
0917 A1 04     CMP    #$04
0919 24 70     BCC    $098B
                                         {
091B 97        TAX                           if ( arg  >= dectable [i] )
091C 58        LSLX
091D D6 08 0B  LDA    $080B,X
0920 B1 6A     CMP    $6A
0922 26 07     BNE    $092B
0924 D6 08 0A  LDA    $080A,X
0927 B1 69     CMP    $69
0929 27 5C     BEQ    $0987
                                                 {
092B BE 6B     LDX    $6B                         l = dectable[i];
092D 58        LSLX
092E D6 08 0A  LDA    $080A,X
```

```
0931 B7 6C     STA    $6C
0933 D6 08 0B  LDA    $080B,X
0936 B7 6D     STA    $6D
0938 B6 6A     LDA    $6A                              digit[i] = arg / 1;
093A B7 58     STA    $58
093C B6 69     LDA    $69
093E B7 57     STA    $57
0940 B6 6C     LDA    $6C
0942 B7 66     STA    $66
0944 B6 6D     LDA    $6D
0946 B7 67     STA    $67
0948 CD 0A 5E  JSR    $0A5E
094B CD 0A 8F  JSR    $0A8F
094E BF 57     STX    $57
0950 B7 58     STA    $58
0952 BE 6B     LDX    $6B
0954 E7 50     STA    $50,X
0956 BE 6B     LDX    $6B                              arg = arg-(digit[i] * 1);
0958 E6 50     LDA    $50,X
095A 3F 57     CLR    $57
095C B7 58     STA    $58
095E B6 6C     LDA    $6C
0960 B7 66     STA    $66
0962 B6 6D     LDA    $6D
0964 B7 67     STA    $67
0966 CD 0A 3F  JSR    $0A3F
0969 BF 57     STX    $57
096B B7 58     STA    $58
096D 33 57     COM    $57
096F 30 58     NEG    $58
0971 26 02     BNE    $0975
0973 3C 57     INC    $57
0975 B6 58     LDA    $58
0977 BB 6A     ADD    $6A
0979 B7 58     STA    $58
097B B6 57     LDA    $57
097D B9 69     ADC    $69
097F B7 57     STA    $57
0981 B7 69     STA    $69
0983 B6 58     LDA    $58
0985 B7 6A     STA    $6A
                                                    }
                                               }
0987 3C 6B     INC    $6B
0989 20 8A     BRA    $0915
098B B6 6A     LDA    $6A           digit[i] = arg;
098D B7 58     STA    $58
098F B6 69     LDA    $69
0991 B7 57     STA    $57
0993 BE 6B     LDX    $6B
0995 B6 58     LDA    $58
0997 E7 50     STA    $50,X

                                    /* now zero suppress and send the lcd pattern to the display */
0999 9B        SEI                  SEI;
```

```
099A 3D 50     TST   $50         if ( digit[0] == 0 )   /* leading zero suppression */
099C 26 04     BNE   $09A2
099E 3F 02     CLR   $02           portc = 0;
09A0 20 07     BRA   $09A9           else
09A2 BE 50     LDX   $50              portc = ( lcdtab[digit[0]] );     /* 100's digit */
09A4 D6 08 00  LDA   $0800,X
09A7 B7 02     STA   $02
09A9 3D 50     TST   $50               if ( digit[0] == 0 && digit[1] == 0 )
09AB 26 08     BNE   $09B5
09AD 3D 51     TST   $51
09AF 26 04     BNE   $09B5
09B1 3F 01     CLR   $01                 portb=0;
09B3 20 07     BRA   $09BC                 else
09B5 BE 51     LDX   $51                     portb = ( lcdtab[digit[1]] );      /* 10's digit */
09B7 D6 08 00  LDA   $0800,X
09BA B7 01     STA   $01
09BC BE 52     LDX   $52                     porta = ( lcdtab[digit[2]]+1 ); /* 1's digit + decimal point */
09BE D6 08 00  LDA   $0800,X
09C1 4C        INCA
09C2 B7 00     STA   $00
09C4 9A        CLI               CLI;
09C5 CD 08 17  JSR   $0817                   delay();
09C8 81        RTS               }

                                 /*****************************************************************/

                                 void display_psi(void)
                                 /* At power-up it is assumed that the pressure port of the sensor
                                    is open to atmosphere. The code in initio() delays for the
                                    sensor and power to stabilize. One hundred A/D conversions are
                                    averaged and divided by 100. The result is called xdcr_offset.
                                    This routine calls the A/D routine which performs one hundred
                                    conversions, divides the result by 100 and returns the value.
                                    If the value returned is less than or equal to the xdcr_offset,
                                    the value of xdcr_offset is substituted. If the value returned
                                    is greater than xdcr_offset, xdcr_offset is subtracted from the
                                    returned value. That result is multiplied by a constant to yield
                                    pressure in PSI * 10 to yield a "decimal point".
                                 */
                                 {
                                  while(1)
                                    {
09C9 3F 59     CLR   $59         slope = 64;
09CB A6 40     LDA   #$40
09CD B7 5A     STA   $5A
09CF B6 03     LDA   $03              k = portd & 0xc0;  /* this lets us "rubber" the slope to closer fit
09D1 A4 C0     AND   #$C0
09D3 B7 62     STA   $62
                                                          the slope of the sensor */
09D5 A1 80     CMP   #$80              if ( k == 0x80 )    /* J2 removed, J1 installed */
09D7 26 06     BNE   $09DF
09D9 3F 59     CLR   $59                 slope = 65;
09DB A6 41     LDA   #$41
09DD B7 5A     STA   $5A
09DF B6 62     LDA   $62                  if ( k == 0x40 ) /* J1 removed, J2 installed */
```

```
09E1 A1 40     CMP    #$40
09E3 26 06     BNE    $09EB
09E5 3F 59     CLR    $59                     slope = 63;
09E7 A6 3F     LDA    #$3F
09E9 B7 5A     STA    $5A
                                     /* else both jumpers are removed or installed... don't change the slope */
09EB CD 08 37  JSR    $0837              atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
09EE 3F 55     CLR    $55
09F0 B7 56     STA    $56
09F2 B0 5D     SUB    $5D                  if ( atodtemp <= xdcr_offset )
09F4 B7 58     STA    $58
09F6 B6 5C     LDA    $5C
09F8 A8 80     EOR    #$80
09FA B7 57     STA    $57
09FC B6 55     LDA    $55
09FE A8 80     EOR    #$80
0A00 B2 57     SBC    $57
0A02 BA 58     ORA    $58
0A04 22 08     BHI    $0A0E
0A06 B6 5C     LDA    $5C                   atodtemp = xdcr_offset;
0A08 B7 55     STA    $55
0A0A B6 5D     LDA    $5D
0A0C B7 56     STA    $56
0A0E B6 56     LDA    $56                  atodtemp -=  xdcr_offset; /* remove the offset */
0A10 B0 5D     SUB    $5D
0A12 B7 56     STA    $56
0A14 B6 55     LDA    $55
0A16 B2 5C     SBC    $5C
0A18 B7 55     STA    $55
0A1A B6 56     LDA    $56                atodtemp *= slope; /* convert to psi */
0A1C B7 58     STA    $58
0A1E B6 55     LDA    $55
0A20 B7 57     STA    $57
0A22 B6 59     LDA    $59
0A24 B7 66     STA    $66
0A26 B6 5A     LDA    $5A
0A28 B7 67     STA    $67
0A2A CD 0A 3F  JSR    $0A3F
0A2D BF 55     STX    $55
0A2F B7 56     STA    $56
0A31 CD 08 FE  JSR    $08FE              cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0A34 20 93     BRA    $09C9           }
0A36 81        RTS                 }

                                  /*************************************************************************/

                                   main()
                                   {
0A37 CD 08 CE  JSR    $08CE         initio(); /* set-up the processor's i/o */
0A3A AD 8D     BSR    $09C9          display_psi();
0A3C 20 FE     BRA    $0A3C           while(1);   /* should never get here */
0A3E 81        RTS                 }

0A3F BE 58     LDX    $58
0A41 B6 67     LDA    $67
```

```
0A43 42         MUL
0A44 B7 70      STA    $70
0A46 BF 71      STX    $71
0A48 BE 57      LDX    $57
0A4A B6 67      LDA    $67
0A4C 42         MUL
0A4D BB 71      ADD    $71
0A4F B7 71      STA    $71
0A51 BE 58      LDX    $58
0A53 B6 66      LDA    $66
0A55 42         MUL
0A56 BB 71      ADD    $71
0A58 B7 71      STA    $71
0A5A 97         TAX
0A5B B6 70      LDA    $70
0A5D 81         RTS

0A5E 3F 70      CLR    $70
0A60 5F         CLRX
0A61 3F 6E      CLR    $6E
0A63 3F 6F      CLR    $6F
0A65 5C         INCX
0A66 38 58      LSL    $58
0A68 39 57      ROL    $57
0A6A 39 6E      ROL    $6E
0A6C 39 6F      ROL    $6F
0A6E B6 6E      LDA    $6E
0A70 B0 67      SUB    $67
0A72 B7 6E      STA    $6E
0A74 B6 6F      LDA    $6F
0A76 B2 66      SBC    $66
0A78 B7 6F      STA    $6F
0A7A 24 0D      BCC    $0A89
0A7C B6 67      LDA    $67
0A7E BB 6E      ADD    $6E
0A80 B7 6E      STA    $6E
0A82 B6 66      LDA    $66
0A84 B9 6F      ADC    $6F
0A86 B7 6F      STA    $6F
0A88 99         SEC
0A89 59         ROLX
0A8A 39 70      ROL    $70
0A8C 24 D8      BCC    $0A66
0A8E 81         RTS
0A8F 53         COMX
0A90 9F         TXA
0A91 BE 70      LDX    $70
0A93 53         COMX
0A94 81         RTS
1FFE 0A 37
```

```
SYMBOL TABLE

LABEL           VALUE  LABEL          VALUE  LABEL          VALUE  LABEL          VALUE

IRQ             0813 | SCI            0816 | TIMERCAP       0814 | TIMERCMP       089B
TIMEROV         0815 | __LDIV         0A5E | __LongIX       0066 | __MUL          0000
__MUL16x16      0A3F | __RDIV         0A8F | __RESET        1FFE | __STARTUP      0000
__STOP          0000 | __SWI          0812 | __WAIT         0000 | __longAC       0057
acnthi          001A | acntlo         001B | adcnt          005B | addata         0008
adstat          0009 | adzero         08A4 | arg            0069 | atodtemp       0055
b               0000 | bothbytes      0002 | cvt_bin_dec    08FE | ddra           0004
ddrb            0005 | ddrc           0006 | dectable       080A | delay          0817
digit           0050 | display_psi    09C9 | eeclk          0007 | fixcompare     0880
hi              0000 | i              005E | icaphi1        0014 | icaphi2        001C
icaplo1         0015 | icaplo2        001D | initio         08CE | isboth         0002
j               0060 | k              0062 | l              0000 | lcdtab         0800
lo              0001 | main           0A37 | misc           000C | ocmphi1        0016
ocmphi2         001E | ocmplo1        0017 | ocmplo2        001F | plma           000A
plmb            000B | porta          0000 | portb          0001 | portc          0002
portd           0003 | q              0063 | read_a2d       0837 | scibaud        000D
scicntl1        000E | scicntl2       000F | scidata        0011 | scistat        0010
slope           0059 | tcnthi         0018 | tcntlo         0019 | tcr            0012
tsr             0013 | xdcr_offset    005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0100 : ---------------- ---------------- ---------------- ----------------
0140 : ---------------- ---------------- ---------------- ----------------
0180 : ---------------- ---------------- ---------------- ----------------
01C0 : ---------------- ---------------- ---------------- --------------X-

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXX----------- ---------------- ----------------
0AC0 : ---------------- ---------------- ---------------- ----------------

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.
Errors              :    0
Warnings            :    0
```

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1307

A Simple Pressure Regulator Using Semiconductor Pressure Transducers

Prepared by: Denise Williams
Discrete Applications Engineering

INTRODUCTION

Semiconductor pressure transducers offer an economical means of achieving high reliability and performance in pressure sensing applications. The completely integrated MPX5100 (0-15 PSI) series pressure transducer provides a temperature-compensated and calibrated, high-level linear output that is suitable for interfacing directly with many linear control systems. The circuit described herein illustrates how this sensor can be used with a simple pressure feedback system to establish pressure regulation.

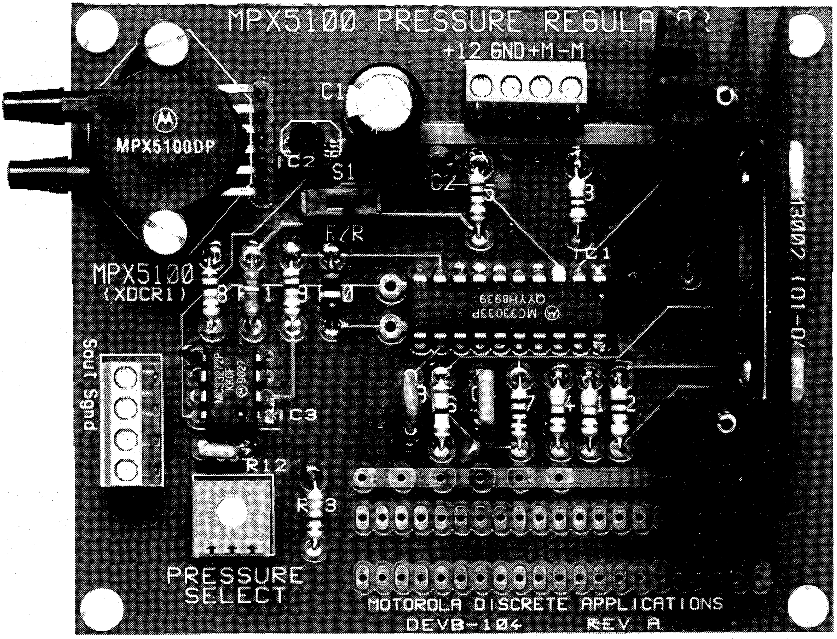


Figure 1. DEVB-104 MPX5100 Pressure Regulator

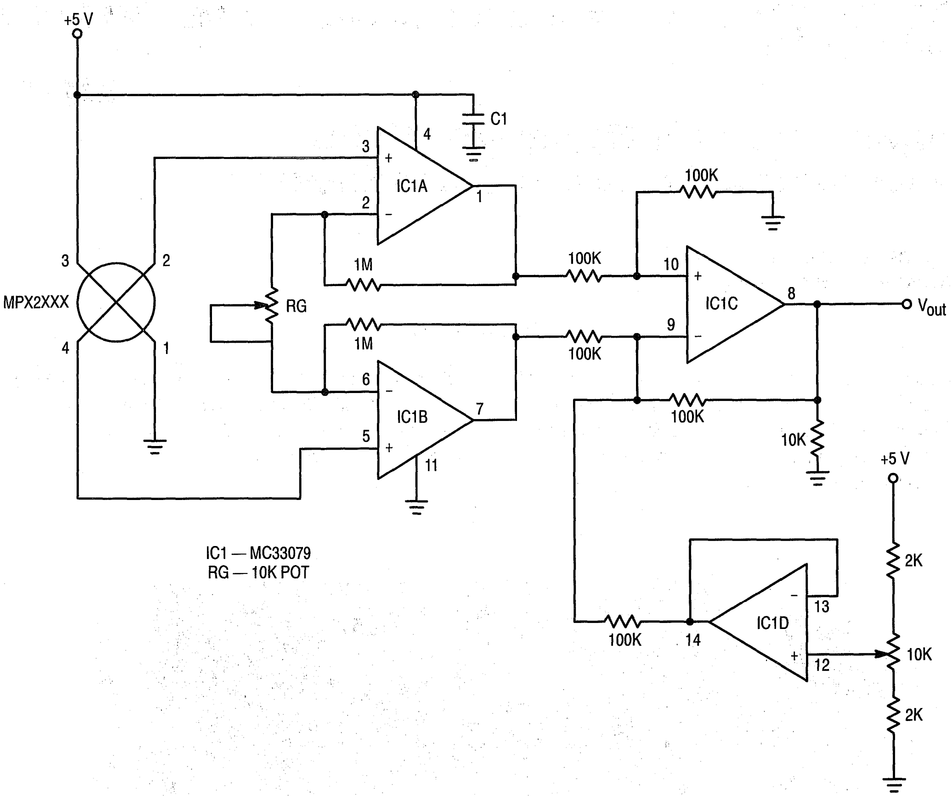


Figure 2. High Level, Ground Referenced Output Using an MPX2000 Series Transducer

THE SENSOR

The MPX5100 is the next level of integration beyond the MPX2000 series. The MPX2000 series of pressure transducers already incorporates, on-chip, more than a dozen external components needed for temperature compensation and offset calibration. Figure 2 shows the basic circuitry required to create a ground referenced output amplified to a high-level from an MPX2100 (0-15 PSI) transducer. For optimum performance, matched metal film resistor pairs and precision operational amplifiers are required.

The MPX5100 goes one step further by adding the differential to ground referenced conversion and the amplification circuitry on-chip. Therefore, the eighteen-component circuit shown in Figure 2 can be reduced to one signal-conditioned sensor, as shown in Figure 3.

All of the MPX devices contain a single piezoresistive implant which replaces the four-element Wheatstone bridge circuit found in most semiconductor-based transducers. The MPX5100 transducer uses an interactively laser-trimmed, four-stage network to perform signal conditioning. Figure 4 is an internal block diagram of the MPX5100 showing these four stages.

The first stage compensates for the temperature coefficient of offset while the second stage performs the differential to single-ended conversion. Stage three is a precision voltage reference that calibrates the zero pressure offset of the entire system, which comprises the sensor offset and the input offset voltages of the other three operational amplifiers. The final stage provides the full-scale span calibration. The MPX5100 is compensated for operation over 0 to 85°C with a response time (10% to 90%) of 10 msec.

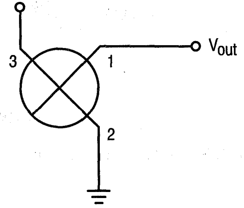


Figure 3. High Level, Ground Referenced Output Using an MPX5100

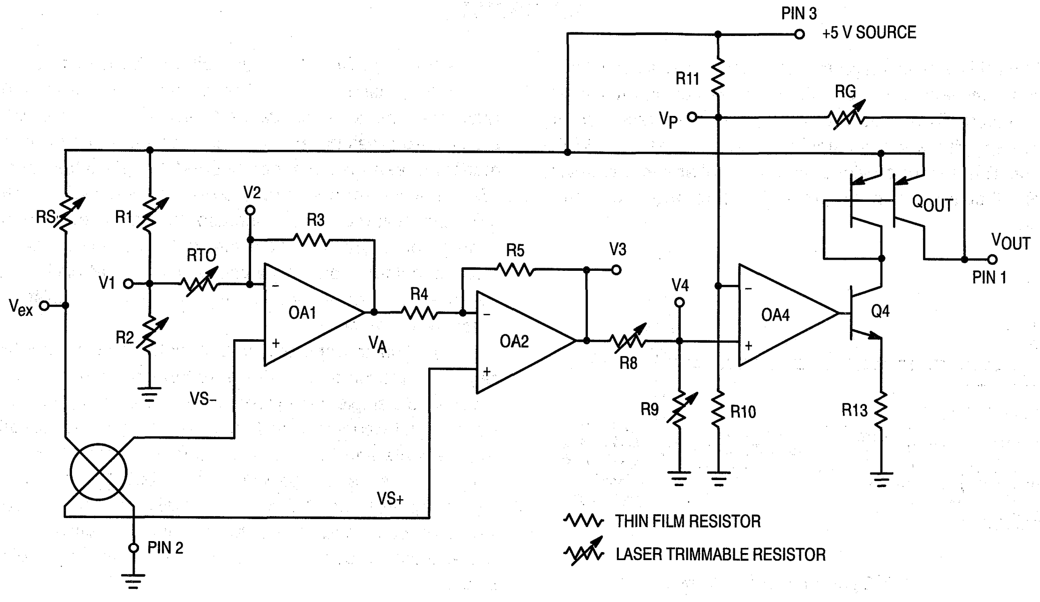


Figure 4. Fully Integrated Pressure Sensor Schematic

Some terms commonly used when discussing pressure sensors are:

- V_{FSS} (Full Scale Span) — the output voltage variation between zero differential pressure applied to the sensor and the maximum recommended operating pressure applied to the sensor, with a given supply voltage.
- V_{OFF} (Offset) — the voltage output given by a sensor with zero differential pressure applied, with a given supply voltage.
- Sensitivity — the amount of output voltage variation per unit pressure input variation.
- Linearity — the maximum deviation of the output from a straight line relationship over the operating pressure range.

Motorola specifies linearity using an “end-point straight line” method.

Each transducer is laser trimmed to provide the specified V_{FSS} with the supply voltage indicated on the data sheet. For example, V_{FSS} for the MPX5100 is trimmed to 4.0 V with a supply voltage of +5.0 Vdc.

For the MPX5100, V_{OFF} = 0.5 V with a 5.0 Vdc supply. Therefore, the output of the sensor varies from 0.5 V to 4.5 V for differential pressures from 0 kPa to 100 kPa, respectively. This is ideal for interfacing directly with many linear devices such as the MC33033 motor controller described in this application note or the A/D of a microprocessor controlled system.

THE CIRCUIT

Figure 5 is a block diagram of a simple pressure regulator feedback system. The motor/pump is used to fill a reservoir as required. The pressure created in this reservoir is monitored with a gauge and fed back to the MPX5100 sensor. The sensor provides an output voltage to the Motor Drive Circuitry which is proportional to the monitored pressure.

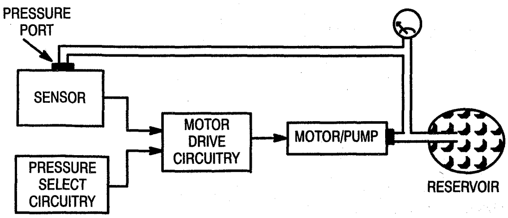


Figure 5. System Block Diagram

The Pressure Select Circuitry allows the user to choose a desired pressure by creating a reference voltage. This reference voltage is equivalent to the sensor output when the desired pressure exists in the system. A comparison is made between the sensor output and the reference voltage. When the system pressure is below the selected pressure, the motor is turned on to increase the pressure. When the system pressure reaches the selected pressure, the motor/pump turns off. Hysteresis is used to set different trip voltages for turn-off and turn-on to allow for noise and pressure fluctuations.

For particular applications that only require one fixed regulated pressure, the Pressure Select Circuitry can be reduced to a single voltage reference. Additionally, the Motor Drive Circuitry can be simplified depending on the application requirements and the motor to be used. Since a +5.0 Vdc supply to the sensor provides an output that is ideal for interfacing with an A/D converter, this comparison could easily be converted to a software function, allowing for a digital pressure select input as well as controlling a digital display.

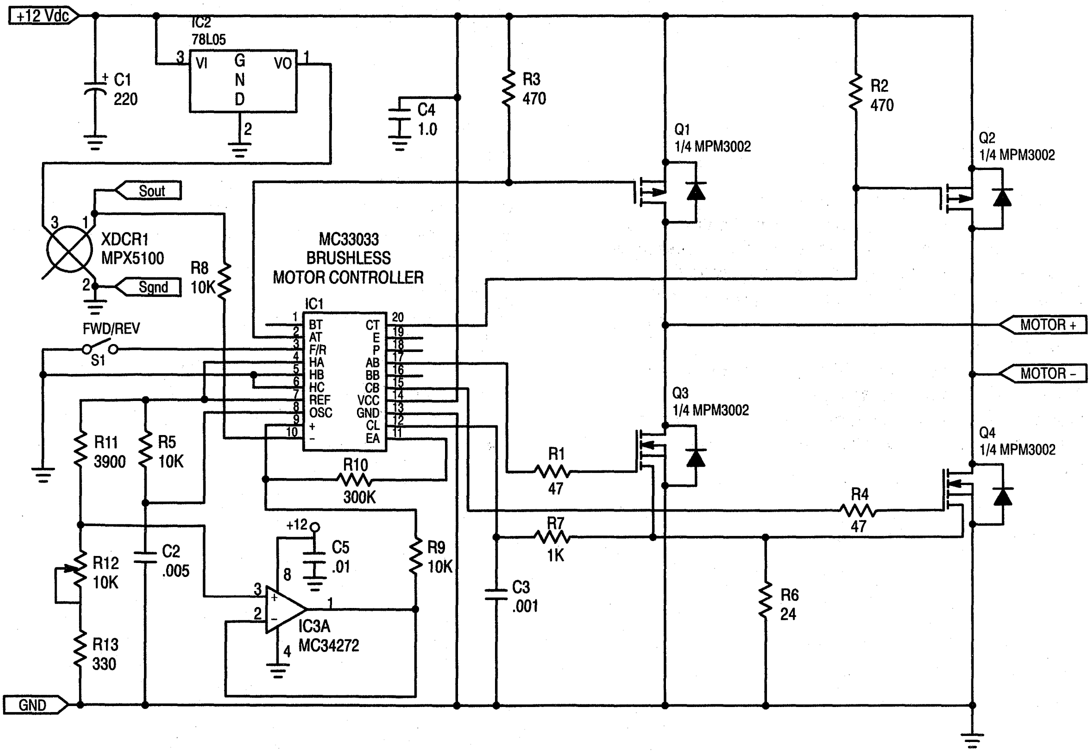


Figure 6. MPX5100 Pressure Regulator

DETAILED CIRCUIT DESCRIPTION

The Supply Voltage

Figure 6 is a schematic of the control electronics for this pressure regulator system. The +12 Vdc supply is used by the MPM3002 power transistors, the MC33033 motor controller and the MC34272 operational amplifier. In addition, this voltage is regulated down to +5.0 Vdc for the sensor supply.

The Pressure Select Circuitry

R11, R12 and R13 provide a variable reference from 0.5 V to 4.5 V. By adjusting R12, the reference voltage can be set to the desired pressure turn-off point. The error amplifier internal to the MC33033, along with R8, R9 and R10, is configured as a comparator with hysteresis. The sensor output voltage and the reference voltage are inputs to the comparator and are used to determine when the motor is turned on or turned off. When the sensor output is less than the reference voltage the motor is on. Pressure in the system increases until the sensor output is equal to the reference voltage plus the hysteresis voltage then the motor is turned off. If the pressure decreases while the motor is off, the sensor output will decrease until it is equal to the reference voltage at which time the motor turns on.

Hysteresis is set to prevent the motor from turning off and on due to small voltage variations such as noise or small pressure fluctuations in the system. The ratio of R10 to both R8 and R9 can be adjusted to provide the hysteresis required in a particular application. The resistor values shown in Figure 6 provide a ratio of 300 kΩ to 10 kΩ. This corresponds to a hysteresis of 300 mV or 7.5 kPa between the turn-off and turn-on trip points. The operational amplifier (MC34272) is used to provide a low impedance output to isolate the divider network from the comparator circuit.

The Motor Drive Circuitry

In a brush motor drive, the primary function of the controller IC is to translate speed and direction inputs into appropriate drive for the power transistors. This can be done efficiently by using the MC33033 Brushless DC controller as shown in Figure 6. In a brushless application, two of six output transistors are switched on in response to Hall sensor inputs H_A, H_B and H_C. In order to drive a brush motor, all that is required is to select a single Hall code that will drive a four transistor H-bridge in a way that is suitable for brush motors. By using phase A and phase C outputs, a 1-0-0 Hall code produces the correct drive for brush motors. A_T, B_T and C_T are open collector outputs, therefore, a logic 0 represents the on state. Conversely, A_B, B_B and C_B are totem pole drivers, and a logic 1 turns on the corresponding output transistor.

Generating the Hall code is easy. Since it is fixed at 1-0-0, tying the Hall inputs to DC levels is sufficient. Logic 1 is obtained from V_{REF}, and logic 0 from ground. The result is the connections for pins 4, 5 and 6 that are shown in Figure 6. In addition to providing drive to the output transistors, the MC33033 has a current limit function and controls speed by pulse width modulating the lower output transistors, Q3 and Q4. The current limit operates on a 100 mV threshold. Once tripped, it latches the lower transistor drive off until the next clock cycle begins. The latching feature prevents high frequency oscillations which would otherwise overheat the power transistors. Compatibility with SENSEFETs™ is provided by the 100 mV threshold and allows the lossless current sensing configuration that is also shown in Figure 6.

For low-power, low-voltage motors, level shifting the gate-drain for Q1 and Q2, the upper output transistors, is not a problem. Open collector top-side outputs in the MC33033 interface directly to P-Channel MOSFETs. All that is required in the way of top-side drive circuitry is gate-to-source resistors on the P-Channel transistors, such as R2 and R3 in Figure 6.

Since an H-Bridge motor drive uses four power transistors, a power module can considerably simplify the output stage. The MPM3002 that is shown as Q1, Q2, Q3 and Q4 in Figure 6 is ideally suited to fractional horsepower motor drives. It consists of two P-Channel MOSFETs and two N-Channel SENSEFETs connected in an H-Bridge configuration, and housed in an isolated 12-pin, single, in-line package. The P-Channels have a maximum on-resistance of 0.4 ohms, and the N-Channels 0.15 ohms. All four transistors have 100 V breakdown ratings.

The MPM3002's P-Channel/N-Channel configuration makes interfacing to an MC33033 control IC especially easy. The schematic shows an example. The SENSEFETs are connected to outputs A_B and C_B through series gate resistors, and the P-Channels are connected directly to A_T and C_T and tied to the +12 V rail through pull-up resistors. If the source voltage is greater than +12 V, a divider can be used to keep gate voltage on the P-Channels within reasonable limits.

In the schematic, the mirror outputs of both SENSEFETs are tied together. They are then fed into the MC33033's current limit input through a noise suppression filter consisting of R7 and C3. Since only one SENSEFET is on at any given time, this connection is a logic wired-OR. It provides overcurrent protection for both directions of motor rotation, and does not alter trip points for the individual legs. The trip point is calculated with the aid of the following expression.

$$I_{LIMIT}=V_{SENSE}\ (R_{SENSE}-r_m(on))/(r_a(on)\cdot R_{SENSE})$$

Where:

V_{SENSE} is sense voltage
R_{SENSE} is the mirror-to-source sense resistor
$r_m(on)$ is mirror-active resistance = 112 ohms
$r_a(on)$ is source-active resistance = 0.14 ohms

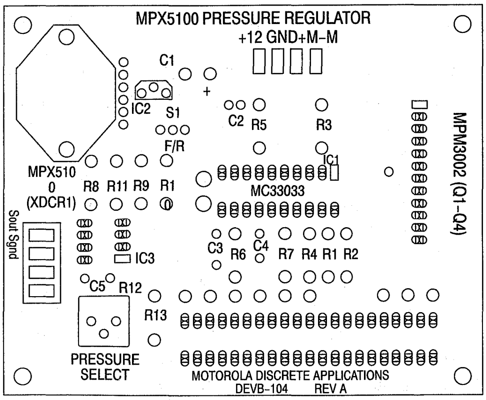


Figure 7a. PCB Component Layout

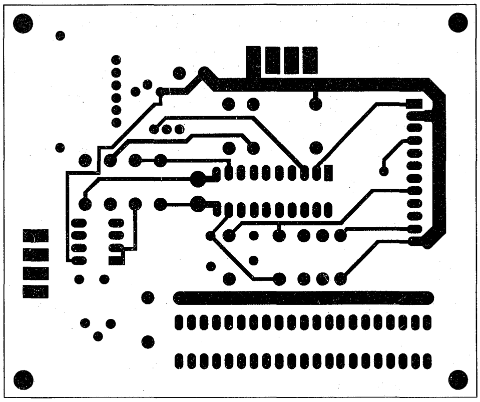


Figure 7c. PCB Solder Side Artwork

Since the current limit threshold in the MC33033 is 100 mV, current limiting will occur when V_{SENSE} reaches 100 mV. For the circuit in Figure 6, using 100 mV for V_{SENSE}, and with R_{SENSE} = R6 = 24 ohms then:

$$I_{LIMIT} = 0.1(24 + 112)/(0.14 \cdot 24) = 4.1 \text{ Amps}$$

By using SENSEFETs in the lower half bridge in lieu of a power sense resistor in series with the motor, about 1/2 watt (4.1 A·0.1 V) of dissipation is saved.

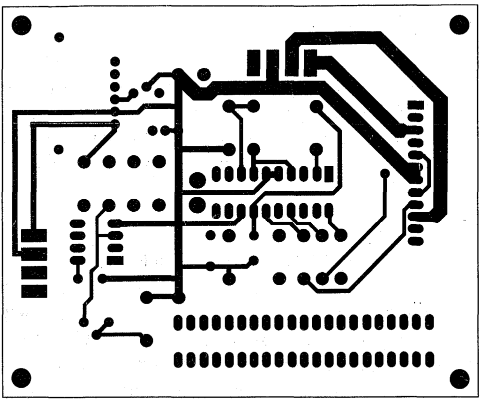


Figure 7b. PCB Component Side Artwork

Figure 7 shows a printed circuit board and component layout for the electronics portion of this pressure regulator system, and Table 1 is the corresponding parts list.

System Performance

The entire system draws 4.0 Amps with all but 50 mA used to drive the motor/pump. The pressure sensor provides a sensitivity to regulate well within a few kPa. However, most applications can allow far greater fluctuations in pressure. The system performance, therefore, depends mostly on the motor/pump selected and the hysteresis set in the control circuitry. Using a well-sealed pump will help ensure the motor turns off when the desired pressure is reached. Many pumps are designed to leak to prevent over inflation. In this case, the circuit will turn the motor off until the pressure is reduced, through leakage, by the designed hysteresis amount, then turn on and continue cycling to hold the pressure in the desired range.

Table 1. Parts List for Pressure Regulator PC Board

Reference Designator	Qty	Description	Comments
		MISCELLANEOUS	
	1	PC Board	See Figure 7
	2	Input/Output Terminals	PHX CONT #1727036
	1	Heat Sink	for ICePAK™
	4	1/2″ nylon standoffs, threaded	
	6	1/2″ nylon screws	
	2	4-40 nylon nuts	
S1	1	switch	SS-12SDP2
		RESISTORS, FIXED	
		Comp., ±5%, 1/4 W	
R1, R4	2	47 Ω	
R2, R3	2	470 Ω	
R5, R8, R9	3	10 kΩ	
R6	1	24 Ω	
R7	1	1 kΩ	
R10	1	300 kΩ	
R11	1	3900 Ω	
R13	1	330 Ω	
		RESISTORS, VARIABLE	
R12	1	10 kΩ, one turn	3386P-1-103-T
		INTEGRATED CIRCUITS	
IC1	1	Motor Controller	MC33033P
IC2	1	Reference	78L05
IC3	1	Operational Amplifier	MC33272P
Q1-Q4	1	Integrated H-Bridge	MPM3002
		SENSOR	
XDCR1	1	MPX5100DP	
		CAPACITORS	
C1	1	220 μF, 25 V	
C2	1	0.005 μF, ceramic, 25 V	
C3	1	0.001 μF, ceramic, 25 V	
C4	1	1 μF, ceramic, 50 V	
C5	1	0.01 μF, ceramic, 25 V	

CONCLUSION

This circuit is one example of how the MPX5100 with its high level output can directly interface with linear systems. It provides a simple design alternative where pressure measurement or control is required.

REFERENCE

1) Schultz, Warren. “ICs Simplify Brush DC Motor Drives,” *MOTION* November 1989.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1309

Compensated Sensor Bar Graph Pressure Gauge

Prepared by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

Compensated semiconductor pressure sensors such as the MPX2000 family are relatively easy to interface with digital systems. With these sensors and the circuitry described herein, pressure is translated into a 0.5 to 4.5 volt output range that is directly compatible with Microcomputer A/D inputs. The 0.5 to 4.5 volt range also facilitates interface with an LM3914, making Bar Graph Pressure Gauges relatively simple.

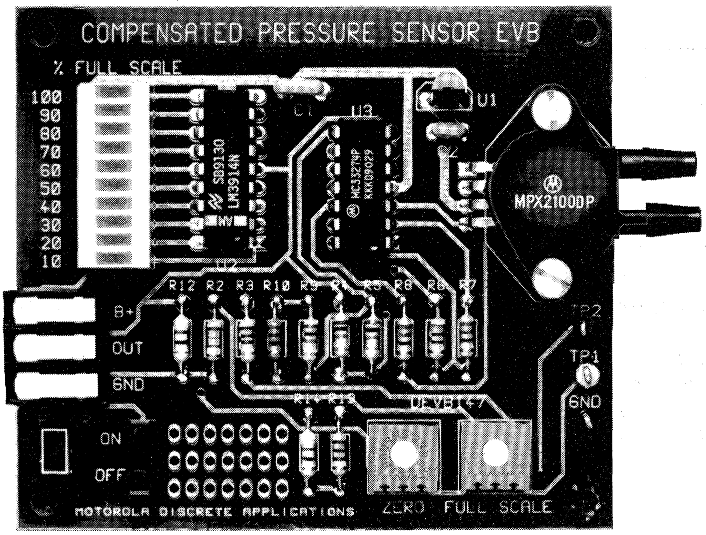


Figure 1. DEVB147 Compensated Pressure Sensor Evaluation Board

EVALUATION BOARD DESCRIPTION

The information required to use evaluation board number DEVB147 follows, and a discussion of the design appears in the Design Considerations section.

FUNCTION

The evaluation board shown in Figure 1 is supplied with an MPX2100DP sensor and provides a 100 kPa full scale pressure measurement. It has two input ports. P1, the pressure port, is on the top side of the sensor and P2, a vacuum port, is on the bottom side. These ports can be supplied up to 100 kPa (15 psi) of pressure on P1 or up to 100 kPa of vacuum on P2, or a differential pressure up to 100 kPa between P1 and P2. Any of these sources will produce the same output.

The primary output is a 10 segment LED bar graph, which is labeled in increments of 10% of full scale, or 10 kPa with the MPX2100 sensor. An analog output is also provided. It nominally supplies 0.5 volts at zero pressure and 4.5 volts at full scale. Zero and full scale adjustments are made with potentiometers so labeled at the bottom of the board. Both adjustments are independent of one another.

ELECTRICAL CHARACTERISTICS

The following electrical characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B+	6.8	—	13.2	dc Volts
Full Scale Pressure	P_{FS}	—	—	100	kPa
Overpressure	P_{MAX}	—	—	700	kPa
Analog Full Scale	V_{FS}	—	4.5	—	Volts
Analog Zero Pressure Offset	V_{OFF}	—	0.5	—	Volts
Analog Sensitivity	S_{AOUT}	—	40	—	mV/kPa
Quiescent Current	I_{CC}	—	40	—	mA
Full Scale Current	I_{FS}	—	160	—	mA

CONTENT

Board contents are described in the parts list shown in Table 1. A schematic and silk screen plot are shown in Figures 2 and 6. A pin by pin circuit description follows.

PIN-BY-PIN DESCRIPTION

B+:

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 volts and maximum is 13.2 volts. The upper limit is based upon power dissipation in the LM3914 assuming all 10 LED's are lit and ambient temperature is 25°C. The board will survive input transients up to 25 volts provided that average power dissipation in the LM3914 does not exceed 1.3 watts.

OUT:

An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 volts at zero pressure and 4.5 volts at full scale. Zero pressure voltage is adjustable and set with R11. This output is designed to be directly connected to a microcomputer A/D channel, such as one of the E ports on an MC68HC11.

GND:

There are two ground connections. The ground terminal on the left side of the board is intended for use as the power supply return. On the right side of the board one of the test point terminals is also connected to ground. It provides a convenient place to connect instrumentation grounds.

TP1:

Test point 1 is connected to the LM3914's full scale reference voltage which sets the trip point for the uppermost LED segment. This voltage is adjusted via R1 to set full scale pressure.

TP2:

Test point 2 is connected to the +5.0 volt regulator output. It can be used to verify that supply voltage is within its 4.75 to 5.25 volt tolerance.

P1, P2:

Pressure and Vacuum ports P1 & P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither port is labeled. Maximum safe pressure is 700 kPa.

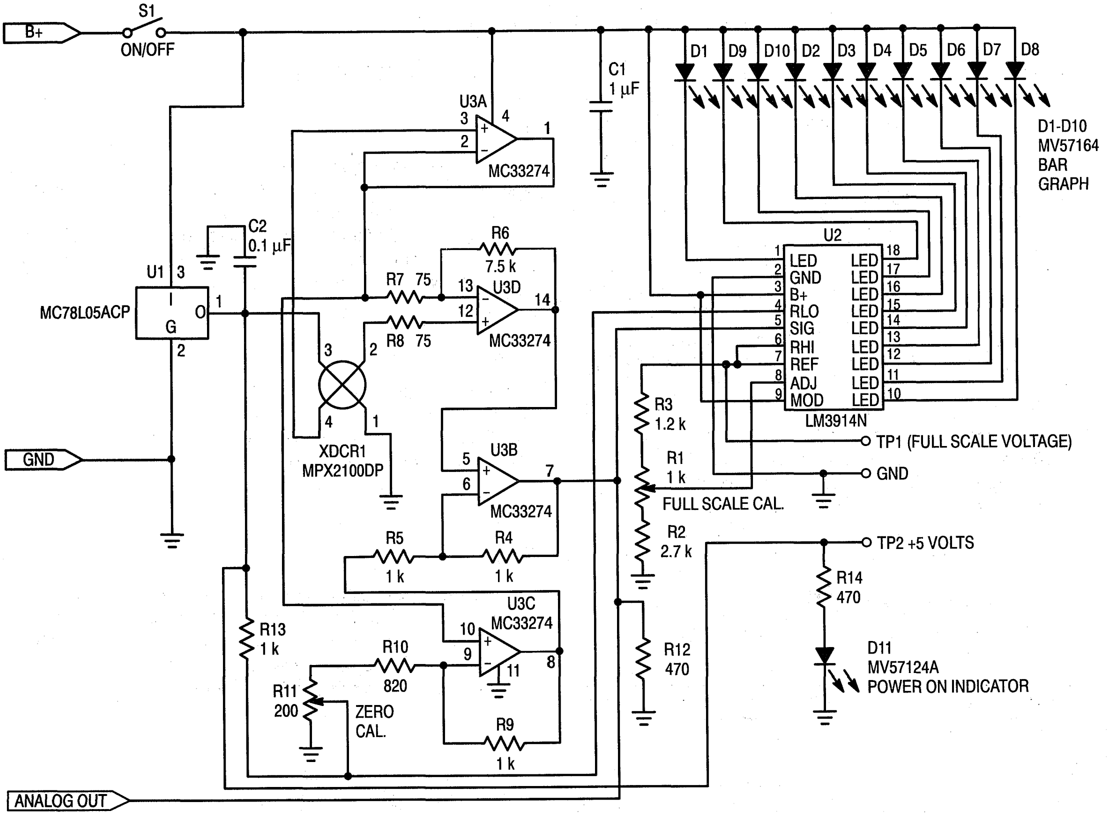
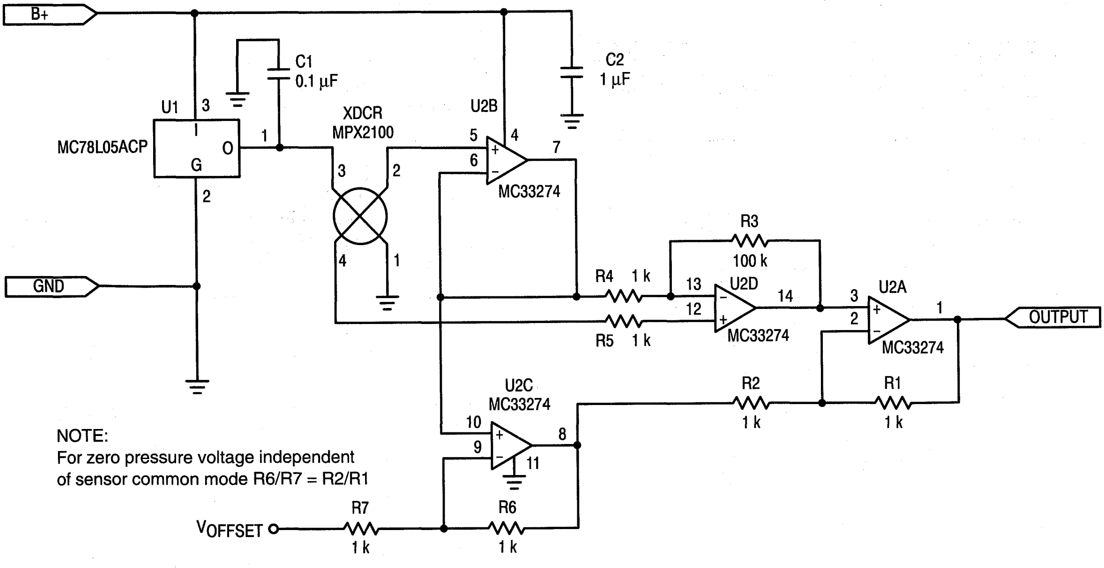


Figure 2. Compensated Pressure Sensor EVB Schematic



NOTE:
For zero pressure voltage independent
of sensor common mode R6/R7 = R2/R1

Figure 3. Compensated Sensor Interface

DESIGN CONSIDERATIONS

In this type of application the design challenge is how to take a relatively small DC coupled differential signal and produce a ground referenced output that is suitable for driving microcomputer A/D inputs. A user friendly interface circuit that will do this job 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 U2D which is configured as a differential amplifier. It is isolated from the sensor's positive output by U2B. The purpose of U2B is to prevent feedback current that flows through R3 & R4 from flowing into the sensor. At zero pressure the voltage from pin 2 to pin 4 on the sensor is zero volts. For example with the common mode voltage at 2.5 volts, the zero pressure output voltage at pin 14 of U2D is then 2.5 volts, since any other voltage would be coupled back to pin 13 via R3 and create a nonzero bias across U2D's differential inputs. This 2.5 volt zero pressure DC output voltage is then level translated to the desired zero pressure offset voltage (V_{OFFSET}) by U2C and U2A. To see how the level translation works, assume 0.5 volts at (V_{OFFSET}). With 2.5 volts at pin 10, pin 9 is also at 2.5 volts. This leaves 2.5 – 0.5 = 2.0 volts across R7. Since no current flows into pin 9, the same current flows through R6, producing 2.0 volts across R6 also. Adding the voltages (0.5 + 2.0 +2.0) yields 4.5 volts at pin 8. Similarly 2.5 volts at pin 3 implies 2.5 volts at pin 2, and the drop across R2 is 4.5 V – 2.5 V = 2.0 volts. Again 2.0 volts across R2 implies an equal drop across R1, and the voltage at pin 1 is 2.5 V – 2.0 V = 0.5 volts. For this DC output voltage to be independent of the sensor's common mode voltage it is necessary to satisfy the condition that R6/R7 = R2/R1.

Gain is close but not exactly equal to R3/R4(R1/R2+1), which predicts 200.0 for the values shown in Figure 3. A more exact calculation can be performed by doing a nodal analysis, which yields 199.9. Cascading the gains of U2D and U2A 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 U2A.

The resulting 0.5 V to 4.5 V output from U2A is directly compatible with microprocessor A/D inputs. Tying this output to an LM3914 for a bar graph readout is also very straight forward. The block diagram that appears in Figure 4 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 volt zero pressure output voltage. In Figure 2, this is accomplished by dividing down the 5.0 volt regulator's output voltage through R13 and adjustment pot R11. The voltage generated at R11's wiper is the offset voltage identified as V_{OFFSET} in Figure 3. Its source impedance is chosen to keep the total input impedance to U3C at approximately 1K. The wiper of R11 is also fed into R_{LO} for zeroing the bar graph.

The full scale measurement is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R2, R3, and adjustment pot R1 that are shown in Figure 2.

Five volt regulated power is supplied by an MC78L05. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R3, R1, and R2 to ground. In this design it is nominally (4.5 V/4.9K)10 = 9.2 mA.

Over a zero to 50°C temperature range combined accuracy for the sensor, interface and driver IC are +/– 10%. Given a 10 segment display total accuracy for the bar graph readout is approximately +/– (10 kPa +10%).

APPLICATION

Using the analog output to provide pressure information to a microcomputer is very straightforward. The output voltage range, which goes from 0.5 volts at zero pressure to 4.5 volts at full scale, is designed to make optimum use of microcomputer A/D inputs. A direct connection from the evaluation board analog output to an A/D input is all that is required. Using the MC68HC11 as an example, the output is connected to any of the E ports, such as port E0 as shown in Figure 5. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 volts and V_{REFL} is tied to 0.3 volts by dividing down a 5.0 volt reference with 1% resistors.

CONCLUSION

Perhaps the most noteworthy aspect to the bar graph pressure gauge described here is the ease with which it can be designed. The interface between an MPX2000 series sensor and LM3914 bar graph display driver consists of one quad op amp and a few resistors. The result is a simple and inexpensive circuit that is capable of measuring pressure, vacuum, or differential pressure with an output that is directly compatible to a microprocessor.

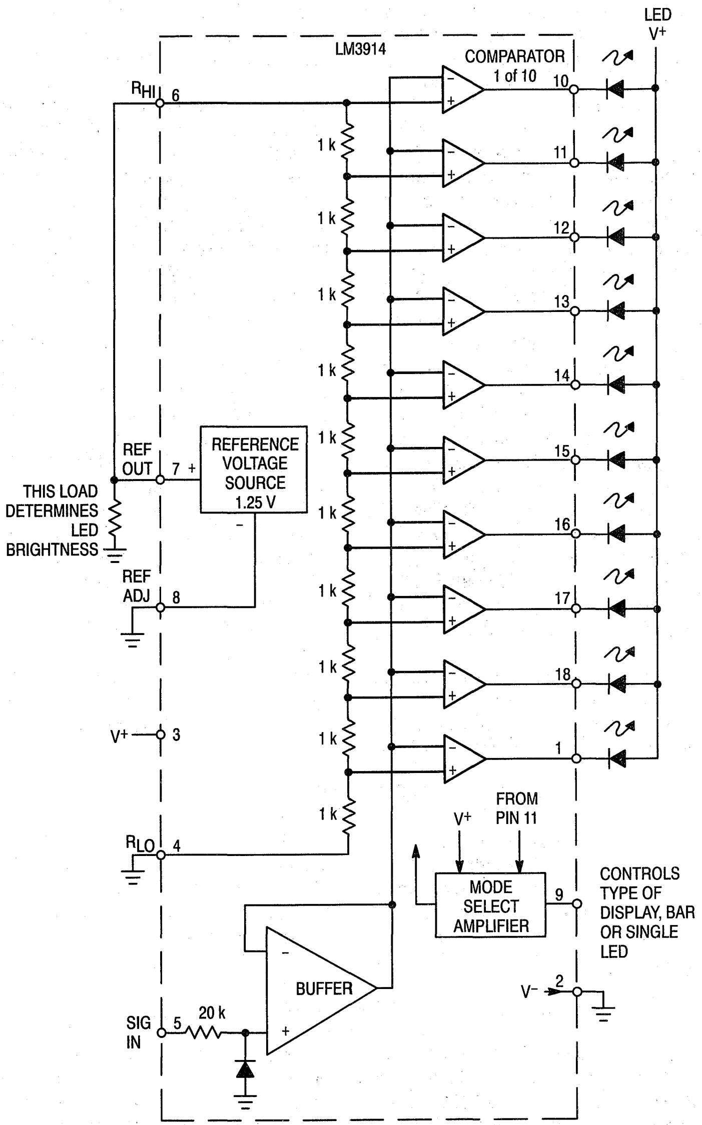


Figure 4. LM3914 Block Diagram

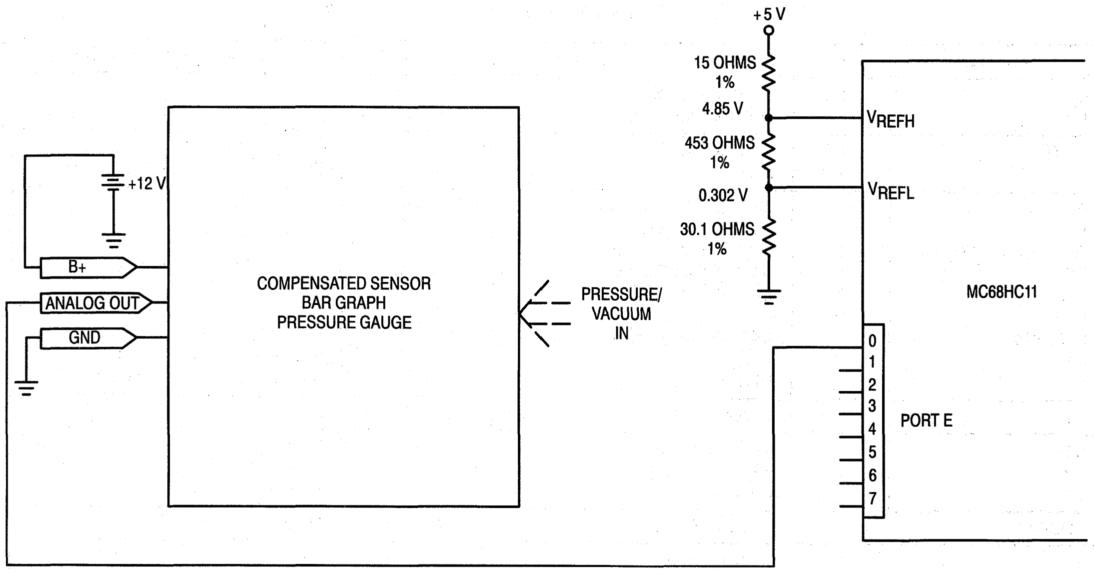


Figure 5. Application Example

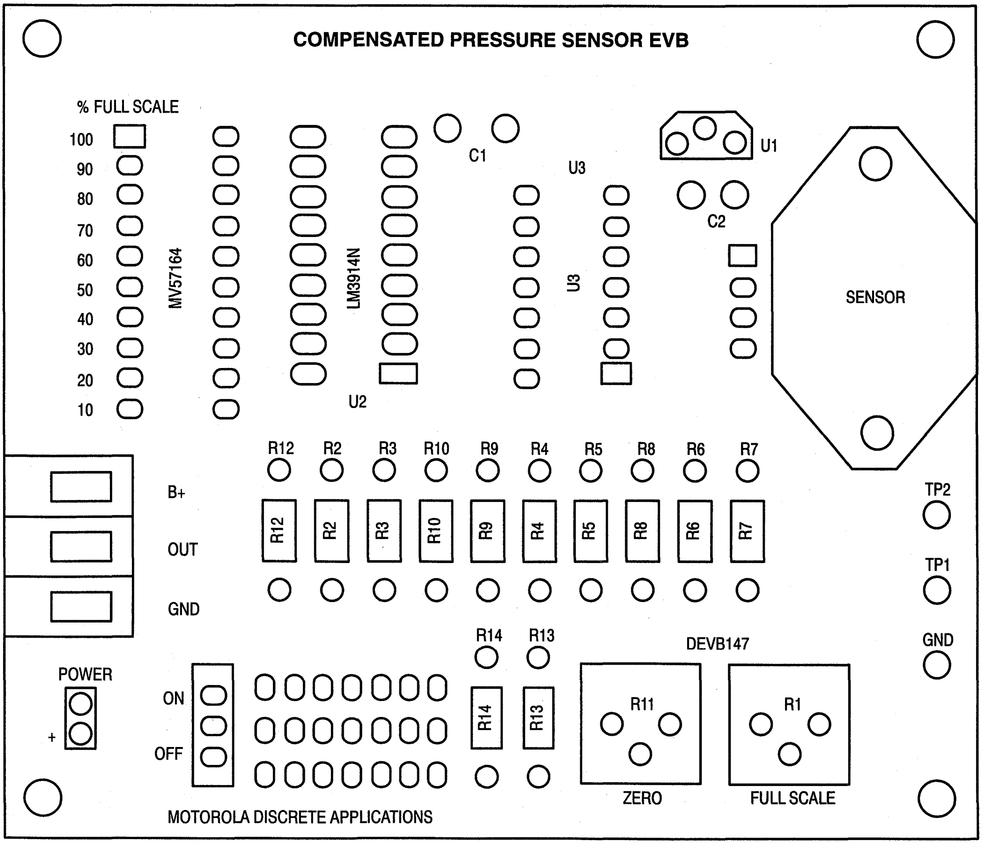


Figure 6. Silk Screen

Table 2. Parts List

Designator	Qty.	Description	Value	Vendor	Part
C1	1	Ceramic Capacitor	1.0 μF		
C2	1	Ceramic Capacitor	0.1 μF		
D1-D10	1	Bar Graph LED		GI	MV57164
D11	1	LED		GI	MV57124A
R2	1	1/4 Watt Film Resistor	2.7K		
R3	1	1/4 Watt Film Resistor	1.2K		
R4, R5, R9, R13	4	1/4 Watt Film Resistor	1.0K		
R6	1	1/4 Watt Film Resistor	7.5K		
R7, R8	2	1/4 Watt Film Resistor	75		
R10	1	1/4 Watt Film Resistor	820		
R12, R14	2	1/4 Watt Film Resistor	470		
R1	1	Trimpot	1.0K	Bourns	3386P-1-102
R11	1	Trimpot	200	Bourns	3386P-1-201
S1	1	Switch		NKK	12SDP2
U1	1	5.0 V Regulator		Motorola	MC78L05ACP
U2	1	Bar Graph IC		National	LM3914N
U3	1	Op Amp		Motorola	MC33274P
XDCR1	1	Pressure Sensor		Motorola	MPX2100DP
—	1	Terminal Block		Augat	2SV03
—	1	Test Point Terminal (Black)		Components Corp.	TP1040100
—	1	Test Point Terminal (Red)		Components Corp.	TP1040102
—	1	Test Point Terminal (Yellow)		Components Corp.	TP1040104

AN1315

An Evaluation System Interfacing The MPX2000 Series Pressure Sensors To A Microprocessor

Prepared by: Bill Lucas
Discrete Applications Engineering

INTRODUCTION

Outputs from compensated and calibrated semiconductor pressure sensors such as the MPX2000 series devices are easily amplified and interfaced to a microprocessor. Design considerations and the description of an evaluation board using a simple analog interface connected to a microprocessor is presented here.

PURPOSE

The evaluation system shown in Figure 1 shows the ease of operating and interfacing the MOTOROLA MPX2000 series pressure sensors to a quad operational amplifier, which amplifies the sensor's output to an acceptable level for an analog-to-digital converter. The output of the op amp is connected to the A/D converter of the microprocessor and that analog value is then converted to engineering units and displayed on a liquid crystal display (LCD). This system may be used to evaluate any of the MPX2000 series pressure sensors for your specific application.

DESCRIPTION

The DEVB158 evaluation system is constructed on a small printed circuit board. Designed to be powered from a 12 Vdc power supply, the system will display the pressure applied to the MPX2000 series sensor in pounds per square inch (PSI) on the liquid crystal display. Table 1 shows the pressure sensors that may be used with the system and the pressure range associated with that particular sensor as well as the jumper configuration required to support that sensor. These jumpers are installed at assembly time to correspond with the supplied sensor. Should the user chose to evaluate a different sensor other than that supplied with the board, the jumpers must be changed to correspond to Table 1 for the new sensor. The displayed pressure is scaled to the full scale (PSI) range of the installed pressure sensor. No potentiometers are used in the system to adjust its span and offset. This function is performed by software.

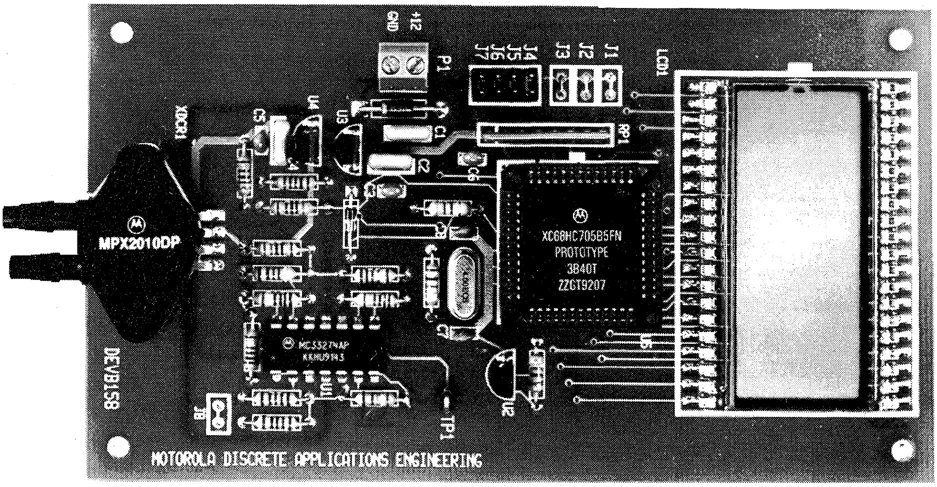


Figure 1. DEVB158 2000 Series LCD Pressure Gauge EVB

Table 1

Sensor Type	Input Pressure PSI	Jumpers			
		J8	J3	J2	J1
MPX2010	0–1.5	IN	IN	IN	IN
MPX2050	0–7.5	OUT	IN	IN	OUT
MPX2100	0–15.0	OUT	IN	OUT	IN
MPX2200	0–30	OUT	IN	OUT	OUT
MPX2700	0–100	OUT	OUT	IN	IN

The signal conditioned sensor's zero pressure offset voltage with no pressure applied to the sensor is empirically computed each time power is applied to the system and stored in RAM. The sensitivity of the MPX2000 series pressure sensors is quite repeatable from unit to unit. There is a facility for a small adjustment of the slope constant built into the program. It is accomplished via jumpers J4 thru J7, and will be explained in the OPERATION section.

Figure 2 shows the printed circuit silkscreen and Figures 3A and 3B show the schematic for the system.

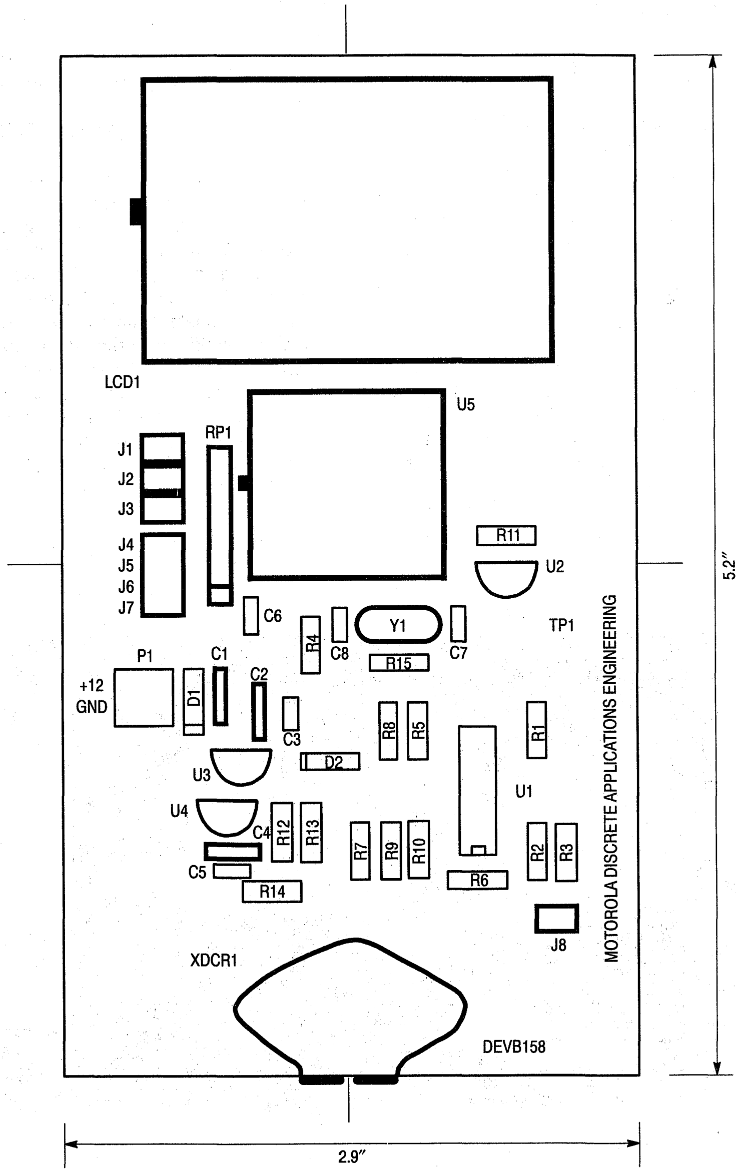


Figure 2. Printed Circuit Silkscreen

The analog section of the system can be broken down into two subsections. These sections are the power supply and the amplification section. The power supply section consists of a diode, used to protect the system from input voltage reversal, and two fixed voltage regulators. The 5 volt regulator (U3) is used to power the microprocessor and display. The 8 volt regulator (U4) is used to power the pressure sensor, voltage references and a voltage offset source.

The microprocessor section (U5) requires minimal support hardware to function. The MC34064P-5 (U2) provides an under voltage sense function and is used to reset the microprocessor at system power-up. The 4.0 MHz crystal (Y1) provides the external portion of the oscillator function for clocking the microprocessor and providing a stable base for timing functions.

Table 2. Parts List

Designators	Quant.	Description	Rating	Manufacturer	Part Number
C3, C4, C6	3	.1 µF Ceramic Cap.	50 Vdc	Sprague	1C105Z5U104M050B
C1, C2, C5	3	1 µF Ceramic Cap.	50 Vdc	muRATA ERIE	RPE123Z5U105M050V
C7, C8	2	22 pF Ceramic Cap.	100 Vdc	Mepco/Centralab	CN15A220K
J1–J3, J8	3 OR 4	#22 or #24 AWG Tined Copper		As Required	
J4–J7	1	Dual Row Straight 4 Pos. Arranged On .1″ Grid		AMP	87227-2
LCD1	1	Liquid Crystal Display		IEE	LCD5657
P1	1	Power Connector		Phoenix Contact	MKDS 1/2-3.81
R1	1	6.98K Ohm resistor 1%			
R2	1	121 Ohm Resistor 1%			
R3	1	200 Ohm Resistor 1%			
R4, R11	2	4.7K Ohm Resistor			
R7	1	340 Ohm Resistor 1%			
R5, R6	2	2.0K Ohm Resistor 1%			
R8	1	23.7 Ohm Resistor 1%			
R9	1	976 Ohm Resistor 1%			
R10	1	1K Ohm Resistor 1%			
R12	1	3.32K Ohm Resistor 1%			
R13	1	4.53K Ohm Resistor 1%			
R14	1	402 Ohm Resistor 1%			
R15	1	10 Meg Ohm Resistor			
RP1	1	47K Ohm x 7 SIP Resistor 2%		CTS	770 Series
TP1	1	Test Point	Red	Components Corp.	TP-104-01-02
U1	1	Quad Operational Amplifier		Motorola	MC33274P
U2	1	Under Voltage Detector		Motorola	MC34064P-5
U3	1	5 Volt Fixed Voltage Regulator		Motorola	MC78L05ACP
U4	1	8 Volt Fixed Voltage Regulator		Motorola	MC78L08ACP
U5	1	Microprocessor		Motorola Motorola	MC68HC705B5FN or XC68HC705B5FN
XDCR	1	Pressure Sensor		Motorola	MPX2xxxDP
Y1	1	Crystal (Low Profile)	4.0 MHz	CTS	ATS040SLV
No Designator	1	52 Pin PLCC Socket for U5		AMP	821-575-1
No Designator	4	Jumpers For J4 thru J7		Molex	15-29-1025
No Designator	1	Bare Printed Circuit Board			
No Designator	4	Self Sticking Feet		Fastex	5033-01-00-5001

Note: All resistors are 1/4 W resistors with a tolerance of 5% unless otherwise noted.
All capacitors are 100 volt, ceramic capacitors with a tolerance of 10% unless otherwise noted.

OPERATIONAL CHARACTERISTICS

The following operational characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Max	Unit
Power Supply Voltage	+12	10.75	16	Volts
Operating Current	I_{CC}		75	mA
Full Scale Pressure	P_{fs}			
MPX2010			1.5	PSI
MPX2050			7.5	PSI
MPX2100			15	PSI
MPX2200			30	PSI
MPX2700			100	PSI

PIN-BY-PIN DESCRIPTION

+12:

Input power is supplied at the +12 terminal. The minimum operating voltage is 10.75 Vdc and the maximum operating voltage is 16 Vdc.

GND:

The ground terminal is the power supply return for the system.

TP1:

Test point 1 is connected to the final op amp stage. It is the voltage that is applied to the microprocessor's A/D converter.

There are two ports on the pressure sensor located at the bottom center of the printed circuit board. The pressure port is on the top left and the vacuum port is on the bottom right of the sensor.

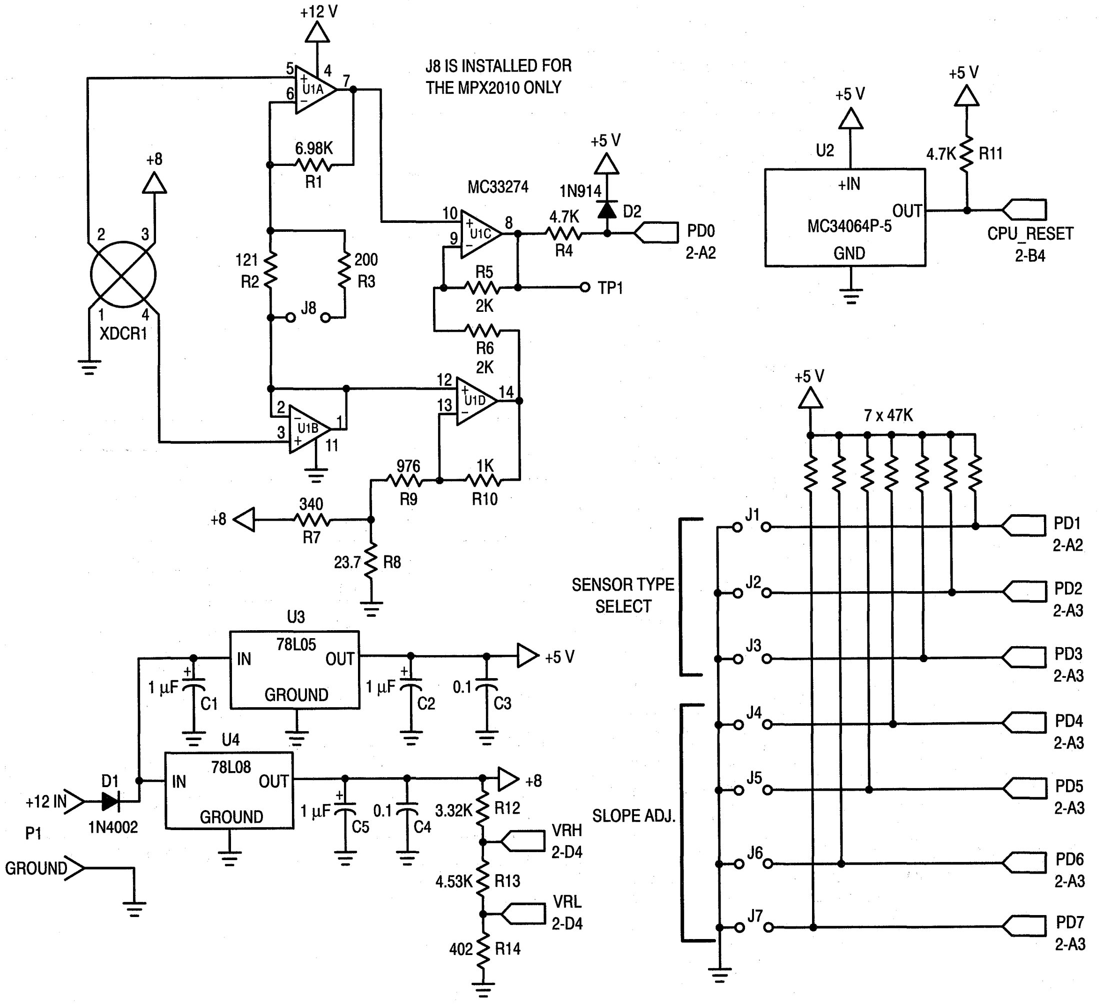


Figure 3a. Schematic

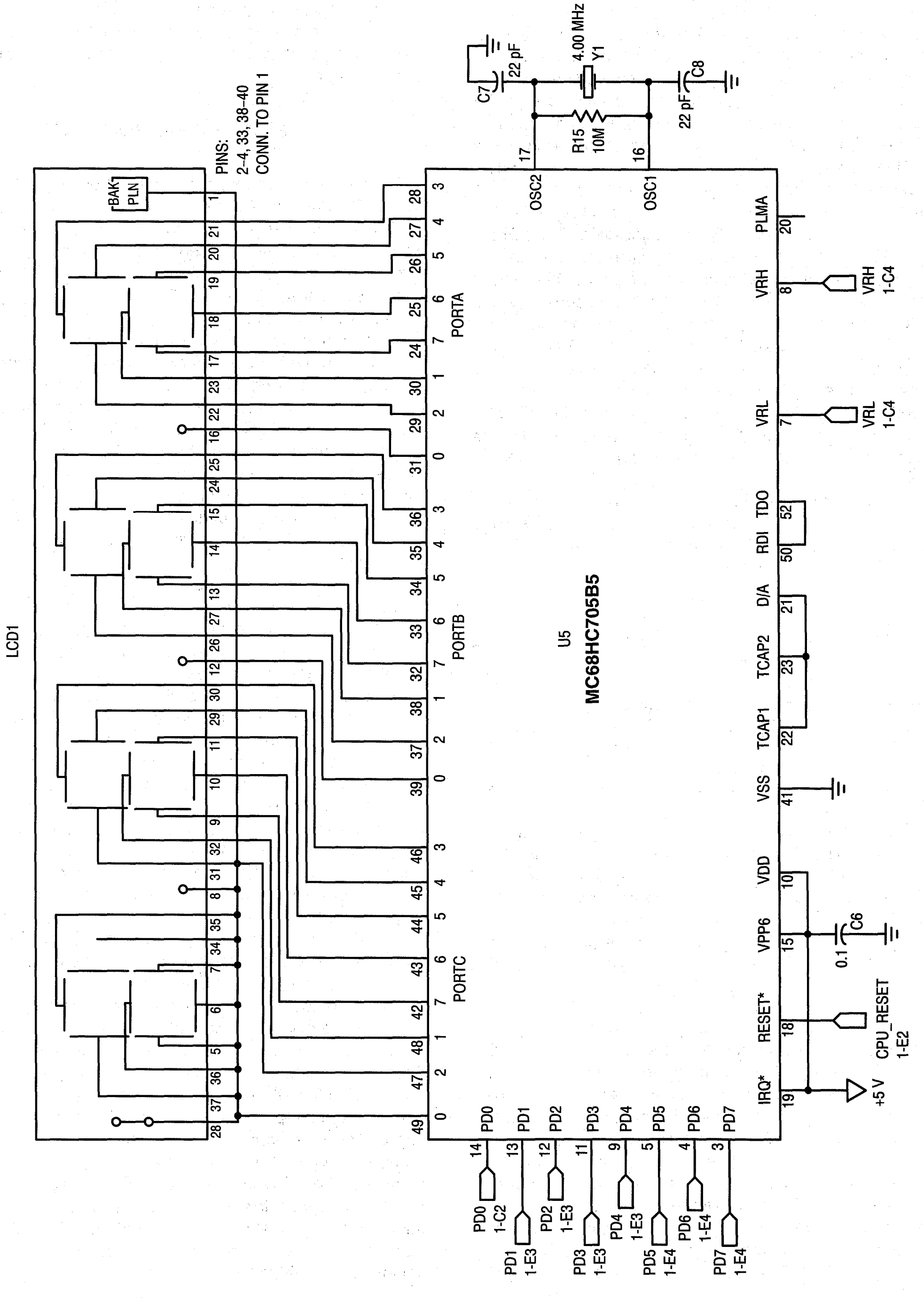


Figure 3b. Schematic

OPERATION

Connect the system to a 12 Vdc regulated power supply. (Note the polarity marked on the power terminal P1.) Depending on the particular pressure sensor being used with the system, wire jumpers J1 through J3 and J8 must be installed at board assembly time. If at some later time it is desirable to change the type of sensor that is installed on the board, jumpers J1 through J3 and J8, must be reconfigured for the system to function properly (see Table 1). If an invalid J1 through J3 jumper combination (i.e., not listed in Table 1) is used the LCD will display "SE" to indicate that condition. These jumpers are read by the software and are used to determine which sensor is installed on the board. Wire jumper J8 is installed only when an MPX2010DP pressure sensor is used on the system. The purpose of wire jumper J8 will be explained later in the text. Jumpers J4 through J7 are read by the software to allow the user to adjust the slope constant used for the engineering units calculation (see Table 3). The pressure and vacuum ports on the sensor must be left open to atmosphere anytime the board is powered-up. This is because the zero pressure offset voltage is computed at power-up.

When you apply power to the system, the LCD will display CAL for approximately 5 seconds. After that time, pressure or vacuum may be applied to the sensor. The system will then start displaying the applied pressure in PSI.

Table 3

J7	J6	J5	J4	Action
IN	IN	IN	IN	Normal Slope
IN	IN	IN	OUT	Decrease the Slope Approximately 7%
IN	IN	OUT	IN	Decrease the Slope Approximately 6%
IN	IN	OUT	OUT	Decrease the Slope Approximately 5%
IN	OUT	IN	IN	Decrease the Slope Approximately 4%
IN	OUT	IN	OUT	Decrease the Slope Approximately 3%
IN	OUT	OUT	IN	Decrease the Slope Approximately 2%
IN	OUT	OUT	OUT	Decrease the Slope Approximately 1%
OUT	IN	IN	IN	Increase the Slope Approximately 1%
OUT	IN	IN	OUT	Increase the Slope Approximately 2%
OUT	IN	OUT	IN	Increase the Slope Approximately 3%
OUT	IN	OUT	OUT	Increase the Slope Approximately 4%
OUT	OUT	IN	IN	Increase the Slope Approximately 5%
OUT	OUT	IN	OUT	Increase the Slope Approximately 6%
OUT	OUT	OUT	IN	Increase the Slope Approximately 7%
OUT	OUT	OUT	OUT	Normal Slope

To improve the accuracy of the system, you can change the constant used by the program that determines the span of the sensor and amplifier. You will need an accurate test gauge (using PSI as the reference) to measure the pressure applied to the sensor. Anytime after the display has completed the zero calculation, (after CAL is no longer displayed) apply the sensor's full scale pressure (see Table 1), to the sensor. Make sure that jumpers J4 through J7 are in the "normal" configuration (see Table 3). Referring to Table 3, you can better "calibrate" the system by changing the configuration of J4 through J7. To "calibrate" the system, compare the display reading against that of the test gauge (with J4 through J7 in the "normal slope" configuration). Change the configuration of J4 through J7 according to Table 3 to obtain the best results. The calibration jumpers may be changed while the system is powered up as they are read by the software before each display update.

DESIGN CONSIDERATIONS

To build a system that will show how to interface an MPX2000 series pressure sensor to a microprocessor, there are two main challenges. The first is to take a small differential signal produced by the sensor and produce a ground referenced signal of sufficient amplitude to drive a microprocessor's A/D input. The second challenge is to understand the microprocessor's operation and to write software that makes the system function.

From a hardware point of view, the microprocessor portion of the system is straight forward. The microprocessor needs power, a clock source (crystal Y1, two capacitors and a resistor), and a reset signal to make it function. As for the A/D converter, external references are required to make it function. In this case, the power source for the sensor is divided to produce the voltage references for the A/D converter. Accurate results will be achieved since the output from the sensor and the A/D references are ratiometric to its power supply voltage.

The liquid crystal display is driven by Port A, B and C of the microprocessor. There are enough I/O lines on these ports to provide drive for three full digits, the backplane and two decimal points. Software routines provide the AC waveform necessary to drive the display.

The analog portion of the system consists of the pressure sensor, a quad operational amplifier and the voltage references for the microprocessor's A/D converter and signal conditioning circuitry. Figure 4 shows an interface circuit that will provide a single ended signal with sufficient amplitude to drive the microprocessor's A/D input. It uses a quad operational amplifier and several resistors to amplify and level shift the sensor's output. It is necessary to level shift the output from the final amplifier into the A/D. Using single power supplied op amps, the V_{CE} saturation of the output from an op amp cannot be guaranteed to pull down to zero volts. The analog design shown here will provide a signal to the A/D converter with a span of approximately 4 volts when zero to full-scale pressure is applied to the sensor. The final amplifier's output is level shifted to approximately 0.7 volts. This will provide a signal that will swing between approximately 0.7 volts and 4.7 volts. The offset of 0.7 volts in this implementation does not have to be trimmed to an exact point. The software will sample the voltage applied to the A/D converter at initial power up time and call that value "zero". The important thing to remember is that the span of the signal will be approximately 4 volts when zero to full scale pressure is applied to the sensor. The 4 volt swing in signal may vary slightly from sensor to sensor and can also vary due to resistor tolerances in the analog circuitry. Jumpers J4 through J7 may be placed in various configurations to compensate for these variations (see Table 3).

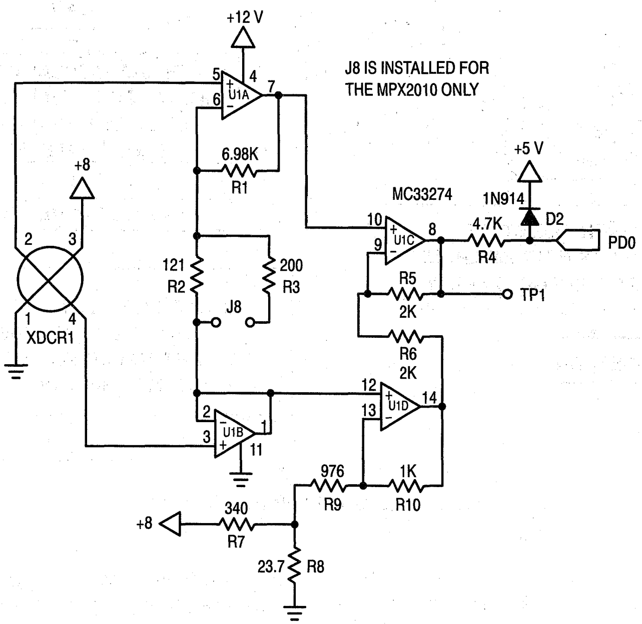


Figure 4. Analog Interface

Referring to Figure 4, most of the amplification of the voltage from the pressure sensor is provided by U1A which is configured as a differential amplifier. U1B serves as a unity gain buffer in order to keep any current that flows through R2 (and R3) from being fed back into the sensor's negative output. With zero pressure applied to the sensor, the differential voltage from pin 2 to pin 4 of the sensor is zero or very close to zero volts. The common mode, or the voltage measured between pins 2 or 4 to ground, is equal to approximately one half of the voltage applied to the sensor, or 4 volts. The zero pressure output voltage at pin 7 of U1A will then be 4 volts because pin 1 of U1B is also at 4 volts, creating a zero bias between pins 5 and 6 of U1A. The four volt zero pressure output will then be level shifted to the desired zero pressure offset voltage (approximately 0.7 volts) by U1C and U1D.

To further explain the operation of the level shifting circuitry, refer again to Figure 4. Assuming zero pressure is applied to the sensor and the common mode voltage from the sensor is 4 volts, the voltage applied to pin 12 of U1D will be 4 volts, implying pin 13 will be at 4 volts. The gain of amplifier U1D will be (R10/(R8+R9)) +1 or a gain of 2. R7 will inject a V_{offset} (0.7 volts) into amplifier U1D, thus causing the output at U1D pin 14 to be 7.3 = (4 volts @ U1D pin 12 $\times$ 2) – 0.7 volts. The gain of U1C is also set at 2 ((R5/R6)+1). With 4 volts applied to pin 10 of U1C, its output at U1C pin 8 will be 0.7 = ((4 volts @ U1C pin 10 $\times$ 2) – 7.3 volts). For this scheme to work properly, amplifiers U1C and U1D must have a gain of 2 and the output of U1D must be shifted down by the V_{offset} provided by R7. In this system, the 0.7 volts V_{offset} was arbitrarily picked and could have been any voltage greater than the V_{sat} of the op amp being used. The system software will take in account any variations of V_{offset} as it assumes no pressure is applied to the sensor at system power up.

The gain of the analog circuit is approximately 117. With the values shown in Figure 4, the gain of 117 will provide a span of approximately 4 volts on U1C pin 8 when the pressure sensor and the 8 volt fixed voltage regulator are at their maximum output voltage tolerance. All of the sensors listed in Table 1 with the exception of the MPX2010DP output approximately 33 mV when full scale pressure is applied. When the MPX2010DP sensor is used, its full scale sensor differential output is approximately 20 mV. J8 must be installed to increase the gain of the analog circuit to still provide the 4 volts span out of U1C pin 8 with a 20 mV differential from the sensor.

Diode D2 is used to protect the microprocessor's A/D input if the output from U1C exceeds 5.6 volts. R4 is used to provide current limiting into D4 under failure or overvoltage conditions.

SOFTWARE

The source code, compiled listing, and S-record output for the software used in this system are available on the Motorola Freeware Bulletin Board Service in the MCU directory under the filename DEVB158.ARC. To access the bulletin board, you must have a telephone line, a 300, 1200 or 2400 baud modem and a personal computer. The modem must be compatible with the Bell 212A standard. Call (512) 891-3733 to access the Bulletin Board Service.

Figure 5 is a flowchart for the program that controls the system. The software for the system consists of a number of modules. Their functions provide the capability for system calibration as well as displaying the pressure input to the MPX2000 series pressure sensor.

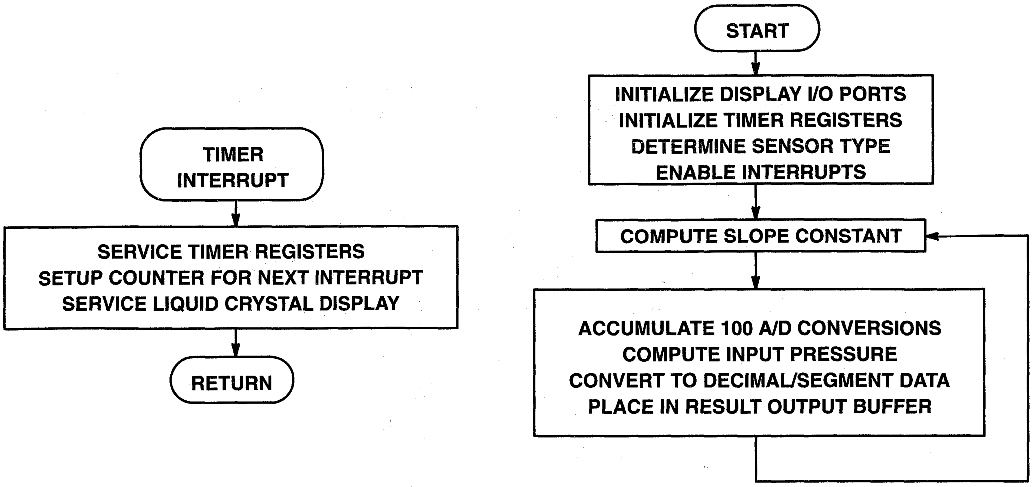


Figure 5. DEVB-158 Software Flowchart

The “C” compiler used in this project was provided by BYTE CRAFT LTD. (519) 888-6911. A compiler listing of the program is included at the end of this document. The following is a brief explanation of the routines:

delay() Used to provide a software loop delay.

read_a2d() Performs 100 reads on the A/D converter on multiplexer channel 0 and returns the accumulation.

fixcompare() Services the internal timer for 15 ms. timer compare interrupts.

TIMERCMP() Alternates the data and backplane inputs to the liquid crystal display.

initio() Sets up the microprocessor’s I/O ports, timer and enables processor interrupts.

adzero() This routine is called at powerup time. It delays to let the power supply and the transducer stabilize. It then calls ‘read_atod()’ and saves the returned value as the sensors output voltage with zero pressure applied.

cvt_bin_dec(unsigned long arg) This routine converts the unsigned binary argument passed in ‘arg’ to a five digit decimal number in an array called ‘digit’. It then uses the decimal results for each digit as an index into a table that converts the decimal number into a segment pattern for the display. This is then output to the display.

display_psi() This routine is called from ‘main()’ never to return. The A/D converter routine is called, the pressure is calculated based on the type sensor detected and the pressure applied to the sensor is displayed. The loop then repeats.

sensor_type() This routine determines the type of sensor from reading J1 to J3, setting the full scale pressure for that particular sensor in a variable for use by display_psi().

sensor_slope() This routine determines the slope constant to be used by display_psi() for engineering units output.

main() This is the main routine called from reset. It calls ‘initio()’ to setup the system’s I/O. ‘display_psi()’ is called to compute and display the pressure applied to the sensor.

```
6805 'C' COMPILER V3.48  16-Oct-1991                        PAGE  1

                              #pragma option f0;
                              /*

                              THE FOLLOWING 'C' SOURCE CODE IS WRITTEN FOR THE DEVB158 EVALUATION
                              BOARD. IT WAS COMPILED WITH A COMPILER COURTESY OF:

                                                                  BYTE CRAFT LTD.
                                                                  421 KING ST.
                                                                  WATERLOO, ONTARIO
                                                                  CANADA  N2J 4E4
                                                                  (519)888-6911

                              SOME SOURCE CODE CHANGES MAY BE NECESSARY FOR COMPILATION WITH OTHER
                              COMPILERS.
                                                          BILL LUCAS 2/5/92
                                                          MOTOROLA, SPS

                              Revision history
                              rev. 1.0 initial release 3/19/92
                              rev. 1.1 added additional decimal digit to the MPX2010 sensor. Originally
                              resolved the output to .1 PSI. Modified cvt_bin_dec to output PSI resolved
                              to .01 PSI. WLL 9/25/92

                              */
0800 1700                     #pragma memory ROMPROG  [5888]  @ 0x0800 ;
0050 0096                     #pragma memory RAMPAGE0 [150]   @ 0x0050 ;

                              /*      Vector assignments    */
1FFE                          #pragma vector __RESET   @ 0x1ffe ;
1FFC                          #pragma vector __SWI     @ 0x1ffc ;
1FFA                          #pragma vector IRQ       @ 0x1ffa ;
1FF8                          #pragma vector TIMERCAP  @ 0x1ff8 ;
1FF6                          #pragma vector TIMERCMP  @ 0x1ff6 ;
1FF4                          #pragma vector TIMEROV   @ 0x1ff4 ;
1FF2                          #pragma vector SCI       @ 0x1ff2 ;

                              #pragma has STOP ;
                              #pragma has WAIT ;
                              #pragma has MUL ;

                              /*      Register assignments for the 68HC705B5 microcontroller     */
0000                          #pragma portrw porta   @ 0x00;  /*                                          */
0001                          #pragma portrw portb   @ 0x01;  /*                                          */
0002                          #pragma portrw portc   @ 0x02;  /*                                          */
0003                          #pragma portrw portd   @ 0x03;  /* in  ,-    ,SS   ,SCK  ,MOSI ,MISO,TxD,RxD */
0004                          #pragma portrw ddra    @ 0x04;  /* Data direction, Port A                   */
0005                          #pragma portrw ddrb    @ 0x05;  /* Data direction, Port B                   */
0006                          #pragma portrw ddrc    @ 0x06;  /* Data direction, Port C (all output)      */
0007                          #pragma portrw eeclk   @ 0x07;  /* eeprom/eclk cntl */
0008                          #pragma portrw addata  @ 0x08;  /* a/d data register */
0009                          #pragma portrw adstat  @ 0x09;  /* a/d stat/control */
000A                          #pragma portrw plma    @ 0x0a;  /* pulse length modulation a */
000B                          #pragma portrw plmb    @ 0x0b;  /* pulse length modulation b */
000C                          #pragma portrw misc    @ 0x0c;  /* miscellaneous register */
000D                          #pragma portrw scibaud @ 0x0d;  /* sci baud rate register */
000E                          #pragma portrw scicntl1 @ 0x0e; /* sci control 1  */
000F                          #pragma portrw scicntl2 @ 0x0f; /* sci control 2  */
0010                          #pragma portrw scistat @ 0x10;  /* sci status reg */
0011                          #pragma portrw scidata   @ 0x11;  /* SCI Data  */
0012                          #pragma portrw tcr       @ 0x12;  /* ICIE,OCIE,TOIE,0;0,0,IEGE,OLVL         */
0013                          #pragma portrw tsr       @ 0x13;  /* ICF,OCF,TOF,0; 0,0,0,0                 */
0014                          #pragma portrw icaphi1   @ 0x14;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0015                          #pragma portrw icaplo1   @ 0x15;  /* Input Capture Reg (Hi-0x14, Lo-0x15)   */
0016                          #pragma portrw ocmphi1   @ 0x16;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0017                          #pragma portrw ocmplo1   @ 0x17;  /* Output Compare Reg (Hi-0x16, Lo-0x17)  */
0018                          #pragma portrw tcnthi    @ 0x18;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
0019                          #pragma portrw tcntlo    @ 0x19;  /* Timer Count Reg (Hi-0x18, Lo-0x19)     */
001A                          #pragma portrw aregnthi    @ 0x1A;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001B                          #pragma portrw aregntlo    @ 0x1B;  /* Alternate Count Reg (Hi-$1A, Lo-$1B)   */
001C                          #pragma portrw icaphi2   @ 0x1c;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
001D                          #pragma portrw icaplo2   @ 0x1d;  /* Input Capture Reg (Hi-0x1c, Lo-0x1d)   */
001E                          #pragma portrw ocmphi2   @ 0x1e;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */
001F                          #pragma portrw ocmplo2   @ 0x1f;  /* Output Compare Reg (Hi-0x1e, Lo-0x1f)  */
```

```
1EFE 74                          #pragma mor @ 0x1efe = 0x74; /* this disables the watchdog counter and does
                                                                  not add pull-down resistors on ports B and C */

                                      /* put constants and variables here...they must be global */
                                   /***************************************************************************/

0800 FC 30 DA 7A 36 6E E6 38 FE  const char lcdtab[]={0xfc,0x30,0xda,0x7a,0x36,0x6e,0xe6,0x38,0xfe,0x3e };
0809 3E
                                   /* lcd pattern table  0    1    2    3    4    5    6    7    8    9     */

080A 27 10 03 E8 00 64 00 0A     const long dectable[] = { 10000, 1000, 100, 10 };

0050 0005                        unsigned int digit[5]; /* buffer to hold results from cvt_bin_dec function */

0812 00 96 00 4B 00 96 00 1E 00  const long type[] = {  150,     75,      150,     30,      103   };
081B 67
                                   /*                  MPX2010  MPX2050  MPX2100  MPX2200  MPX2700
                                   The table above will cause the final results of the pressure to
                                   engineering units to display the 1.5, 7.3 and 15.0 devices with a
                                   decimal place in the tens position. The 30 and 103 psi devices will
                                   display in integer units.
                                   */

                                   const long slope_const[]={ 450,418,423,427,432,436,441,445,454,459,
081C 01 C2 01 A2 01 A7 01 AB 01                               463,468,472,477,481,450 };
0825 B0 01 B4 01 B9 01 BD 01 C6
082E 01 CB 01 CF 01 D4 01 D8 01
0837 DD 01 E1 01 C2

0000                             registera areg;    /* processor's A register */

0055                             long atodtemp;     /* temp to accumulate 100 a/d readings for smoothing */

0059                             long slope;        /* multiplier for adc to engineering units conversion */

005B                             int adcnt;         /* a/d converter loop counter */

005C                             long xdcr_offset;  /* initial xdcr offset */

005E                             long sensor_model; /*  installed sensor based on J1..J3 */
0060                             int sensor_index;  /*  determine the location of the decimal pt. */

0061 0063                        unsigned long i,j; /* counter for loops */

0065                             unsigned int k;    /* misc variable */

                                   struct bothbytes
                                     {  int hi;
                                        int lo;
                                     };

                                     union isboth
                                       {  long  l;
                                        struct bothbytes b;
                                       };

0066 0002                              union isboth q;  /* used for timer set-up */

                                   /***************************************************************************/

                                  /* variables for add32  */
0068 0004                        unsigned long SUM[2];     /*     result        */
006C 0004                        unsigned long ADDEND[2]; /*     one input     */
0070 0004                        unsigned long AUGEND[2]; /*     second input  */

                                  /* variables for sub32  */
0074 0004                        unsigned long MINUE[2];  /*     minuend       */
0078 0004                        unsigned long SUBTRA[2]; /*     subtrahend    */
007C 0004                        unsigned long DIFF[2];   /*     difference    */

                                  /* variables for mul32  */
0080 0004                        unsigned long MULTP[2];  /*     multiplier    */
0084 0004                        unsigned long MTEMP[2];  /*     high order 4 bytes at return */
0088 0004                        unsigned long MULCAN[2]; /*     multiplicand at input, low 4 bytes at return */
```

```
                                     /* variables for div32 */
008C 0004                         unsigned long DVDND[2];  /*     Dividend      */
0090 0004                         unsigned long DVSOR[2];  /*     Divisor       */
0094 0004                         unsigned long QUO[2];    /*     Quotient      */
0098                              unsigned int  CNT;       /*     Loop counter  */

                                                       /* The code starts here */

                                     /***************************************************************************/

                                     void add32()
                                     {
                                     #asm
                         *----------------------------------------------------------------------------*
                         * Add two 32-bit values.
                         *    Inputs:
                         *       ADDEND: ADDEND[0..3]  HIGH ORDER BYTE IS ADDEND+0
                         *       AUGEND: AUGEND[0..3]  HIGH ORDER BYTE IS AUGEND+0
                         *    Output:
                         *       SUM: SUM[0..3]  HIGH ORDER BYTE IS SUM+0
                         *----------------------------------------------------------------------------*
                         *
083C B6 6F                      LDA  ADDEND+3   low byte
083E BB 73                      ADD  AUGEND+3
0840 B7 6B                      STA  SUM+3
0842 B6 6E                      LDA  ADDEND+2   medium low byte
0844 B9 72                      ADC  AUGEND+2
0846 B7 6A                      STA  SUM+2
0848 B6 6D                      LDA  ADDEND+1   medium high byte
084A B9 71                      ADC  AUGEND+1
084C B7 69                      STA  SUM+1
084E B6 6C                      LDA  ADDEND     high byte
0850 B9 70                      ADC  AUGEND
0852 B7 68                      STA  SUM
0854 81                         RTS             done
                         *
                                  #endasm
0855 81        RTS                }

                                     void sub32()
                                     {
                                     #asm
                         *----------------------------------------------------------------------------*
                         * Subtract two 32-bit values.
                         *    Input:
                         *       Minuend: MINUE[0..3]
                         *       Subtrahend: SUBTRA[0..3]
                         *    Output:
                         *       Difference: DIFF[1..0]
                         *----------------------------------------------------------------------------*
                         *
0856 B6 77                      LDA  MINUE+3    low byte
0858 B0 7B                      SUB  SUBTRA+3
085A B7 7F                      STA  DIFF+3
085C B6 76                      LDA  MINUE+2    medium low byte
085E B2 7A                      SBC  SUBTRA+2
0860 B7 7E                      STA  DIFF+2
0862 B6 75                      LDA  MINUE+1    medium high byte
0864 B2 79                      SBC  SUBTRA+1
0866 B7 7D                      STA  DIFF+1
0868 B6 74                      LDA  MINUE      high byte
086A B2 78                      SBC  SUBTRA
086C B7 7C                      STA  DIFF
086E 81                         RTS             done
                         *
                                  #endasm
086F 81        RTS                }

                                     void mul32()
                                     {
                                     #asm
                         *----------------------------------------------------------------------------*
                         * Multiply 32-bit value by a 32-bit value
                         *
                         *
                         *    Input:
```

```
                                *       Multiplier:    MULTP[0..3]
                                *       Multiplicand:  MULCAN[0..3]
                                *    Output:
                                *       Product:       MTEMP[0..3] AND MULCAN[0..3] MTEMP[0] IS THE HIGH
                                *                           ORDER BYTE AND MULCAN[3] IS THE LOW ORDER BYTE
                                *
                                *   THIS ROUTINE DOES NOT USE THE MUL INSTRUCTION FOR THE SAKE OF USERS NOT
                                *   USING THE HC(7)05 SERIES PROCESSORS.
                                *---------------------------------------------------------------------------*
                                *
                                *
0870 AE 20                             LDX  #32        loop counter
0872 3F 84                             CLR  MTEMP      clean-up for result
0874 3F 85                             CLR  MTEMP+1    *
0876 3F 86                             CLR  MTEMP+2    *
0878 3F 87                             CLR  MTEMP+3    *
087A 36 88                             ROR  MULCAN     low but to carry, the rest one to the right
087C 36 89                             ROR  MULCAN+1   *
087E 36 8A                             ROR  MULCAN+2   *
0880 36 8B                             ROR  MULCAN+3   *
0882 24 18                      MNEXT  BCC  ROTATE     if carry is set, do the add
0884 B6 87                             LDA  MTEMP+3    *
0886 BB 83                             ADD  MULTP+3    *
0888 B7 87                             STA  MTEMP+3    *
088A B6 86                             LDA  MTEMP+2    *
088C B9 82                             ADC  MULTP+2    *
088E B7 86                             STA  MTEMP+2    *
0890 B6 85                             LDA  MTEMP+1    *
0892 B9 81                             ADC  MULTP+1    *
0894 B7 85                             STA  MTEMP+1    *
0896 B6 84                             LDA  MTEMP      *
0898 B9 80                             ADC  MULTP      *
089A B7 84                             STA  MTEMP      *
089C 36 84                      ROTATE ROR  MTEMP     else: shift low bit to carry, the rest to the right
089E 36 85                             ROR  MTEMP+1    *
08A0 36 86                             ROR  MTEMP+2    *
08A2 36 87                             ROR  MTEMP+3    *
08A4 36 88                             ROR  MULCAN     *
08A6 36 89                             ROR  MULCAN+1   *
08A8 36 8A                             ROR  MULCAN+2   *
08AA 36 8B                             ROR  MULCAN+3   *
08AC 5A                                DEX             bump the counter down
08AD 26 D3                             BNE  MNEXT      done yet ?
08AF 81                                RTS             done

                                         #endasm
08B0 81        RTS                       }

                                            void div32()
                                            {
                                            #asm
                                *
                                *---------------------------------------------------------------------------*
                                * Divide 32 bit by 32 bit unsigned integer routine
                                *
                                *    Input:
                                *       Dividend:  DVDND [+0..+3] HIGH ORDER BYTE IS DVND+0
                                *       Divisor:   DVSOR [+0..+3] HIGH ORDER BYTE IS DVSOR+0
                                *    Output:
                                *       Quotient:  QUO [+0..+3]   HIGH ORDER BYTE IS QUO+0
                                *---------------------------------------------------------------------------*
                                *
08B1 3F 94                             CLR  QUOzero result registers
08B3 3F 95                             CLR  QUO+1      *
08B5 3F 96                             CLR  QUO+2      *
08B7 3F 97                             CLR  QUO+3      *
08B9 A6 01                             LDA  #1         initial loop count
08BB 3D 90                             TST  DVSOR      if the high order bit is set..no need to shift DVSOR
08BD 2B 0F                             BMI  DIV153
                                *
08BF 4C                         DIV151  INCA            bump the loop counter
08C0 38 93                       ASL  DVSOR+3    now shift the divisor until the high order bit = 1
08C2 39 92                             ROL  DVSOR+2
08C4 39 91                             ROL  DVSOR+1    *
08C6 39 90                             ROL  DVSOR      *
08C8 2B 04                       BMI  DIV153     done if high order bit = 1
```

```
08CA A1 21                      CMP  #33        have we shifted all possible bits in the DVSOR yet ?
08CC 26 F1                      BNE  DIV151     no
                          *
08CE B7 98              DIV153  STA  CNT        save the loop counter so we can do the divide
                          *
08D0 B6 8F              DIV163  LDA  DVDND+3    sub 32 bit divisor from dividend
08D2 B0 93                      SUB  DVSOR+3    *
08D4 B7 8F                      STA  DVDND+3    *
08D6 B6 8E                      LDA  DVDND+2    *
08D8 B2 92                      SBC  DVSOR+2    *
08DA B7 8E                      STA  DVDND+2    *
08DC B6 8D                      LDA  DVDND+1    *
08DE B2 91                      SBC  DVSOR+1    *
08E0 B7 8D                      STA  DVDND+1    *
08E2 B6 8C                      LDA  DVDND      *
08E4 B2 90                      SBC  DVSOR      *
08E6 B7 8C                      STA  DVDND      *
08E8 24 1B                      BCC  DIV165     carry is clear if DVSOR was larger than DVDND
                          *
08EA B6 8F                      LDA  DVDND+3    add the divisor back...was larger than the dividend
08EC BB 93                      ADD  DVSOR+3    *
08EE B7 8F                      STA  DVDND+3    *
08F0 B6 8E                      LDA  DVDND+2    *
08F2 B9 92                      ADC  DVSOR+2    *
08F4 B7 8E                      STA  DVDND+2    *
08F6 B6 8D                      LDA  DVDND+1    *
08F8 B9 91                      ADC  DVSOR+1    *
08FA B7 8D                      STA  DVDND+1    *
08FC B6 8C                      LDA  DVDND      *
08FE B9 90                      ADC  DVSOR      *
0900 B7 8C                      STA  DVDND      *
0902 98                         CLC             this will clear the respective bit in QUO due to
                          *                      the need to add DVSOR back to DVND
0903 20 01                      BRA  DIV167
0905 99                 DIV165  SEC             this will set the respective bit in QUO
0906 39 97              DIV167  ROL  QUO+3      set or clear the low order bit in QUO based on above
0908 39 96                      ROL  QUO+2      *
090A 39 95                      ROL  QUO+1      *
090C 39 94                      ROL  QUO        *
090E 34 90                      LSR  DVSOR      divide the divisor by 2
0910 36 91                      ROR  DVSOR+1    *
0912 36 92                      ROR  DVSOR+2    *
0914 36 93                      ROR  DVSOR+3    *
0916 3A 98                      DEC  CNT        bump the loop counter down
0918 26 B6                      BNE  DIV163     finished yet ?
091A 81                         RTSyes
                          *
                                   #endasm
091B 81        RTS                 }

                                      /***************************************************************************/

                                      /* These interrupts are not used...give them a graceful return if for
                                        some reason one occurs */

1FFC 09 1C                         __SWI(){}
091C 80        RTI
1FFA 09 1D                         IRQ(){}
091D 80        RTI
1FF8 09 1E                         TIMERCAP(){}
091E 80        RTI
1FF4 09 1F                         TIMEROV(){}
091F 80        RTI
1FF2 09 20                         SCI(){}
0920 80        RTI

                                      /***************************************************************************/

                                      void sensor_type()
                                      {
0921 B6 03     LDA     $03         k = portd & 0x0e;  /* we only care about bits 1..3 */
0923 A4 0E     AND     #$0E
0925 B7 65     STA     $65
0927 34 65     LSR     $65          k = k >> 1;    /* right justify the variable */
0929 B6 65     LDA     $65           if ( k > 4 )
092B A1 04     CMP     #$04
```

```
092D 23 0C     BLS    $093B
                                   { /* we have a set-up error in wire jumpers J1 - J3 */
092F 3F 02     CLR    $02         portc = 0;     /*   */
0931 A6 6E     LDA    #$6E        portb = 0x6e;  /* S */
0933 B7 01     STA    $01
0935 A6 CE     LDA    #$CE        porta = 0xce;  /* E */
0937 B7 00     STA    $00
0939 20 FE     BRA    $0939        while(1);
                                   }
093B B6 65     LDA    $65     sensor_index = k;
093D B7 60     STA    $60
093F 97        TAX            sensor_model = type[k];
0940 58        LSLX
0941 D6 08 12  LDA    $0812,X
0944 B7 5E     STA    $5E
0946 D6 08 13  LDA    $0813,X
0949 B7 5F     STA    $5F
094B 81        RTS            }

                                /**************************************************************************/

                                void sensor_slope()
                                {
094C B6 03     LDA    $03     k=portd & 0xf0;  /* we only care about bits 4..7 */
094E A4 F0     AND    #$F0
0950 B7 65     STA    $65
0952 34 65     LSR    $65      k = k >> 4;    /* right justify the variable */
0954 34 65     LSR    $65
0956 34 65     LSR    $65
0958 34 65     LSR    $65
095A BE 65     LDX    $65     slope = slope_const[k];
095C 58        LSLX
095D D6 08 1C  LDA    $081C,X
0960 B7 59     STA    $59
0962 D6 08 1D  LDA    $081D,X
0965 B7 5A     STA    $5A
0967 81        RTS            }

                                /**************************************************************************/

                                void delay(void)  /* just hang around for a while */
                                {
0968 3F 62     CLR    $62     for (i=0; i<20000; ++i);
096A 3F 61     CLR    $61
096C B6 62     LDA    $62
096E A0 20     SUB    #$20
0970 B6 61     LDA    $61
0972 A2 4E     SBC    #$4E
0974 24 08     BCC    $097E
0976 3C 62     INC    $62
0978 26 02     BNE    $097C
097A 3C 61     INC    $61
097C 20 EE     BRA    $096C
097E 81        RTS            }

                                /**************************************************************************/

                                read_a2d(void)
                                {
                                /* read the a/d converter on channel 5 and accumulate the result
                                in atodtemp */

097F 3F 56     CLR    $56     atodtemp=0;   /* zero for accumulation */
0981 3F 55     CLR    $55
0983 3F 5B     CLR    $5B        for ( adcnt = 0 ; adcnt<100; ++adcnt) /* do 100 a/d conversions */
0985 B6 5B     LDA    $5B
0987 A8 80     EOR    #$80
0989 A1 E4     CMP    #$E4
098B 24 21     BCC    $09AE
                                      {
098D A6 20     LDA    #$20          adstat = 0x20;  /* convert on channel 0 */
098F B7 09     STA    $09
0991 0F 09 FD  BRCLR 7,$09,$0991     while (!(adstat & 0x80));  /* wait for a/d to complete */
0994 B6 08     LDA    $08             atodtemp = addata + atodtemp;
0996 3F 57     CLR    $57
0998 B7 58     STA    $58
```

```
099A BB 56     ADD    $56
099C B7 58     STA    $58
099E B6 57     LDA    $57
09A0 B9 55     ADC    $55
09A2 B7 57     STA    $57
09A4 B7 55     STA    $55
09A6 B6 58     LDA    $58
09A8 B7 56     STA    $56
                                              }
09AA 3C 5B     INC    $5B
09AC 20 D7     BRA    $0985
09AE B6 56     LDA    $56                 atodtemp = atodtemp/100;
09B0 B7 58     STA    $58
09B2 B6 55     LDA    $55
09B4 B7 57     STA    $57
09B6 3F 9A     CLR    $9A
09B8 A6 64     LDA    #$64
09BA B7 9B     STA    $9B
09BC CD 0B F1  JSR    $0BF1
09BF CD 0C 22  JSR    $0C22
09C2 BF 55     STX    $55
09C4 B7 56     STA    $56
09C6 81        RTS                       return atodtemp;
                                          }

                                         /**************************************************************************/

                                         void fixcompare (void)  /* sets-up the timer compare for the next interrupt */
                                           {
09C7 B6 18     LDA    $18                 q.b.hi =tcnthi;
09C9 B7 66     STA    $66
09CB B6 19     LDA    $19                   q.b.lo = tcntlo;
09CD B7 67     STA    $67
09CF AB 4C     ADD    #$4C                   q.l +=7500;  /* ((4mhz xtal/2)/4) = counter period = 2us.*7500 = 15ms. */
09D1 B7 67     STA    $67
09D3 B6 66     LDA    $66
09D5 A9 1D     ADC    #$1D
09D7 B7 66     STA    $66
09D9 B7 16     STA    $16                   ocmphi1 = q.b.hi;
09DB B6 13     LDA    $13                  areg=tsr;  /* dummy read */
09DD B6 67     LDA    $67                 ocmplo1 = q.b.lo;
09DF B7 17     STA    $17
09E1 81        RTS                         }

                                         /**************************************************************************/

                                         void TIMERCMP (void)    /* timer service module */
1FF6 09 E2                               {
09E2 33 02     COM    $02                  portc =~ portc;    /* service the lcd by inverting the ports */
09E4 33 01     COM    $01                  portb =~ portb;
09E6 33 00     COM    $00                  porta =~ porta;
09E8 AD DD     BSR    $09C7              fixcompare();
09EA 80        RTI                       }

                                         /**************************************************************************/

                                         void adzero(void)  /* called by initio() to save initial xdcr's zero
                                                                 pressure offset voltage output */
                                         {
09EB 3F 64     CLR    $64                for ( j=0; j<20; ++j)  /* give the sensor time to "warm-up" and the
09ED 3F 63     CLR    $63
09EF B6 64     LDA    $64
09F1 A0 14     SUB    #$14
09F3 B6 63     LDA    $63
09F5 A2 00     SBC    #$00
09F7 24 0B     BCC    $0A04
                                                                 power supply time to settle down */
                                         {
09F9 CD 09 68  JSR    $0968                delay();
                                         }
09FC 3C 64     INC    $64
09FE 26 02     BNE    $0A02
0A00 3C 63     INC    $63
0A02 20 EB     BRA    $09EF
0A04 CD 09 7F  JSR    $097F                 xdcr_offset =  read_a2d();
```

```
0A07 3F 5C      CLR     $5C
0A09 B7 5D      STA     $5D
0A0B 81         RTS                     }

                                          /****************************************************************************/

                                          void initio (void)     /*  setup the I/O */
                                            {
0A0C A6 20      LDA     #$20                adstat = 0x20; /* power-up the A/D */
0A0E B7 09      STA     $09
0A10 3F 02      CLR     $02                 porta = portb = portc = 0;
0A12 3F 01      CLR     $01
0A14 3F 00      CLR     $00
0A16 A6 FF      LDA     #$FF                ddra = ddrb = ddrc = 0xff;
0A18 B7 06      STA     $06
0A1A B7 05      STA     $05
0A1C B7 04      STA     $04
0A1E B6 13      LDA     $13                 areg=tsr;  /* dummy read */
0A20 3F 1E      CLR     $1E                 ocmphi1 = ocmphi2 = 0;
0A22 3F 16      CLR     $16
0A24 B6 1F      LDA     $1F                 areg = ocmplo2; /* clear out output compare 2 if it happens to be set */
0A26 AD 9F      BSR     $09C7               fixcompare(); /* set-up for the first timer interrupt */
0A28 A6 40      LDA     #$40                tcr = 0x40;
0A2A B7 12      STA     $12
0A2C 9A         CLI                         CLI;  /* let the interrupts begin !  */
                                          /* write CAL to the display */
0A2D A6 CC      LDA     #$CC                portc = 0xcc; /* C */
0A2F B7 02      STA     $02
0A31 A6 BE      LDA     #$BE                portb = 0xbe; /* A */
0A33 B7 01      STA     $01
0A35 A6 C4      LDA     #$C4                porta = 0xc4; /* L */
0A37 B7 00      STA     $00
0A39 CD 09 21   JSR     $0921               sensor_type(); /* get the model of the sensor based on J1..J3 */
0A3C AD AD      BSR     $09EB               adzero();  /* auto zero */
0A3E 81         RTS                        }

                                          /****************************************************************************/

                                          void cvt_bin_dec(unsigned long arg)

                                          /* First converts the argument to a five digit decimal value. The msd is in
                                          the lowest address. Then leading zero suppress the value and write it to the
                                          display ports.
                                             The argument value is 0..65535 decimal. */

009D                                    {
0A3F BF 9D      STX     $9D
0A41 B7 9E      STA     $9E
009F                                    char i;
00A0                                    unsigned long l;
0A43 3F 9F      CLR     $9F               for ( i=0; i < 5; ++i )
0A45 B6 9F      LDA     $9F
0A47 A1 05      CMP     #$05
0A49 24 07      BCC     $0A52
                                              {
0A4B 97         TAX                           digit[i] = 0x0;  /* put blanks in all digit positions */
0A4C 6F 50      CLR     $50,X
                                              }
0A4E 3C 9F      INC     $9F
0A50 20 F3      BRA     $0A45
0A52 3F 9F      CLR     $9F                    for ( i=0; i < 4; ++i )
0A54 B6 9F      LDA     $9F
0A56 A1 04      CMP     #$04
0A58 24 7A      BCC     $0AD4
                                                   {
0A5A 97         TAX                                  if ( arg  >= dectable [i] )
0A5B 58         LSLX
0A5C D6 08 0B   LDA     $080B,X
0A5F B0 9E      SUB     $9E
0A61 B7 58      STA     $58
0A63 B6 9D      LDA     $9D
0A65 A8 80      EOR     #$80
0A67 B7 57      STA     $57
0A69 D6 08 0A   LDA     $080A,X
0A6C A8 80      EOR     #$80
0A6E B2 57      SBC     $57
```

```
0A70 BA 58     ORA    $58
0A72 22 5C     BHI    $0AD0
                                               {
0A74 BE 9F     LDX    $9F                       l = dectable[i];
0A76 58        LSLX
0A77 D6 08 0A  LDA    $080A,X
0A7A B7 A0     STA    $A0
0A7C D6 08 0B  LDA    $080B,X
0A7F B7 A1     STA    $A1
0A81 B6 9E     LDA    $9E                       digit[i] = arg / l;
0A83 B7 58     STA    $58
0A85 B6 9D     LDA    $9D
0A87 B7 57     STA    $57
0A89 B6 A0     LDA    $A0
0A8B B7 9A     STA    $9A
0A8D B6 A1     LDA    $A1
0A8F B7 9B     STA    $9B
0A91 CD 0B F1  JSR    $0BF1
0A94 CD 0C 22  JSR    $0C22
0A97 BF 57     STX    $57
0A99 B7 58     STA    $58
0A9B BE 9F     LDX    $9F
0A9D E7 50     STA    $50,X
0A9F BE 9F     LDX    $9F                       arg = arg-(digit[i] * l);
0AA1 E6 50     LDA    $50,X
0AA3 3F 57     CLR    $57
0AA5 B7 58     STA    $58
0AA7 B6 A0     LDA    $A0
0AA9 B7 9A     STA    $9A
0AAB B6 A1     LDA    $A1
0AAD B7 9B     STA    $9B
0AAF CD 0B D2  JSR    $0BD2
0AB2 BF 57     STX    $57
0AB4 B7 58     STA    $58
0AB6 33 57     COM    $57
0AB8 30 58     NEG    $58
0ABA 26 02     BNE    $0ABE
0ABC 3C 57     INC    $57
0ABE B6 58     LDA    $58
0AC0 BB 9E     ADD    $9E
0AC2 B7 58     STA    $58
0AC4 B6 57     LDA    $57
0AC6 B9 9D     ADC    $9D
0AC8 B7 57     STA    $57
0ACA B7 9D     STA    $9D
0ACC B6 58     LDA    $58
0ACE B7 9E     STA    $9E
                                                    }
                                               }
0AD0 3C 9F     INC    $9F
0AD2 20 80     BRA    $0A54
0AD4 B6 9E     LDA    $9E           digit[i] = arg;
0AD6 B7 58     STA    $58
0AD8 B6 9D     LDA    $9D
0ADA B7 57     STA    $57
0ADC BE 9F     LDX    $9F
0ADE B6 58     LDA    $58
0AE0 E7 50     STA    $50,X


                                   /* now zero suppress and send the lcd pattern to the display */
0AE2 9B        SEI                  SEI;
0AE3 3D 52     TST    $52           if ( digit[2] == 0 )    /* leading zero suppression */
0AE5 26 04     BNE    $0AEB
0AE7 3F 02     CLR    $02             portc = 0;
0AE9 20 07     BRA    $0AF2             else
0AEB BE 52     LDX    $52                portc = ( lcdtab[digit[2]] );     /* 100's digit */
0AED D6 08 00  LDA    $0800,X
0AF0 B7 02     STA    $02
0AF2 3D 52     TST    $52                 if ( digit[2] == 0 && digit[3] == 0 )
0AF4 26 08     BNE    $0AFE
0AF6 3D 53     TST    $53
0AF8 26 04     BNE    $0AFE
0AFA 3F 01     CLR    $01                   portb=0;
0AFC 20 07     BRA    $0B05                   else
0AFE BE 53     LDX    $53                       portb = ( lcdtab[digit[3]] );    /* 10's digit */
0B00 D6 08 00  LDA    $0800,X
```

```
0B03 B7 01    STA   $01
0B05 BE 54    LDX   $54                    porta = ( lcdtab[digit[4]] );   /* 1's digit */
0B07 D6 08 00 LDA   $0800,X
0B0A B7 00    STA   $00
                                  /* place the decimal point only if the sensor is 15 psi or 7.5 psi */
0B0C B6 60    LDA   $60             if ( sensor_index < 3 )
0B0E A8 80    EOR   #$80
0B10 A1 83    CMP   #$83
0B12 24 08    BCC   $0B1C
0B14 BE 54    LDX   $54             porta = ( lcdtab[digit[4]]+1 ); /* add the decimal point to the lsd */
0B16 D6 08 00 LDA   $0800,X
0B19 4C       INCA
0B1A B7 00    STA   $00
0B1C 3D 60    TST   $60              if(sensor_index ==0) /* special case */
0B1E 26 0F    BNE   $0B2F
                                          {
0B20 BE 54    LDX   $54                 porta = ( lcdtab[digit[4]] ); /* get rid of the decimal at lsd */
0B22 D6 08 00 LDA   $0800,X
0B25 B7 00    STA   $00
0B27 BE 53    LDX   $53                 portb = ( lcdtab[digit[3]]+1 ); /* decimal point at middle digit */
0B29 D6 08 00 LDA   $0800,X
0B2C 4C       INCA
0B2D B7 01    STA   $01
                                          }
0B2F 9A       CLI             CLI;
0B30 CD 09 68 JSR   $0968                delay();
0B33 81       RTS             }

                                /*****************************************************************/

                                void display_psi(void)
                                /*
                                   At power-up it is assumed that the pressure or vacuum port of
                                   the sensor is open to atmosphere. The code in initio() delays
                                   for the sensor and power supply to stabilize. One hundred A/D
                                   conversions are averaged. That result is called xdcr_offset.
                                   This routine calls the A/D routine which performs one hundred
                                   conversions, divides the result by 100 and returns the value.
                                   If the value returned is less than or equal to the xdcr_offset,
                                   the value of xdcr_offset is substituted. If the value returned
                                   is greater than xdcr_offset, xdcr_offset is subtracted from the
                                   returned value.
                                */

                                {
                                 while(1)
                                   {
0B34 CD 09 7F JSR   $097F          atodtemp = read_a2d();  /* atodtemp = raw a/d ( 0..255 ) */
0B37 3F 55    CLR   $55
0B39 B7 56    STA   $56
0B3B B0 5D    SUB   $5D              if ( atodtemp <= xdcr_offset )
0B3D B7 58    STA   $58
0B3F B6 5C    LDA   $5C
0B41 A8 80    EOR   #$80
0B43 B7 57    STA   $57
0B45 B6 55    LDA   $55
0B47 A8 80    EOR   #$80
0B49 B2 57    SBC   $57
0B4B BA 58    ORA   $58
0B4D 22 08    BHI   $0B57
0B4F B6 5C    LDA   $5C                atodtemp = xdcr_offset;
0B51 B7 55    STA   $55
0B53 B6 5D    LDA   $5D
0B55 B7 56    STA   $56
0B57 B6 56    LDA   $56              atodtemp -=  xdcr_offset; /* remove the offset */
0B59 B0 5D    SUB   $5D
0B5B B7 56    STA   $56
0B5D B6 55    LDA   $55
0B5F B2 5C    SBC   $5C
0B61 B7 55    STA   $55
0B63 CD 09 4C JSR   $094C               sensor_slope();  /* establish the slope constant for this output */
0B66 B6 56    LDA   $56              atodtemp *= sensor_model;
0B68 B7 58    STA   $58
0B6A B6 55    LDA   $55
0B6C B7 57    STA   $57
0B6E B6 5E    LDA   $5E
```

```
0B70 B7 9A     STA    $9A
0B72 B6 5F     LDA    $5F
0B74 B7 9B     STA    $9B
0B76 CD 0B D2  JSR    $0BD2
0B79 BF 55     STX    $55
0B7B B7 56     STA    $56
0B7D 3F 89     CLR    $89                 MULTP[0] = MULCAN[0] = 0;
0B7F 3F 88     CLR    $88
0B81 3F 81     CLR    $81
0B83 3F 80     CLR    $80
0B85 9F        TXA                         MULTP[1] = atodtemp;
0B86 B7 82     STA    $82
0B88 B6 56     LDA    $56
0B8A B7 83     STA    $83
0B8C B6 59     LDA    $59                   MULCAN[1] = slope;
0B8E B7 8A     STA    $8A
0B90 B6 5A     LDA    $5A
0B92 B7 8B     STA    $8B
0B94 CD 08 70  JSR    $0870                  mul32();   /* analog value * slope based on J1 through J3 */
0B97 3F 90     CLR    $90                     DVSOR[0] = 1;   /*  now divide by 100000 */
0B99 A6 01     LDA    #$01
0B9B B7 91     STA    $91
0B9D A6 86     LDA    #$86                     DVSOR[1] = 0x86a0;
0B9F B7 92     STA    $92
0BA1 A6 A0     LDA    #$A0
0BA3 B7 93     STA    $93
0BA5 B6 88     LDA    $88                       DVDND[0] = MULCAN[0];
0BA7 B7 8C     STA    $8C
0BA9 B6 89     LDA    $89
0BAB B7 8D     STA    $8D
0BAD B6 8A     LDA    $8A                        DVDND[1] = MULCAN[1];
0BAF B7 8E     STA    $8E
0BB1 B6 8B     LDA    $8B
0BB3 B7 8F     STA    $8F
0BB5 CD 08 B1  JSR    $08B1                       div32();
0BB8 B6 96     LDA    $96                        atodtemp = QUO[1]; /* convert to psi */
0BBA B7 55     STA    $55
0BBC B6 97     LDA    $97
0BBE B7 56     STA    $56
0BC0 BE 55     LDX    $55             cvt_bin_dec( atodtemp ); /* convert to decimal and display */
0BC2 CD 0A 3F  JSR    $0A3F
0BC5 CC 0B 34  JMP    $0B34          }
0BC8 81        RTS                }

                                    /*************************************************************************/

                                    void main()
                                    {
0BC9 CD 0A 0C  JSR    $0A0C       initio(); /* set-up the processor's i/o */
0BCC CD 0B 34  JSR    $0B34        display_psi();
0BCF 20 FE     BRA    $0BCF         while(1);   /* should never get back to here */
0BD1 81        RTS                }
0BD2 BE 58     LDX    $58
0BD4 B6 9B     LDA    $9B
0BD6 42        MUL
0BD7 B7 A4     STA    $A4
0BD9 BF A5     STX    $A5
0BDB BE 57     LDX    $57
0BDD B6 9B     LDA    $9B
0BDF 42        MUL
0BE0 BB A5     ADD    $A5
0BE2 B7 A5     STA    $A5
0BE4 BE 58     LDX    $58
0BE6 B6 9A     LDA    $9A
0BE8 42        MUL
0BE9 BB A5     ADD    $A5
0BEB B7 A5     STA    $A5
0BED 97        TAX
0BEE B6 A4     LDA    $A4
0BF0 81        RTS
0BF1 3F A4     CLR    $A4
0BF3 5F        CLRX
0BF4 3F A2     CLR    $A2
0BF6 3F A3     CLR    $A3
0BF8 5C        INCX
0BF9 38 58     LSL    $58
```

```
0BFB 39 57      ROL     $57
0BFD 39 A2      ROL     $A2
0BFF 39 A3      ROL     $A3
0C01 B6 A2      LDA     $A2
0C03 B0 9B      SUB     $9B
0C05 B7 A2      STA     $A2
0C07 B6 A3      LDA     $A3
0C09 B2 9A      SBC     $9A
0C0B B7 A3      STA     $A3
0C0D 24 0D      BCC     $0C1C
0C0F B6 9B      LDA     $9B
0C11 BB A2      ADD     $A2
0C13 B7 A2      STA     $A2
0C15 B6 9A      LDA     $9A
0C17 B9 A3      ADC     $A3
0C19 B7 A3      STA     $A3
0C1B 99         SEC
0C1C 59         ROLX
0C1D 39 A4      ROL     $A4
0C1F 24 D8      BCC     $0BF9
0C21 81         RTS
0C22 53         COMX
0C23 9F         TXA
0C24 BE A4      LDX     $A4
0C26 53         COMX
0C27 81         RTS
1FFE 0B C9

SYMBOL TABLE

LABEL        VALUE  LABEL        VALUE  LABEL        VALUE  LABEL        VALUE

ADDEND       006C | AUGEND       0070 | CNT          0098 | DIFF         007C
DIV151       08BF | DIV153       08CE | DIV163       08D0 | DIV165       0905
DIV167       0906 | DVDND        008C | DVSOR        0090 | IRQ          091D
MINUE        0074 | MNEXT        0882 | MTEMP        0084 | MULCAN       0088
MULTP        0080 | QUO          0094 | ROTATE       089C | SCI          0920
SUBTRA       0078 | SUM          0068 | TIMERCAP     091E | TIMERCMP     09E2
TIMEROV      091F | __LDIV       0BF1 | __LongIX     009A | __MAIN       0BC9
__MUL        0000 | __MUL16x16   0BD2 | __RDIV       0C22 | __RESET      1FFE
__STARTUP    0000 | __STOP       0000 | __SWI        091C | __WAIT       0000
__longAC     0057 | adcnt        005B | add32        083C | addata       0008
adstat       0009 | adzero       09EB | aregnthi     001A | aregntlo     001B
arg          009D | atodtemp     0055 | b            0000 | bothbytes    0002
cvt_bin_dec  0A3F | ddra         0004 | ddrb         0005 | ddrc         0006
dectable     080A | delay        0968 | digit        0050 | display_psi  0B34
div32        08B1 | eeclk        0007 | fixcompare   09C7 | hi           0000
i            0061 | icaphi1      0014 | icaphi2      001C | icaplo1      0015
icaplo2      001D | initio       0A0C | isboth       0002 | j            0063
k            0065 | l            0000 | lcdtab       0800 | lo           0001
main         0BC9 | misc         000C | mul32        0870 | ocmphi1      0016
ocmphi2      001E | ocmplo1      0017 | ocmplo2      001F | plma         000A
plmb         000B | porta        0000 | portb        0001 | portc        0002
portd        0003 | q            0066 | read_a2d     097F | scibaud      000D
scicntl1     000E | scicntl2     000F | scidata      0011 | scistat      0010
sensor_index 0060 | sensor_model 005E | sensor_slope 094C | sensor_type  0921
slope        0059 | slope_const  081C | sub32        0856 | tcnthi       0018
tcntlo       0019 | tcr          0012 | tsr          0013 | type         0812
xdcr_offset  005C |

MEMORY USAGE MAP ('X' = Used, '-' = Unused)

0800 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0840 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0880 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
08C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0900 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0940 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0980 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
09C0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0A00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0A80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0AC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
```

```
0B00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B40 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0B80 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX
0BC0 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX

0C00 : XXXXXXXXXXXXXXXX XXXXXXXXXXXXXXXX XXXXXXXX-------- ----------------
0C40 : ---------------- ---------------- ---------------- ----------------
0C80 : ---------------- ---------------- ---------------- ----------------
0CC0 : ---------------- ---------------- ---------------- ----------------

1E00 : ---------------- ---------------- ---------------- ----------------
1E40 : ---------------- ---------------- ---------------- ----------------
1E80 : ---------------- ---------------- ---------------- ----------------
1EC0 : ---------------- ---------------- ---------------- --------------X-

1F00 : ---------------- ---------------- ---------------- ----------------
1F40 : ---------------- ---------------- ---------------- ----------------
1F80 : ---------------- ---------------- ---------------- ----------------
1FC0 : ---------------- ---------------- ---------------- --XXXXXXXXXXXXXX

All other memory blocks unused.

Errors             :    0
Warnings           :    0
```

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1316

Frequency Output Conversion for MPX2000 Series Pressure Sensors

Prepared by: Jeff Baum
Discrete Applications Engineering

INTRODUCTION

Typically, a semiconductor pressure transducer converts applied pressure to a "low-level" voltage signal. Current technology enables this sensor output to be temperature compensated and amplified to higher voltage levels on a single silicon integrated circuit (IC). While on-chip temperature compensation and signal conditioning certainly provide a significant amount of added value to the basic sensing device, one must also consider how this final output will be used and/or interfaced for further processing. In most sensing systems, the sensor signal will be input to additional analog circuitry, control logic, or a microcontroller unit (MCU).

MCU-based systems have become extremely cost effective. The level of intelligence which can be obtained for only a couple of dollars, or less, has made relatively simple 8-bit microcontrollers the partner of choice for semiconductor pressure transducers. In order for the sensor to communicate its pressure-dependent voltage signal to the microprocessor, the MCU must have an analog-to-digital converter (A/D) as an on-chip resource or an additional IC packaged A/D. In the latter case, the A/D must have a communications interface that is compatible with one of the MCU's communications protocols. MCU's are adept at detecting logic-level transitions that occur at input pins designated for screening such events. As an alternative to the conventional A/D sensor/MCU interface, one can measure either a period (frequency) or pulse width of an incoming square or rectangular wave signal. Common MCU timer subsystem clock frequencies permit temporal measurements with resolution of hundreds of nanoseconds. Thus, one is capable of accurately measuring the the frequency output of a device that is interfaced to such a timer channel. If sensors can provide a frequency modulated signal that is linearly proportional to the applied pressure being measured, then an accurate, inexpensive (no A/D) MCU-based sensor system is a viable solution to many challenging sensing applications. Besides the inherent cost savings of such a system, this design concept offers additional benefits to remote sensing applications and sensing in electrically noisy environments.

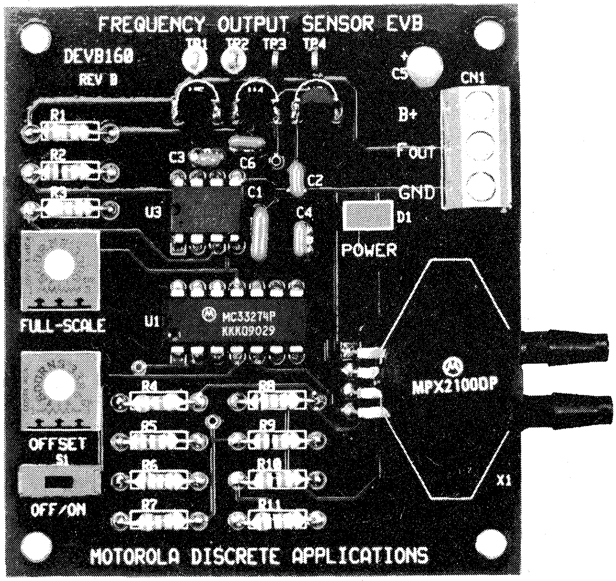


Figure 1. DEVB160 Frequency Output Sensor EVB

The following sections will detail the design issues involved in such a system architecture, and will provide an example circuit which has been developed as an evaluation tool for frequency output pressure sensor applications.

DESIGN CONSIDERATIONS

Signal Conditioning

Motorola's MPX2000 Series sensors are temperature compensated and calibrated – i.e. – offset and full-scale span are precision trimmed – pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 700 kPa (100 psi). Although the specifications in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. At the absolute maximum supply voltage specified, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to a slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level.

Many different "instrumentation-type" amplifier circuits can satisfy the signal conditioning needs of these devices. Depending on the precision and temperature performance demanded by a given application, one can design an amplifier circuit using a wide variety of operational amplifier (op amp) IC packages with external resistors of various tolerances, or a precision-trimmed integrated instrumentation amplifier IC. In any case, the usual goal is to have a single-ended supply, "rail-to-rail" output (i.e. use as much of the range from ground to the supply voltage as possible, without saturating the op amps). In addition, one may need the flexibility of performing zero-pressure offset adjust and full-scale pressure calibration. The circuitry or device used to accomplish the voltage-to-frequency conversion will determine if, how, and where calibration adjustments are needed. See Evaluation Board Circuit Description section for details.

Voltage-to-Frequency Conversion

Since most semiconductor pressure sensors provide a voltage output, one must have a means of converting this voltage signal to a frequency that is proportional to the sensor output voltage. Assuming the analog voltage output of the sensor is proportional to the applied pressure, the resultant frequency will be linearly related to the pressure being measured. There are many different timing circuits that can perform voltage-to-frequency conversion. Most of the "simple" (relatively low number of components) circuits do not provide the accuracy or the stability needed for reliably encoding a signal quantity. Fortunately, many voltage-to-frequency (V/F) converter IC's are commercially available that will satisfy this function.

Switching Time Reduction

One limitation of some V/F converters is the less than adequate switching transition times that effect the pulse or square-wave frequency signal. The required switching speed will be determined by the hardware used to detect the switching edges. The Motorola family of microcontrollers have input-capture functions that employ "Schmitt trigger-like" inputs with hysteresis on the dedicated input pins. In this case, slow rise and fall times will not cause an input capture pin to be in an indeterminate state during a transition. Thus, CMOS logic instability and significant timing errors will be prevented during slow transitions. Since the sensor's frequency output may be interfaced to other logic configurations, a designer's main concern is to comply with a worst-case timing scenario. For high-speed CMOS logic, the maximum rise and fall times are typically specified at several hundreds of nanoseconds. Thus, it is wise to speed up the switching edges at the output of the V/F converter. A single small-signal FET and a resistor are all that is required to obtain switching times below 100 ns.

APPLICATIONS

Besides eliminating the need for an A/D converter, a frequency output is conducive to applications in which the sensor output must be transmitted over long distances, or when the presence of noise in the sensor environment is likely to corrupt an otherwise healthy signal. For sensor outputs encoded as a voltage, induced noise from electromagnetic fields will contaminate the true voltage signal. A frequency signal has greater immunity to these noise sources and can be effectively filtered in proximity to the MCU input. In other words, the frequency measured at the MCU will be the frequency transmitted at the output of a sensor located remotely. Since high-frequency noise and 50-60 Hz line noise are the two most prominent sources for contamination of instrumentation signals, a frequency signal with a range in the low end of the kHz spectrum is capable of being well filtered prior to being examined at the MCU.

Table 1. Specifications

Characteristics	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B^+	10		30	Volts
Full Scale Pressure	P_{FS}				
- MPX2010				10	kPa
- MPX2050				50	kPa
- MPX2100				100	kPa
- MPX2200				200	kPa
- MPX2700				700	kPa
Full Scale Output	f_{FS}		10		kHz
Zero Pressure Offset	f_{OFF}		1		kHz
Sensitivity	S_{AOUT}		$9/P_{FS}$		kHz/kPa
Quiescent Current	I_{CC}		55		mA

EVALUATION BOARD

The following sections present an example of the signal conditioning, including frequency conversion, that was developed as an evaluation tool for the Motorola MPX2000 series pressure sensors. A summary of the information required to use evaluation board number DEVB160 is presented as follows.

Description

The evaluation board shown in Figure 1 is designed to transduce pressure, vacuum or differential pressure into a single-ended, ground referenced voltage that is then input to a voltage-to-frequency converter. It nominally provides a 1 kHz output at zero pressure and 10 kHz at full scale pressure. Zero pressure calibration is made with a trimpot that is located on the lower half of the left side of the board, while the full scale output can be calibrated via another trimpot just above the offset adjust. The board comes with an MPX2100DP sensor installed, but will accommodate any MPX2000 series sensor. One additional modification that may be required is that the gain of the circuit must be increased slightly when using an MPX2010 sensor. Specifically, the resistor R5 must be increased from 7.5 kΩ to 12 kΩ.

Circuit Description

The following pin description and circuit operation corresponds to the schematic shown in Figure 2.

Pin-by-Pin Description

B^+:

Input power is supplied at the B^+ terminal of connector CN1. Minimum input voltage is 10 V and maximum is 30 V.

F_{out}:

A logic-level (5 V) frequency output is supplied at the OUT terminal (CN1). The nominal signal it provides is 1 kHz at zero pressure and 10 kHz at full scale pressure. Zero pressure frequency is adjustable and set with R12. Full-scale frequency is calibrated via R13. This output is designed to be directly connected to a microcontroller timer system input-capture channel.

GND:

The ground terminal on connector CN1 is intended for use as the power supply return and signal common. Test point terminal TP3 is also connected to ground, for measurement convenience.

TP1:

Test point 1 is connected to the final frequency output, F_{out}.

TP2:

Test point 2 is connected to the +5 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

TP3:

Test point 3 is the additional ground point mentioned above in the GND description.

TP4:

Test point 4 is connected to the +8 V regulator output. It can be used to verify that this supply voltage is within its tolerance.

P1, P2:

Pressure and Vacuum ports P1 & P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top (marked side of package) and vacuum port P2, if present, is on the bottom. When the board is set up with a dual ported sensor (DP suffix), pressure applied to P1, vacuum applied to P2 or a differential pressure applied between the two all produce the same output voltage per kPa of input. Neither port is labeled. Absolute maximum differential pressure is 700 kPa.

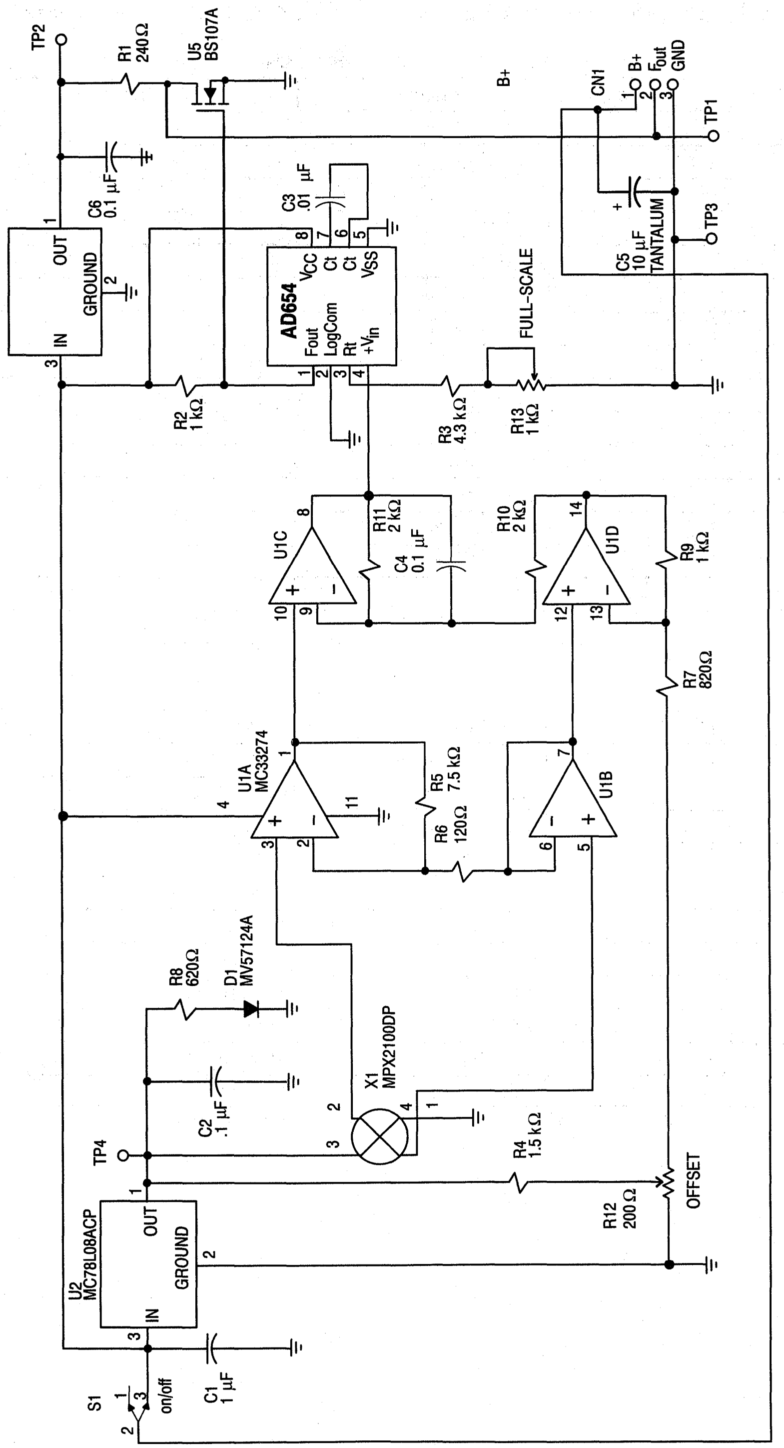


Figure 2. DEVB160 Frequency Output Sensor Evaluation Board

The following is a table of the components that are assembled on the DEVB160 Frequency Output Sensor Evaluation Board.

Table 2. Parts List

Designators	Quantity	Description	Manufacturer	Part Number
C1	1	1 µF Capacitor		
C2	1	.1 µF Capacitor		
C3	1	.01 µF Capacitor		
C4	1	.1 µF Capacitor		
C5	1	10 µF Cap+		tantalum
C6	1	.1 µF Capacitor		
CN1	1	.15LS 3 Term	PHX Contact	1727023
D1	1	RED LED	Quality Tech.	MV57124A
R1	1	240 Ω resistor		
R2, R9	2	1 kΩ resistor		
R3	1	4.3 kΩ resistor		
R4	1	1.5 kΩ resistor		
R5	1	7.5 kΩ resistor		
R6	1	120 Ω resistor		
R7	1	820 Ω resistor		
R8	1	620 Ω resistor		
R10, R11	2	2 kΩ resistor		
R12	1	200 Ω Trimpot	Bourns	3386P-1-201
R13	1	1 kΩ Trimpot	Bourns	3386P-1-102
S1	1	SPDT miniature switch	NKK	SS-12SDP2
TP1	1	YELLOW Testpoint	Control Design	TP-104-01-04
TP2	1	BLUE Testpoint	Control Design	TP-104-01-06
TP3	1	BLACK Testpoint	Control Design	TP-104-01-00
TP4	1	GREEN Testpoint	Control Design	TP-104-01-05
U1	1	Quad Op Amp	Motorola	MC33274
U2	1	8 V Regulator	Motorola	MC78L08ACP
U3	1	AD654	Analog Devices	AD654
U4	1	5 V Regulator	Motorola	MC78L05ACP
U5	1	Small-Signal FET	Motorola	BS107A
X1	1	Pressure Sensor	Motorola	MPX2100DP

NOTE: All resistors are 1/4 watt, 5% tolerance values. All capacitors are 50 V rated, ±20% tolerance values.

Circuit Operation

The voltage signal conditioning portion of this circuit is a variation on the classic instrumentation amplifier configuration. It is capable of providing high differential gain and good common-mode rejection with very high input impedance; however, it provides a more user friendly method of performing the offset/bias point adjustment. It uses four op amps 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. Unwanted current flow through the sensor is prevented by buffer U1B. At zero pressure the differential voltage from pin 2 to pin 4 on the sensor has been precision trimmed to essentially zero volts. The common-mode voltage on each of these nodes is 4 V (one-half the sensor supply voltage). 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 R5 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. The offset voltage is produced by R4 and adjustment trimpot R12. R7's value is such that the total source impedance into pin 13 is approximately 1 k. The gain is approximately (R5/R6)(1 + R11/R10), which is 125 for the values shown in Figure 2. A gain of 125 is selected to provide a 4 V span for 32 mV of full-scale sensor output (at a sensor supply voltage of 8 V).

The resulting .5 V to 4.5 V output from U1C is then converted by the V/F converter to the nominal 1-10 kHz that has been specified. The AD654 V/F converter receives the amplified sensor output at pin 8 of op amp U1C. The full-scale frequency is determined by R3, R13 and C3 according to the following formula:

$$F_{out}\text{ (full-scale)} = \frac{V_{in}}{(10V)(R3 + R13)C3}$$

For best performance, R3 and R13 should be chosen to provide 1 mA of drive current at the full-scale voltage produced at pin 3 of the AD654 (U3). The input stage of the AD654 is an op-amp; thus, it will work to make the voltage at pin 3 of U3 equal to the voltage seen at pin 4 of U3 (pins 3 and 4 are the input terminals of the op amp). Since the amplified sensor output will be 4.5 V at full-scale pressure, R3 + R13 should be approximately equal to 4.5 kΩ to have optimal linearity performance. Once the total resistance from pin 3 of U3 to ground is set, the value of C3 will determine the full-scale frequency output of the V/F. Trimpot R13 should be sized (relative to R3 value) to provide the desired amount of full-scale frequency adjustment. The zero-pressure frequency is adjusted via the offset adjust provided for calibrating the offset voltage of the signal conditioned sensor output. For additional information on using this particular V/F converter, see the applications information provided in the Analog Devices Data Conversion Products Databook.

The frequency output has its edge transitions "sped" up by a small-signal FET inverter. This final output is directly compatible with microprocessor timer inputs, as well as any other high-speed CMOS logic. The amplifier portion of this circuit has been patented by Motorola Inc. and was introduced on evaluation board DEVB150A. Additional information pertaining to this circuit and the evaluation board DEVB150A is contained in Motorola Application Note AN1313.[1]

TEST/CALIBRATION PROCEDURE

1) Connect a +12 V supply between B+ and GND terminals on the connector CN1.
2) Connect a frequency counter or scope probe on the F_{out} terminal of CN1 or on TP1 with the test instrumentation ground clipped to TP3 or GND.
3) Turn the power switch, S1, to the on position. Power LED, D1, should be illuminated. Verify that the voltage at TP2 and TP4 (relative to GND or TP3) is 5 V and 8 V, respectively. While monitoring the frequency output by whichever means one has chosen, one should see a 50% duty cycle square wave signal.
4) Turn the wiper of the OFFSET adjust trimpot, R12, to the approximate center of the pot.
5) Apply 100 kPa to pressure port P1 of the MPX2100DP (topside port on marked side of the package) sensor, X1.
6) Adjust the FULL-SCALE trimpot, R13, until the output frequency is 10 kHz. If 10 kHz is not within the trim range of the full-scale adjustment trimpot, tweak the offset adjust trimpot to obtain 10 kHz (remember, the offset pot was at an arbitrary midrange setting as per step 4).
7) Apply zero pressure to the pressure port (i.e. both ports at ambient pressure, no differential pressure applied). Adjust OFFSET trimpot so frequency output is 1 kHz.
8) Verify that zero pressure and full-scale pressure (100 kPa) produce 1 and 10 kHz respectively, at F_{out} and/or TP1. A second iteration of adjustment on both full-scale and offset may be necessary to fine tune the 1 - 10 kHz range.

CONCLUSION

Transforming conventional analog voltage sensor outputs to frequency has great utility for a variety of applications. Sensing remotely and/or in noisy environments is particularly challenging for low-level (mV) voltage output sensors such as the MPX2000 Series pressure sensors. Converting the MPX2000 sensor output to frequency is relatively easy to accomplish, while providing the noise immunity required for accurate pressure sensing. The evaluation board presented is an excellent tool for either "stand-alone" evaluation of the MPX2000 Series pressure sensors or as a building block for system prototyping which can make use of DEVB160 as a "drop-in" frequency output sensor solution. The output of the DEVB160 circuit is ideally conditioned for interfacing to MCU timer inputs that can measure the sensor frequency signal.

REFERENCES

1. Schultz, Warren (Motorola, Inc.), "Sensor Building Block Evaluation Board", Motorola Application Note AN1313.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1318

Interfacing Semiconductor Pressure Sensors to Microcomputers

Prepared by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

The most popular silicon pressure sensors are piezoresistive bridges that produce a differential output voltage in response to pressure applied to a thin silicon diaphragm. Output voltage for these sensors is generally 25 to 50 mV full scale. Interface to microcomputers, therefore, generally involves gaining up the relatively small output voltage, performing a differential to single ended conversion, and scaling the analog signal into a range appropriate for analog to digital conversion. Alternately, the analog pressure signal can be converted to a frequency modulated 5 V waveform or 4-20 mA current loop, either of which is relatively immune to noise on long interconnect lines.

A variety of circuit techniques that address interface design are presented. Sensing amplifiers, analog to digital conversion, frequency modulation and 4-20 mA current loops are considered.

PRESSURE SENSOR BASICS

The essence of piezoresistive pressure sensors is the Wheatstone bridge shown in Figure 1. Bridge resistors RP1, RP2, RV1 and RV2 are arranged on a thin silicon diaphragm such that when pressure is applied RP1 and RP2 increase in value while RV1 and RV2 decrease a similar amount. Pressure on the diaphragm, therefore, unbalances the bridge and produces a differential output signal. One of the fundamental properties of this structure is that the differential output voltage is directly proportional to bias voltage B+. This characteristic implies that the accuracy of the pressure measurement depends directly on the tolerance of the bias supply. It also provides a convenient means for temperature compensation. The bridge resistors are silicon resistors that have positive temperature coefficients. Therefore, when they are placed in series with zero T_C temperature compensation resistors RC1 and RC2 the amount of voltage applied to the bridge increases with temperature. This increase in voltage produces an increase in electrical sensitivity which offsets and compensates for the negative temperature coefficient associated with piezoresistance.

Since RC1 and RC2 are approximately equal, the output voltage common mode is very nearly fixed at 1/2 B+. In a typical MPX2100 sensor, the bridge resistors are nominally 425 ohms; RC1 and RC2 are nominally 680 ohms. With these values and 10 V applied to B+, a delta R of 1.8 ohms at full scale pressure produces 40 mV of differential output voltage.

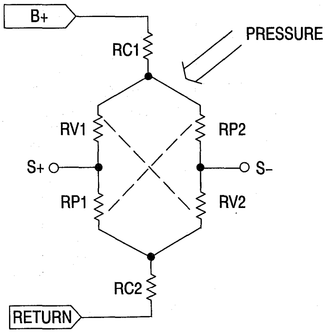
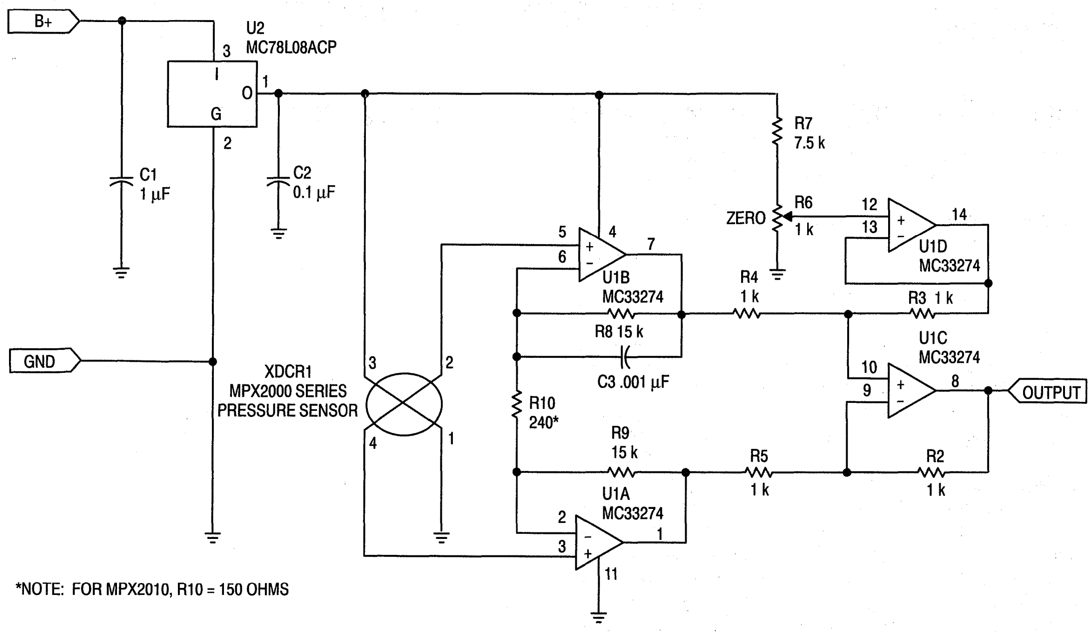


Figure 1. Sensor Equivalent Circuit

INSTRUMENTATION AMPLIFIER INTERFACES

Instrumentation amplifiers are by far the most common interface circuits that are used with pressure sensors. An example of an inexpensive instrumentation amplifier based interface circuit is shown in Figure 2. It uses an MC33274 quad operational amplifier and several resistors that are configured as a classic instrumentation amplifier with one important exception. In an instrumentation amplifier resistor R3 is normally returned to ground. Returning R3 to ground sets the output voltage for zero differential input to 0 V DC. For microcomputer interface a positive offset voltage on the order of 0.3 to 0.8 V is generally desired. Therefore, 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. Within the tolerances of the circuit, whatever voltage appears at the wiper of R6 will also appear as the zero pressure DC offset voltage at the output.

With R10 at 240 ohms, gain is set for a nominal value of 125. This provides a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to .75 V results in a 0.75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs. Over a zero to 50° C temperature range, combined accuracy for an MPX2000 series sensor and this interface is on the order of ± 10%.



*NOTE: FOR MPX2010, R10 = 150 OHMS

Figure 2. Instrumentation Amplifier Interface

For applications requiring greater precision a fully integrated instrument amplifier such as an LTC1100CN8 gives better results. In Figure 3 one of these amplifiers is used to provide a gain of 100, as well as differential to single ended conversion. Zero offset is provided by dividing down the precision reference to 0.5 V and buffering with U2B. This voltage is fed into the LTC1100CN8's ground pin which is equivalent to returning R3 to pin 14 of U1D in Figure 2. An additional non-inverting gain stage consisting of U2A, R1 and R2 is used to scale the sensor's full scale span to 4 V. R2 is also returned to the buffered .5 V to maintain the 0.5 V zero offset that was established in the instrumentation amplifier. Output voltage range is therefore 0.5 to 4.5 V.

Both of these instrumentation amplifier circuits do their intended job with a relatively straightforward tradeoff between cost and performance. The circuit of Figure 2 has the usual cumulative tolerance problem that is associated with instrumentation amplifiers that have discrete resistors, but it has a relatively low cost. The integrated instrumentation amplifier in Figure 3 solves this problem with precision trimmed film resistors and also provides superior input offset performance. Component cost, however, is significantly higher.

SENSOR SPECIFIC INTERFACE AMPLIFIER

A low cost interface designed specifically for pressure sensors improves upon the instrumentation amplifier in Figure 2. Shown in Figure 4, 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 positive 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 0 V. For example, let's say that the common mode voltage on these pins 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 (V_{OFFSET}) by U1C and U1D.

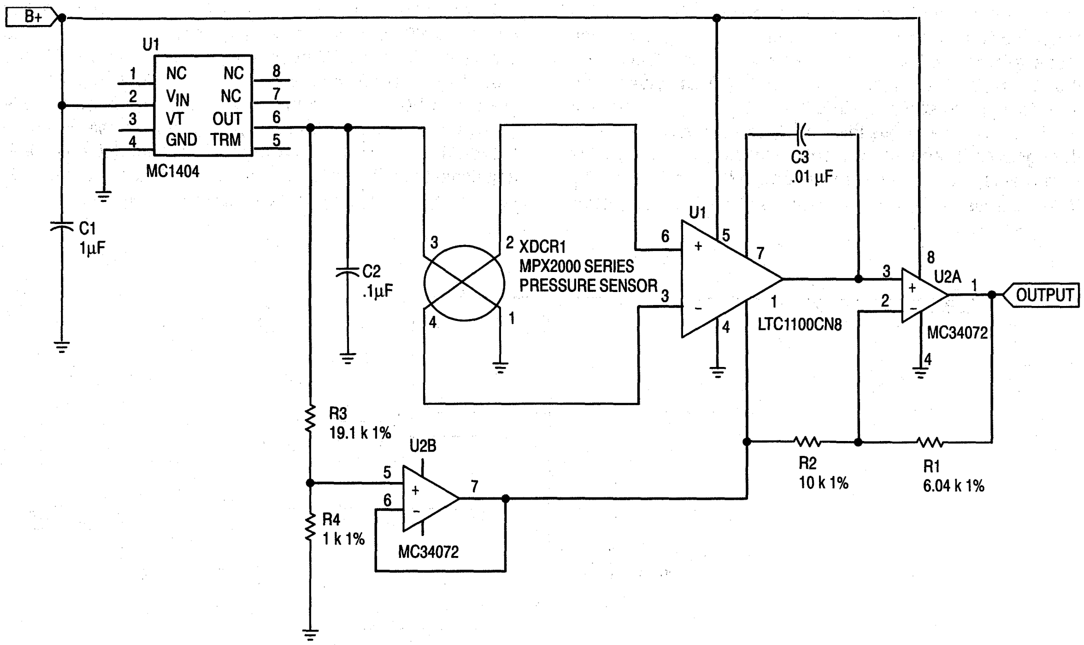
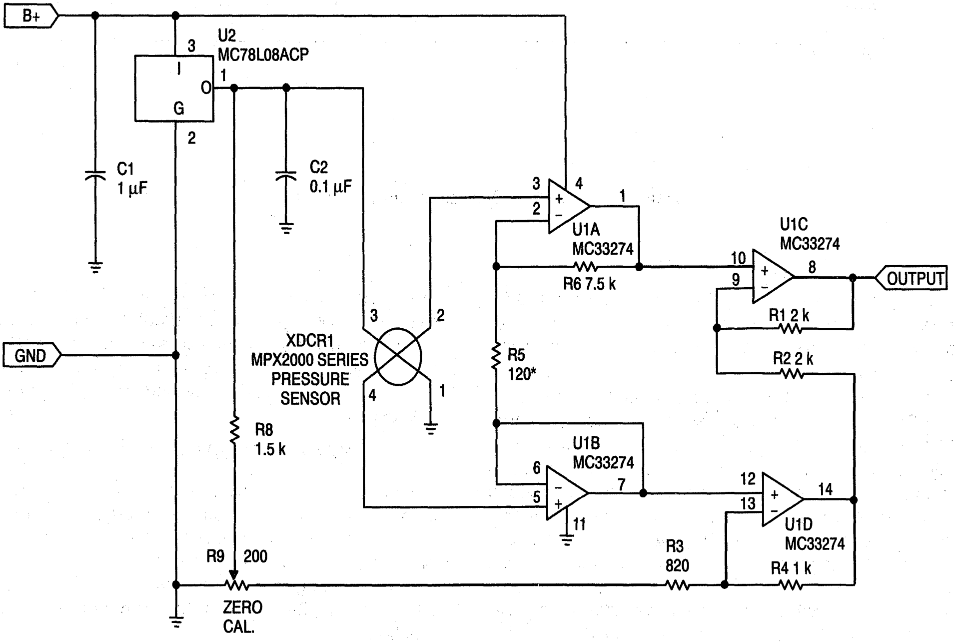


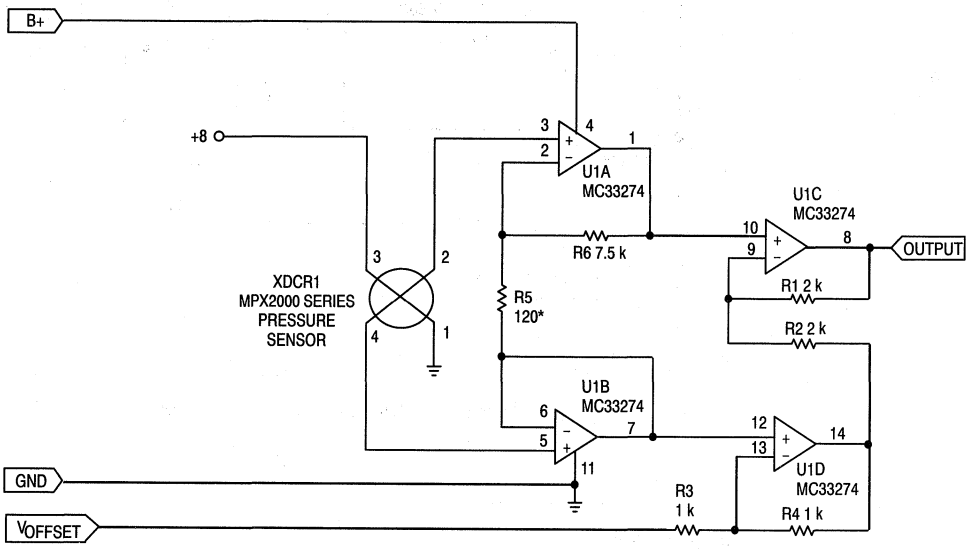
Figure 3. Precision Instrument Amplifier Interface



*NOTE: FOR MPX2010, R5 = 75 OHMS

Figure 4. Sensor Specific Interface Circuit

To see how the level translation works, let's look at the simplified schematic in Figure 5. Again assuming a common mode voltage of 4.0 V, the voltage applied to pin 12 of U1D is 4.0 V, implying that pin 13 is also at 4.0 V. This leaves 4.0 V – V_{OFFSET} across R3, which is 3.5 V if V_{OFFSET} is set to 0.5 V. Since no current flows into pin 13, the same current flows through both R3 and R4. With both of these resistors set to the same value, they have the same voltage drop, implying a 3.5 V drop across R4. Adding the voltages (0.5 + 3.5 + 3.5) yields 7.5 V at pin 14 of U1D. Similarly 4.0 V at pin 10 of U1C implies 4.0 V at pin 9, and the drop across R2 is 7.5 V – 4.0 V = 3.5 V. Again 3.5 V across R2 implies an equal drop across R1, and the voltage at pin 8 is 4.0 V – 3.5 V = .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 R4/R3 = R2/R1. In Figure 4, V_{OFFSET} is produced by R8 and adjustment pot R9. R3's value is adjusted such that the total source impedance into pin 13 is approximately 1 k.



*NOTE: FOR MPX2010, R5 = 75 OHMS

Figure 5. Simplified Sensor Specific Interface

Gain is approximately (R6/R5)(R1/R2+1), which is 125 for the values shown in Figure 4. A gain of 125 is selected to provide a 4 V span for the 32 mV of full scale sensor output that is obtained with 8 V B+.

The resulting 0.5 V to 4.5 V output from U1C is preferable to the 0.75 to 4.75 V range developed by the instrument amplifier configuration in Figure 2. It also uses fewer parts. This circuit does not have the instrument amplifier's propensity for oscillation and therefore does not require compensation capacitor C3 that is shown in Figure 2. It also requires one less resistor, which in addition to reducing component count also reduces accumulated tolerances due to resistor variations.

This circuit as well as the instrumentation amplifier interfaces in Figures 2 and 3 is designed for direct connection to a microcomputer A/D input. Using the MC68HC11 as an example, the interface circuit output is connected to any of the E ports, such as port E0 as shown in Figure 6. To get maximum accuracy from the A/D conversion, V_{REFH} is tied to 4.85 V and V_{REFL} is tied to 0.30 V by dividing down a 5 V reference with 1% resistors.

SINGLE SLOPE A/D CONVERTER

The 8 bit A/D converters that are commonly available on chip in microcomputers are usually well suited to pressure sensing applications. In applications that require more than 8 bits, the circuit in Figure 7 extends resolution to 11 bits with an external analog-to-digital converter. It also provides an interface to digital systems that do not have an internal A/D function.

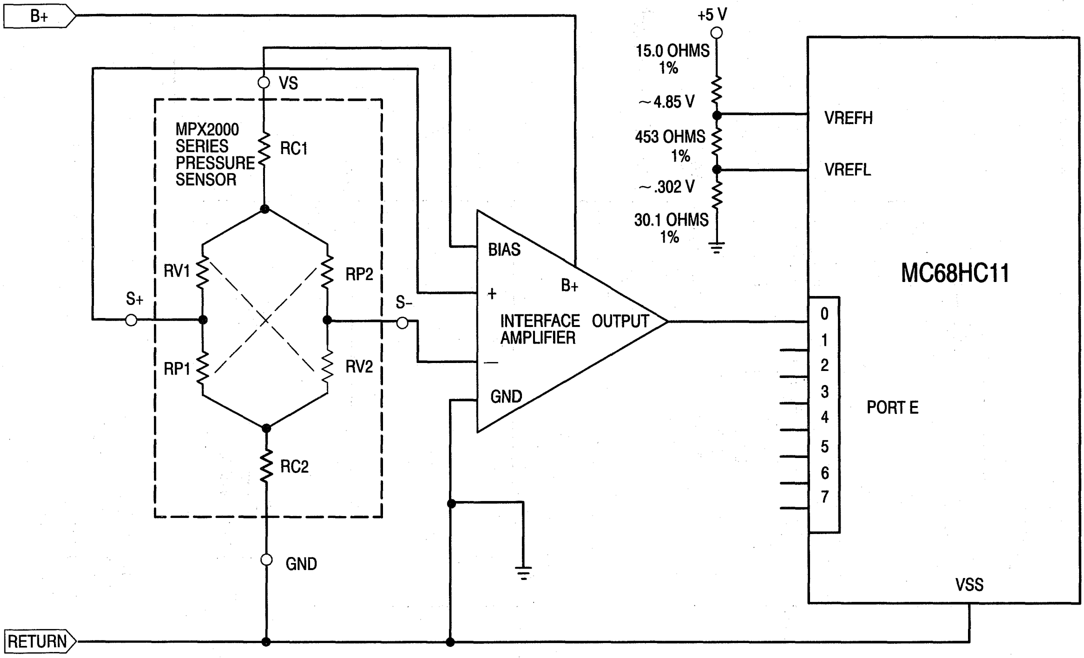


Figure 6. Application Example

Beginning with the ramp generator, a timing ramp is generated with current source U5 and capacitor C3. Initialization is provided by Q1 which sets the voltage on C3 at approximately ground. With the values shown, 470 µA flowing into 0.47 µF provide approximately a 5 msec ramp time from zero to 5 V. Assuming zero pressure on the sensor, inputs to both comparators U2A and U2B are at the same voltage. Therefore, as the ramp voltage sweeps from zero to 5 V, both PA0 and PA1 will go low at the same time when the ramp voltage exceeds the common mode voltage. The processor counts the number of clock cycles between the time that PA0 and PA1 go low, reading zero for zero pressure.

In this circuit, U4A and U4B form the front end of an instrument amplifier. They differentially amplify the sensor's output. The resulting amplified differential signal is then sampled and held in U1 and U3. The sample and hold function is performed in order to keep input data constant during the conversion process. The stabilized signals coming out of U1 and U3 feed a higher output voltage to U2A than U2B, assuming that pressure is applied to the sensor. Therefore, the ramp will trip U2B before U2A is tripped, creating a time difference between PA0 going low and PA1 going low. The processor reads the number of clock cycles between these two events. This number is then linearly scaled with software to represent the amplified output voltage, accomplishing the analog to digital conversion.

When the ramp reaches the reference voltage established by R9 and R10, comparator U2C is tripped, and a reset command is generated. To accomplish reset, Q1 is turned on with an output from PA7, and the sample and hold circuits are delatched with an output from PB1. Resolution is limited by clock frequency and ramp linearity. With the ramp generator shown in Figure 7 and a clock frequency of 2 MHz; resolution is 11 bits.

From a software point of view, the A/D conversion consists of latching the sample and hold, reading the value of the microcomputer's free running counter, turning off Q1, and waiting for the three comparator outputs to change state from logic 1 to logic 0. The analog input voltage is determined by counting, in 0.5 µsec steps, the number of clock cycles between PA0 and PA1 going low.

LONG DISTANCE INTERFACES

In applications where there is a significant distance between the sensor and microcomputer, two types of interfaces are typically used. They are frequency output and 4-20 mA loops. In the frequency output topology, pressure is converted into a zero to 5 V digital signal whose frequency varies linearly with pressure. A minimum frequency corresponds to zero pressure and above this, frequency output is determined by a Hz/unit pressure scaling factor. If minimizing the number of wires to a remote sensor is the most important design consideration, 4-20 mA current loops are the topology of choice. These loops utilize power and ground as the 4-20 mA signal line and therefore require only two wires to the sensor. In this topology 4 mA of total current drain from the sensor corresponds to zero pressure, and 20 mA to full scale.

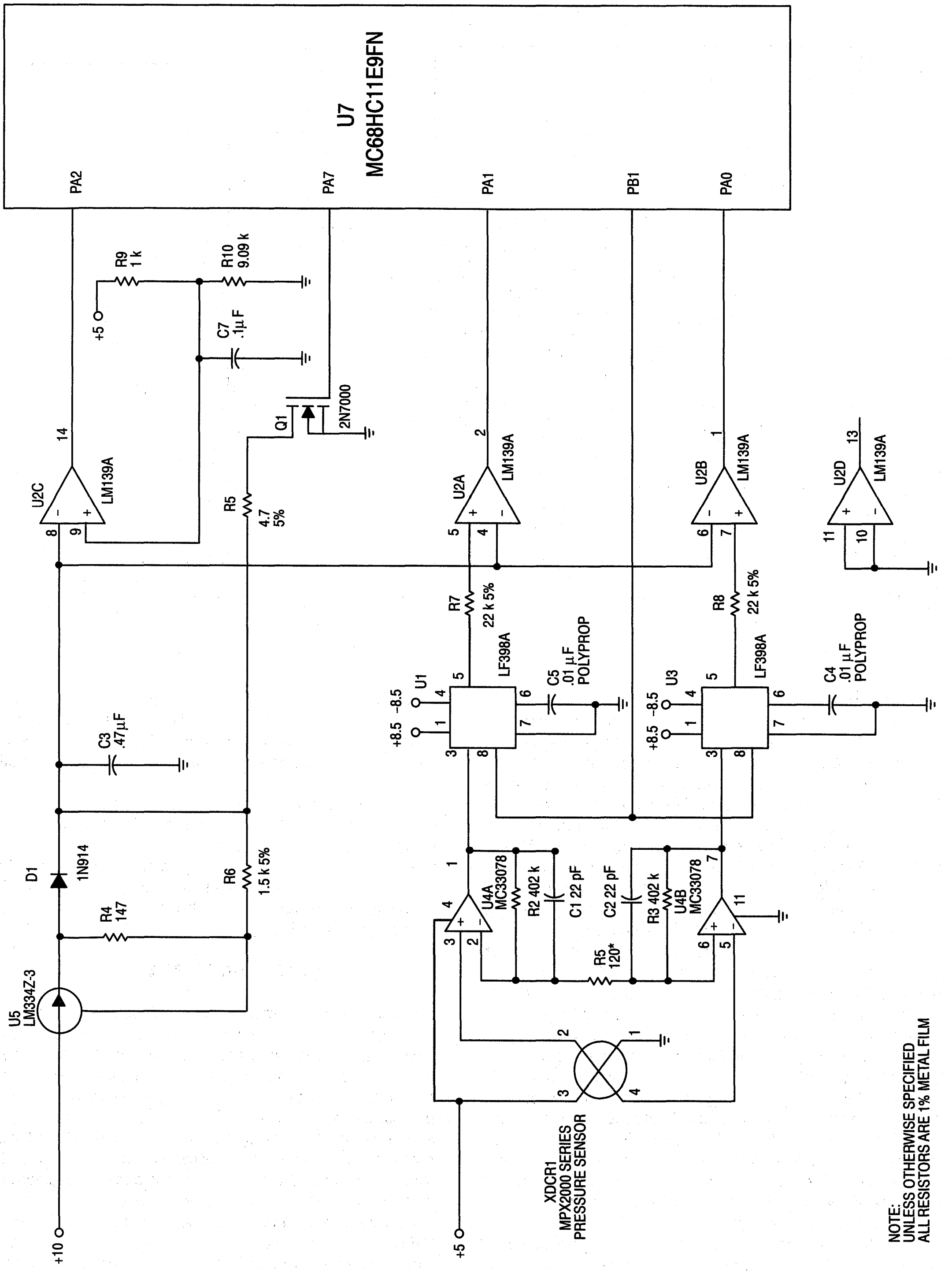
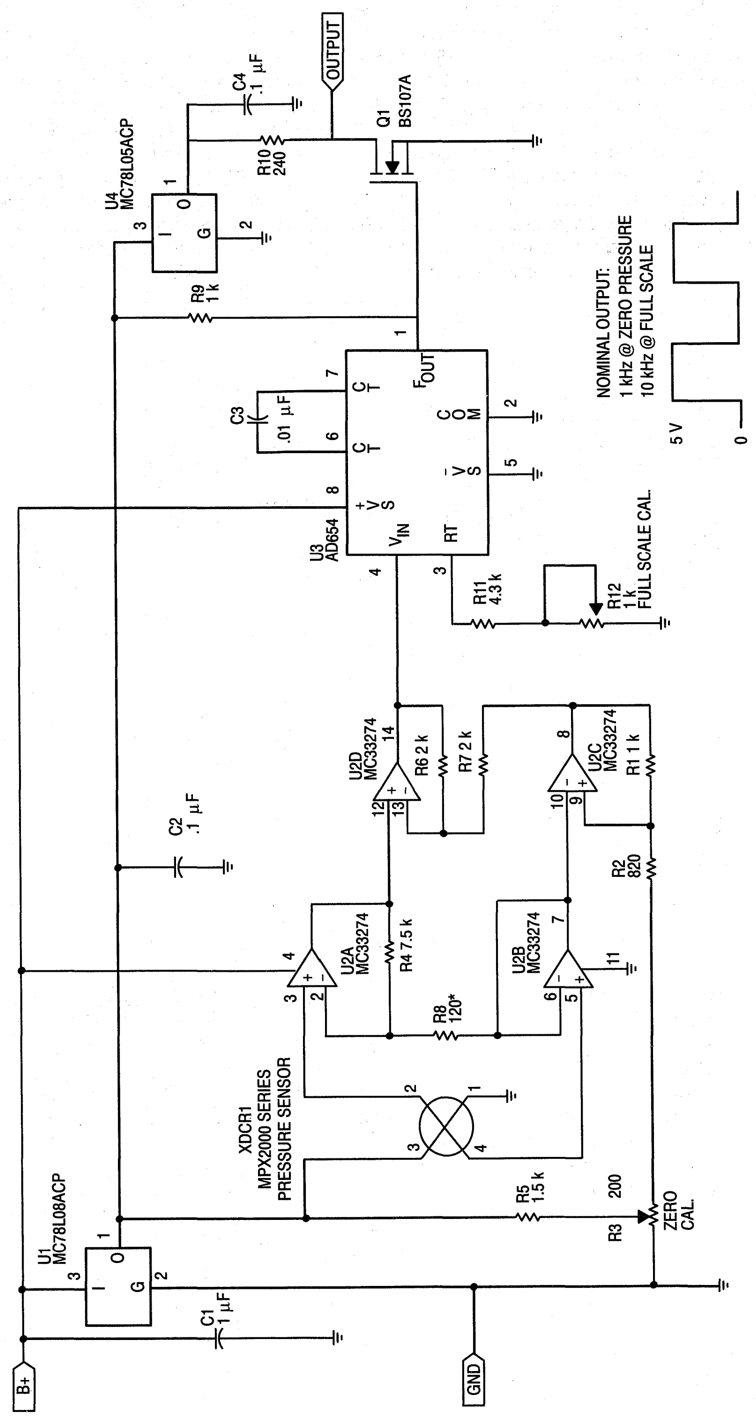


Figure 7. Single Slope A/D Converter



* NOTE: FOR MPX2010, R8 = 75 OHMS

Figure 8. Frequency Output Pressure Sensor

A relatively straightforward circuit for converting pressure to frequency is shown in Figure 8. It consists of three basic parts. The interface amplifier is the same circuit that was described in Figure 4. Its 0.5 to 4.5 V output is fed directly into an AD654 voltage-to-frequency converter. On the AD654, C3 sets nominal output frequency. Zero pressure output is calibrated to 1 kHz by adjusting the zero pressure input voltage with R3. Full scale adjustments are made with R12 which sets the full scale frequency to 10 kHz. The output of the AD654 is then fed into a buffer consisting of Q1 and R10. The buffer is used to clean up the edges and level translate the output to 5 V. Advantages of this approach are that the frequency output is easily read by a microcomputer's timer and transmission over a twisted pair line is relatively easy. Where very long distances are involved, the primary disadvantage is that 3 wires (V_{CC}, ground and an output line) are routed to the sensor.

A 4-20 mA loop reduces the number of wires to two. Its output is embedded in the V_{CC} and ground lines as an active current source. A straightforward way to apply this technique to pressure sensing is shown in Figure 9. In this figure an MPX7000 series high impedance pressure sensor is mated to an XTR101 4-20 mA two-wire transmitter. It is set up to pull 4 mA from its power line at zero pressure and 20 mA at full scale. At the receiving end a 240 ohm resistor referenced to signal ground will provide a 0.96 to 4.8 V signal that is suitable for microcomputer A/D inputs.

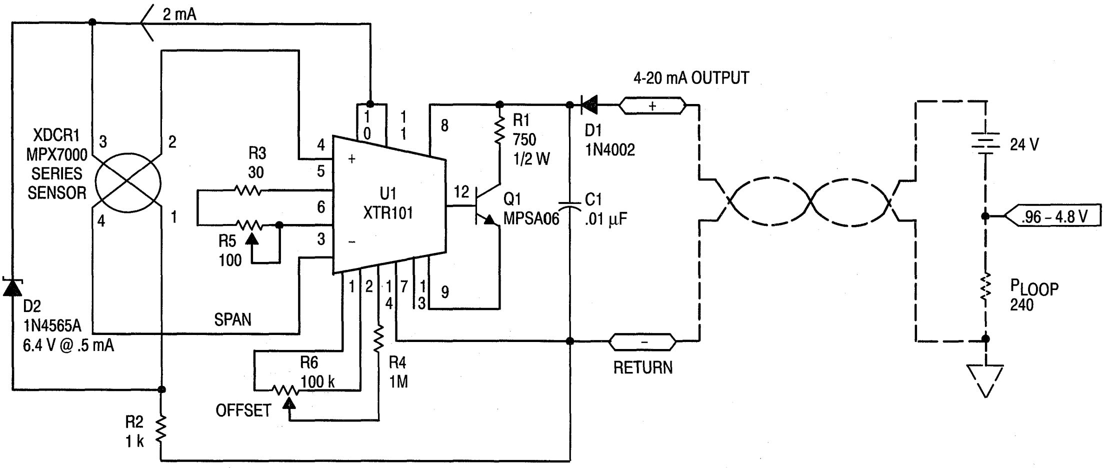


Figure 9. 4-20 mA Pressure Transducer

Bias for the sensor is provided by two 1 mA current sources (pins 10 and 11) that are tied in parallel and run into a 1N4565A 6.4 V temperature compensated zener reference. The sensor's differential output is fed directly into XTR101's inverting and non-inverting inputs. Zero pressure offset is calibrated to 4 mA with R6. Biased with 6.4 V, the sensor's full scale output is 24.8 mV. Given this input R3 + R5 nominally total 64 ohms to produce the 16 mA span required for 20 mA full scale. Calibration is set with R5.

The XTR101 requires that the differential input voltage at pins 3 and 4 has a common mode voltage between 4 and 6 V. The sensor's common mode voltage is one half its supply voltage or 3.2 V. R2 boosts this common mode voltage by 1 k • 2 mA or 2 V, establishing a common mode voltage for the transmitter's input of 5.2 V. To allow operation over a 12 to 40 V range, dissipation is off-loaded from the IC by boosting the output with Q1 and R1. D1 is also included for protection. It prohibits reverse polarity from causing damage. Advantages of this topology include simplicity and, of course, the two wire interface.

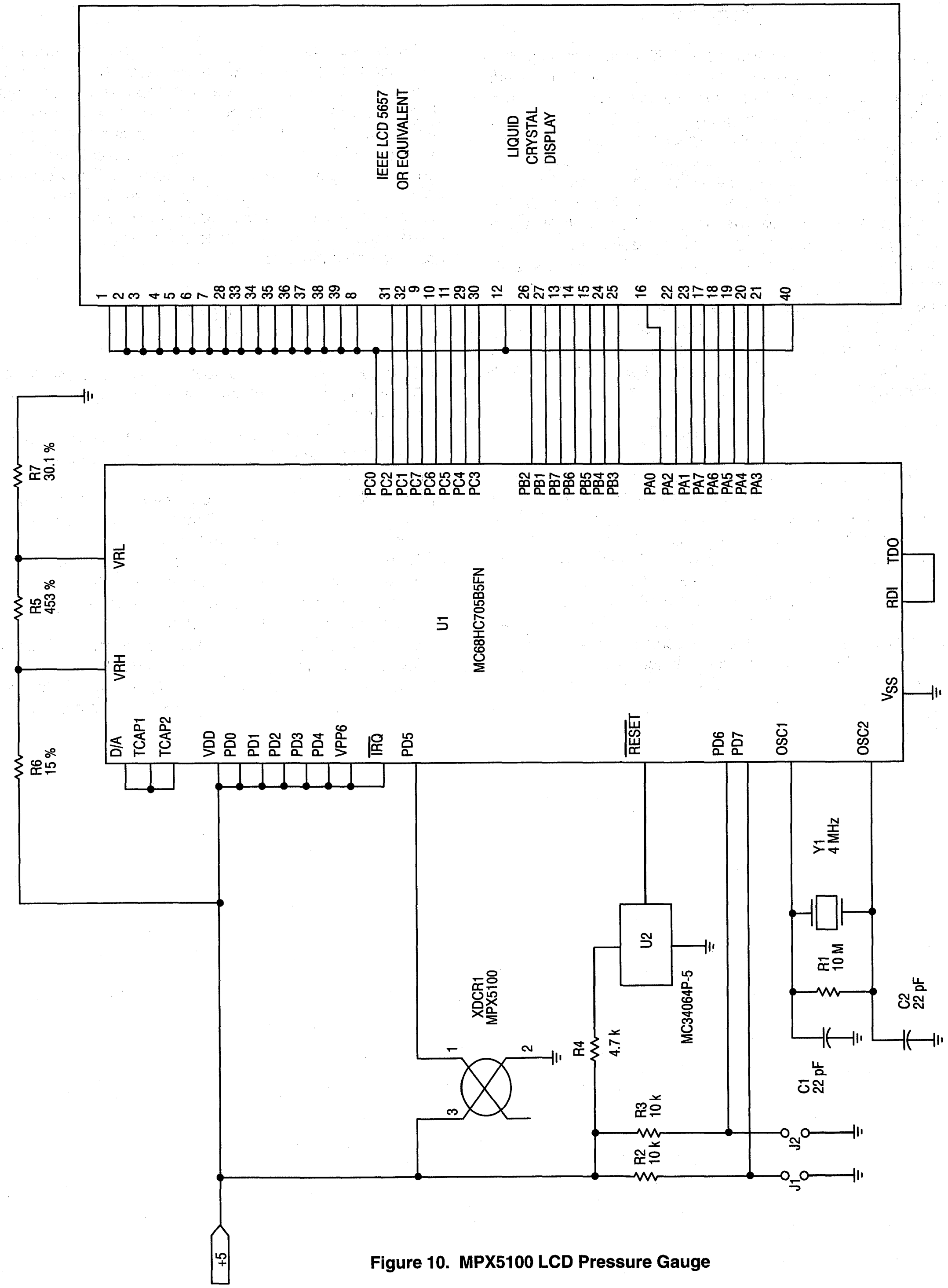


Figure 10. MPX5100 LCD Pressure Gauge

DIRECT INTERFACE WITH INTEGRATED SENSORS

The simplest interface is achieved with an integrated sensor and a microcomputer that has an on-chip A/D converter. Figure 10 shows an LCD pressure gauge that is made with an MPX5100 integrated sensor and MC68HC05 microcomputer. Although the total schematic is reasonably complicated, the interface between the sensor and the micro is a single wire. The MPX5100 has an internal amplifier that outputs a 0.5 to 4.5 V signal that inputs directly to A/D port PD5 on the HC05.

The software in this system is written such that the processor assumes zero pressure at power up, reads the sensor's output voltage, and stores this value as zero pressure offset. Full scale span is adjustable with jumpers J1 and J2. For this particular system the software is written such that with J1 out and J2 in, span is decreased by 1.5%. Similarly with J1 in and J2 out, span is increased by 1.5%. Given the ± 2.5% full scale spec on the sensor, these jumpers allow calibration to ± 1% without the use of pots.

MIX AND MATCH

The circuits that have been described so far are intended to be used as functional blocks. They may be combined in a variety of ways to meet the particular needs of an application. For example, the Frequency Output Pressure Sensor in Figure 8 uses the sensor interface circuit described in Figure 4 to provide an input to the voltage-to-frequency converter. Alternately, an MPX5100 could be directly connected to pin 4 of the AD654 or the output of Figure 3's Precision Instrumentation Amplifier Interface could by substituted in the same way. Similarly, the Pressure Gauge described in Figure 10 could be constructed with any of the interfaces that have been described.

CONCLUSION

The circuits that have been shown here are intended to make interfacing semiconductor pressure sensors to digital systems easier. They provide cost effective and relatively simple ways of interfacing sensors to microcomputers. The seven different circuits contain many tradeoffs that can be matched to the needs of individual applications. When considering these tradeoffs it is important to throw software into the equation. Techniques such as automatic zero pressure calibration can allow one of the inexpensive analog interfaces to provide performance that could otherwise only be obtained with a more costly precision interface.

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MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1322

Applying Semiconductor Sensors to Bar Graph Pressure Gauges

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INTRODUCTION

Bar Graph displays are noted for their ability to very quickly convey a relative sense of how much of something is present. They are particularly useful in process monitoring applications where quick communication of a relative value is more important than providing specific data.

Designing bar graph pressure gauges based upon semiconductor pressure sensors is relatively straightforward. The sensors can be interfaced to bar graph display drive IC's, microcomputers and MC33161 voltage monitors. Design examples for all three types are included.

BAR GRAPH DISPLAY DRIVER

Interfacing semiconductor pressure sensors to a bar graph display IC such as an LM3914 is very similar to microcomputer interface. The same .5 to 4.5 V analog signal that a microcomputer's A/D converter wants to see is also quite suitable for driving an LM3914. In Figure 1, this interface is provided by dual op amp U2 and several resistors.

The op amp interface amplifies and level shifts the sensor's output. To see how this amplifier works, simplify it by grounding the output of voltage divider R3, R5. If the common mode voltage at pins 2 & 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. Assuming that the current in R4 is equal to the current in R6, 323 μA • 100 ohms 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.

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 μA. 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 • 93.1k) = 12.5 V. Dividing 12.5 V by the 100 mV input yields a gain of 125, which provides a 4.0 V span for 32 mV of full scale sensor output.

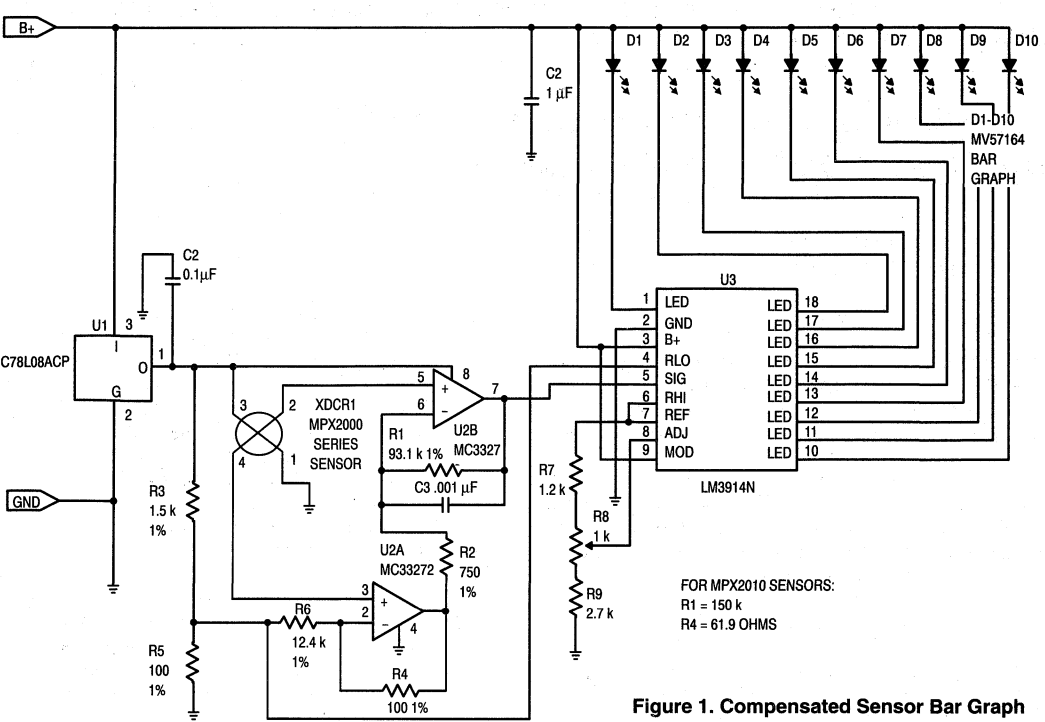
Setting divider R3, R5 at 0.5 V results in a .5 V to 4.5 V output that is easily tied to an LM3914. The block diagram that appears in Figure 2 shows the LM3914's internal architecture. Since the lower resistor in the input comparator chain is pinned out at R_{LO}, it is a simple matter to tie this pin to a voltage that is approximately equal to the interface circuit's 0.5 V zero pressure output voltage. Returning to Figure 1, this is accomplished by using the zero pressure offset voltage that is generated at the output of divider R3, R5.

Again looking at Figure 1, full scale is set by adjusting the upper comparator's reference voltage to match the sensor's output at full pressure. An internal regulator on the LM3914 sets this voltage with the aid of resistors R7, R9, and adjustment pot R8.

Eight volt regulated power is supplied by an MC78L08. The LED's are powered directly from LM3914 outputs, which are set up as current sources. Output current to each LED is approximately 10 times the reference current that flows from pin 7 through R7, R8, and R9 to ground. In this design it is nominally (4.5 V/4.9 k)10 = 9.2 mA.

Over a zero to 50° C temperature range combined accuracy for the sensor, interface, and driver IC are ±10%. Given a 10 segment display total accuracy for the bar graph readout is approximately ± (10 kPa +10%).

This circuit can be simplified by substituting an MPX5100 integrated sensor for the MPX2100 and the op amp interface. The resulting schematic is shown in Figure 3. In this case zero reference for the bar graph is provided by dividing down the 5 V regulator with R4, R1 and adjustment pot R6. The voltage at the wiper of R6 is adjusted to match the sensor's zero pressure offset voltage. It is connected to R_{LO} to zero the bar graph.



FOR MPX2010 SENSORS:
R1 = 150 k
R4 = 61.9 OHMS

Figure 1. Compensated Sensor Bar Graph Pressure Gauge

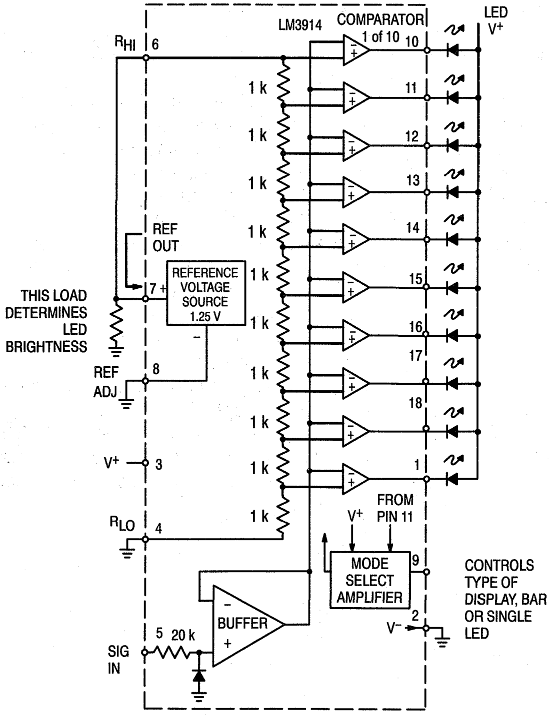


Figure 2. LM3914 Block Diagram

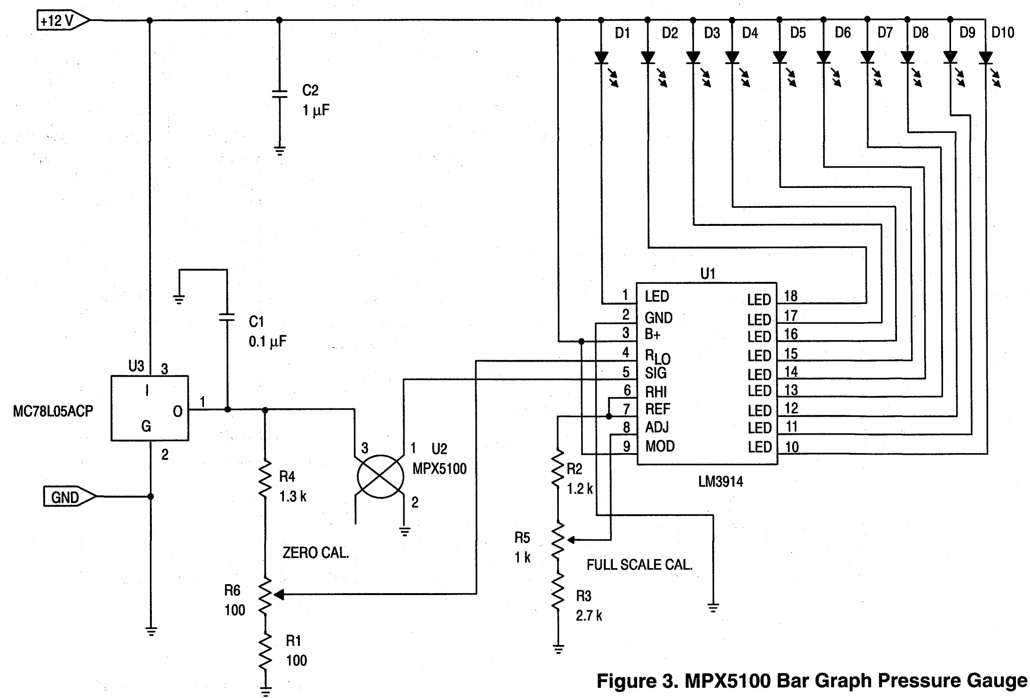


Figure 3. MPX5100 Bar Graph Pressure Gauge

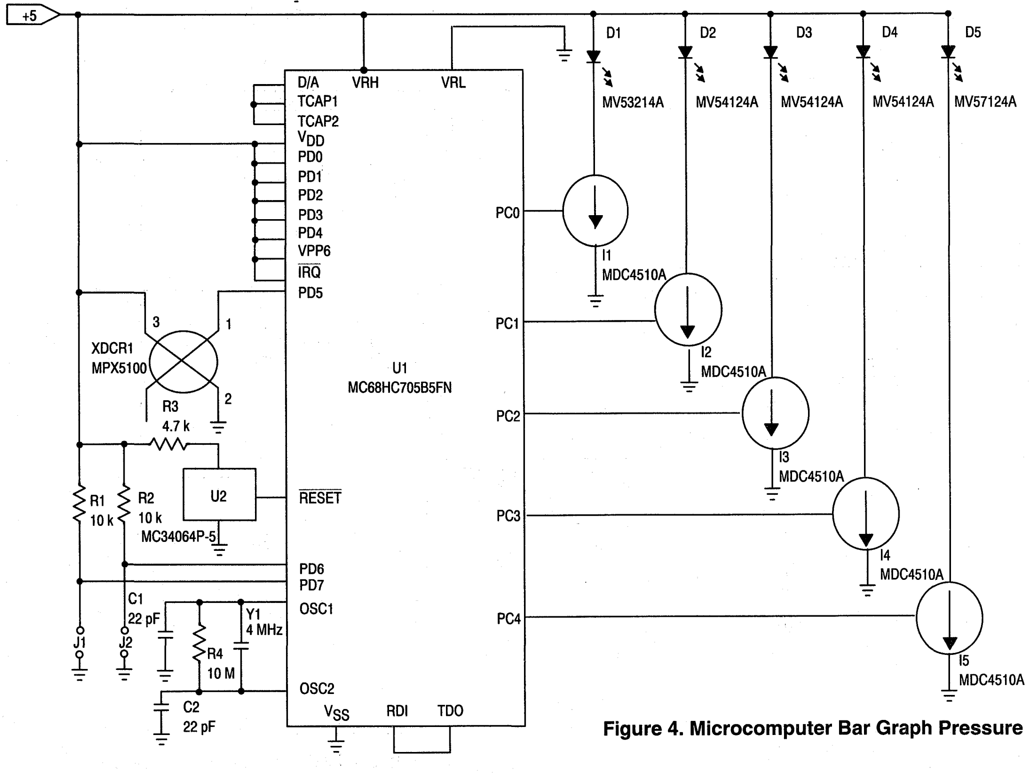


Figure 4. Microcomputer Bar Graph Pressure Gauge

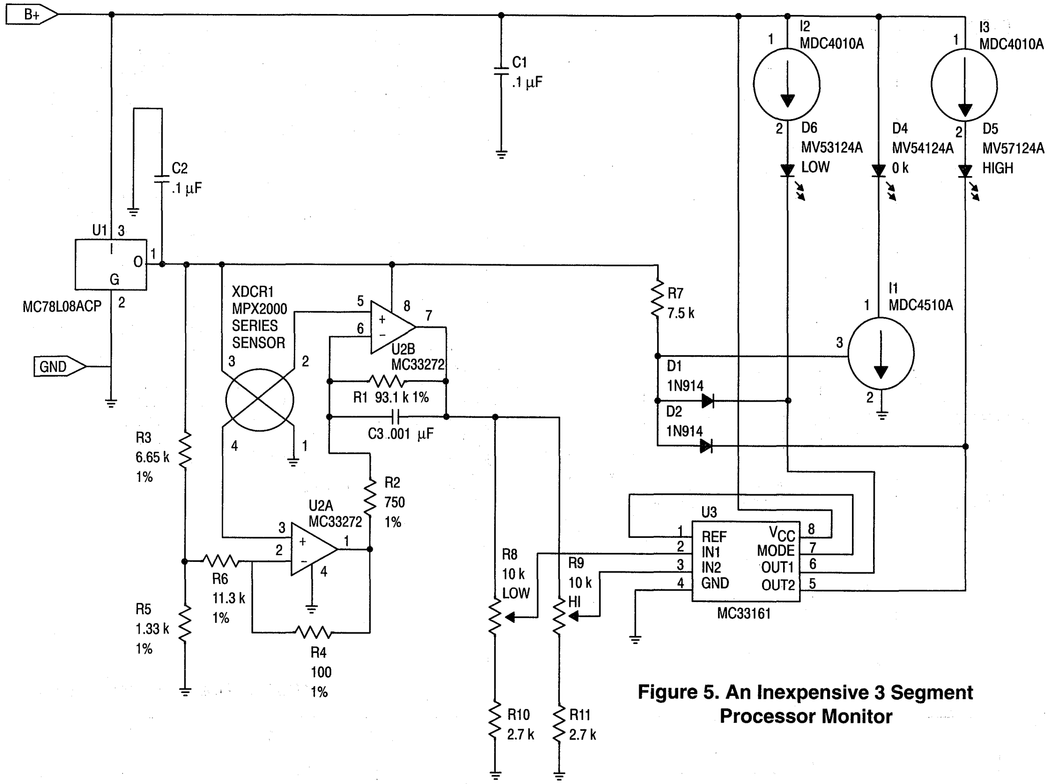


Figure 5. An Inexpensive 3 Segment Processor Monitor

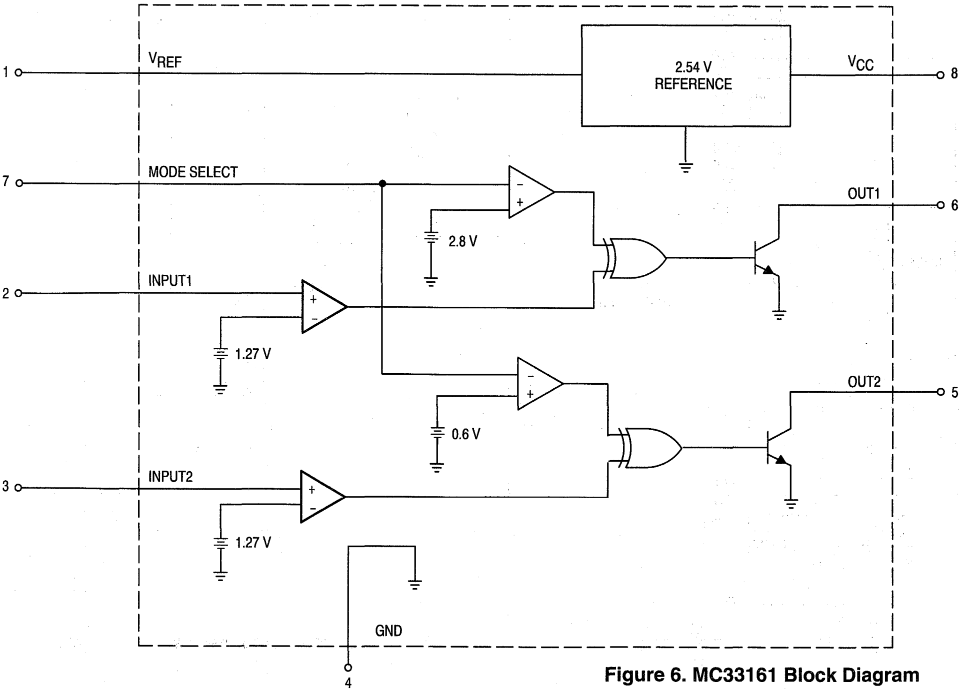


Figure 6. MC33161 Block Diagram

MICROCOMPUTER BAR GRAPH

Microcomputers with internal A/D converters such as an MC68HC05B5 lend themselves to easily creating bar graphs. Using the A/D converter to measure the sensor's analog output voltage and output ports to individually switch LED's makes a relatively straightforward pressure gauge. This type of design is facilitated by a new MDC4510A gated current sink. The MDC4510A takes one of the processor's logic outputs and switches 10 mA to an LED. One advantage of this approach is that it is very flexible regarding the number of segments that are used, and has the availability through software to independently adjust scaling factors for each segment. This approach is particularly useful for process monitoring in systems where a microprocessor is already in place.

Figure 4 shows a direct connection from an MPX5100 sensor to the microcomputer. Similar to the previous example, an MPX2000 series sensor with the op amp interface that is shown in Figure 1 can be substituted for the MPX5100. In this case the op amp interface's output at pin 7 ties to port PD5, and its supply needs to come from a source greater than 6.5 V.

PROCESS MONITOR

For applications where an inexpensive HIGH-LOW-OK process monitor is required, the circuit in Figure 5 does a good job. It uses an MC33161 Universal Voltage Monitor and the same analog interface previously described to indicate high, low or in-range pressure.

A block diagram of the MC33161 is illustrated in Figure 6. By tying pin 1 to pin 7 it is set up as a window detector. Whenever input 1 exceeds 1.27 V, two logic ones are placed at the inputs of its exclusive OR gate, turning off output 1. Therefore this output is on unless the lower threshold is exceeded. When, 1.27 V is exceeded on input 2, just the opposite occurs. A single logic one appears at its exclusive OR gate, turning on output 2. These two outputs drive LED's through MDC4010A 10 mA current sources to indicate low pressure and high pressure.

Returning to Figure 5, an in-range indication is developed by turning on current source I1 whenever both the high and low outputs are off. This function is accomplished with a discrete gate made from D1, D2 and R7. Its output feeds the input of switched current source I1, turning it on with R7 when neither D1 nor D2 is forward biased.

Thresholds are set independently with R8 and R9. They sample the same 4.0 V full scale span that is used in the other examples. However, zero pressure offset is targeted for 1.3 V. This voltage was chosen to approximate the 1.27 V reference at both inputs, which avoids throwing away the sensor's analog output signal to overcome the MC33161's input threshold. In addition, R10 & R11 are selected such that at full scale output, ie., 5.3 V on pin 7, the low side of the pots is nominally at 1.1 V. This keeps the minimum input just below the comparator thresholds of 1.27 V, and maximizes the resolution available from adjustment pots R8 & R9. When level adjustment is not desired, R8 – R11 can be replaced by a simpler string of three fixed resistors.

CONCLUSION

The circuits that have been shown here are intended to make simple, practical and cost effective bar graph pressure gauges. Their application involves a variety of trade-offs that can be matched to the needs of individual applications. In general, the most important trade-offs are the number of segments required and processor utilization. If the system in which the bar graph is used already has a microprocessor with unused A/D channels and I/O ports, tying MDC4510A current sources to the unused output ports is a very cost effective solution. On a stand-alone basis, the MC33161 based process monitor is the most cost effective where only 2 or 3 segments are required. Applications that require a larger number of segments are generally best served by one of the circuits that uses a dedicated bar graph display.

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MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1324

A Simple Sensor Interface Amplifier

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INTRODUCTION

Compensated semiconductor pressure sensors such as the MPX2000 family are relatively easy to interface with digital systems. With these sensors and the circuitry that is described here, pressure is translated into a 0.5 to 4.5 V output range that is directly compatible with Microcomputer A/D inputs. A description of an Evaluation Board and design considerations are presented as follows.

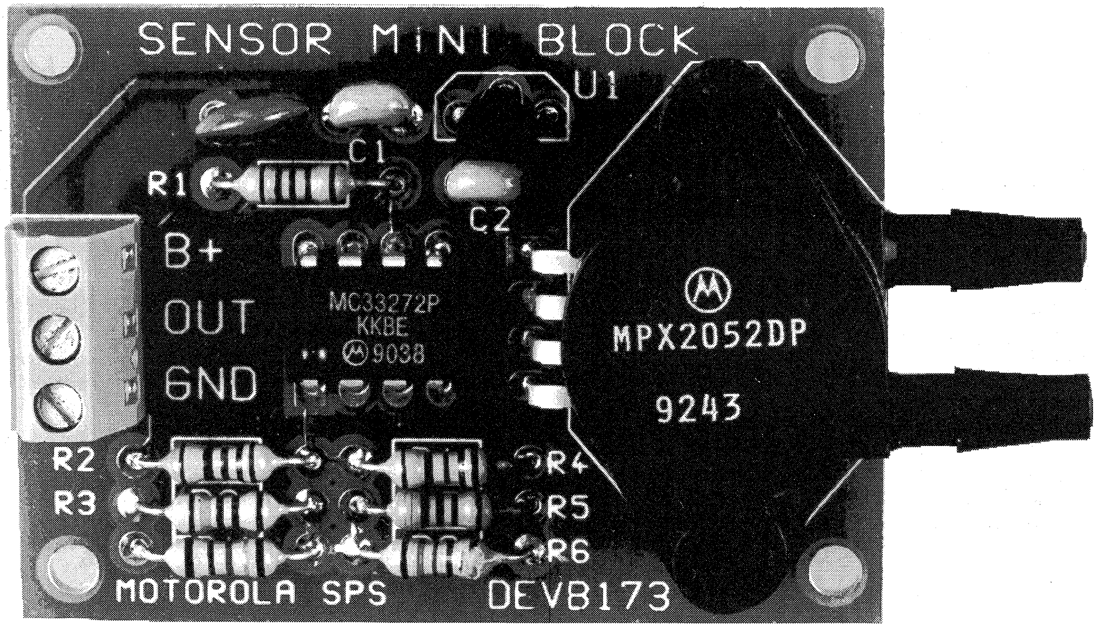


Figure 1. DEVB173 Sensor Building Block Evaluation Board

EVALUATION BOARD DESCRIPTION

A summary of the information required to use the Sensor Mini Block evaluation board, part number DEVB173, is presented as follows. A discussion of the design appears under the heading Design Considerations.

FUNCTION

The evaluation board shown in Figure 1 is designed to translate pressure, vacuum, or differential pressure into a single-ended, ground referenced voltage that is suitable for direct input to microcomputer A/D ports. It has two input ports. P1, the pressure port, is on the top side of the sensor and P2, a vacuum port, is on the bottom side. These ports can be supplied pressure on P1 or vacuum on P2, or a differential pressure between P1 and P2. Any of these sources will produce equivalent outputs.

The output is a ground referenced analog signal. It nominally supplies 0.5 V at zero pressure and 4.5 V at full scale. A zero adjustment has been made at the factory with trim resistor R7. Full scale output is approximately 4 V above the zero setting.

ELECTRICAL CHARACTERISTICS

The following electrical characteristics are included as a guide to operation.

Characteristic	Symbol	Min	Typ	Max	Units
Power Supply Voltage	B+	10	—	30	Volts
Full Scale Pressure MPX2010 MPX2050 MPX2100 MPX2200 MPX2700	P_{FS}	 — — — — —	 — — — — —	 10 50 100 200 700	kPa
Overpressure	P_{MAX}	—	—	700	kPa
Full Scale Output	V_{FS}	—	4.5	—	Volts
Zero Pressure Offset	V_{OFF}	—	0.5	—	Volts
Sensitivity	S_{AOUT}	—	$4V/P_{FS}$	—	V/kPa
Quiescent Current	I_{CC}	—	25	—	mA

CONTENT

Board contents are described in the following parts list and schematic. A pin-by-pin circuit description follows in the next section.

Table 1. Parts List

Designator	Qty.	Description	Value	Vendor	Part
C1	1	Ceramic Capacitor	0.2 µF		
C2	1	Ceramic Capacitor	0.2 µF		
C3	1	Ceramic Capacitor	0.001 µF		
R1*	1	1/4 Watt Film Resistor	93.1 k 1%		
R2	1	1/4 Watt Film Resistor	750 1%		
R3	1	1/4 Watt Film Resistor	39.2 k 1%		
R4*	1	1/4 Watt Film Resistor	100 1%		
R5	1	1/4 Watt Film Resistor	1.33 k 1%		
R6	1	1/4 Watt Film Resistor	11 k 1%		
R7	1	1/4 Watt Film Resistor	Trim		
U1	1	Op Amp		Motorola	MC33272P
U2	1	8 V Regulator		Motorola	MC78L08ACP
XDCR1	1	Pressure Sensor		Motorola	MPX2100DP

*For MPX2010 Sensors R1 = 150 k & R4 = 61.9 ohms

PIN-BY-PIN DESCRIPTION

B+:

Input power is supplied at the B+ terminal. Minimum input voltage is 6.8 V and maximum is 30 V.

OUT:

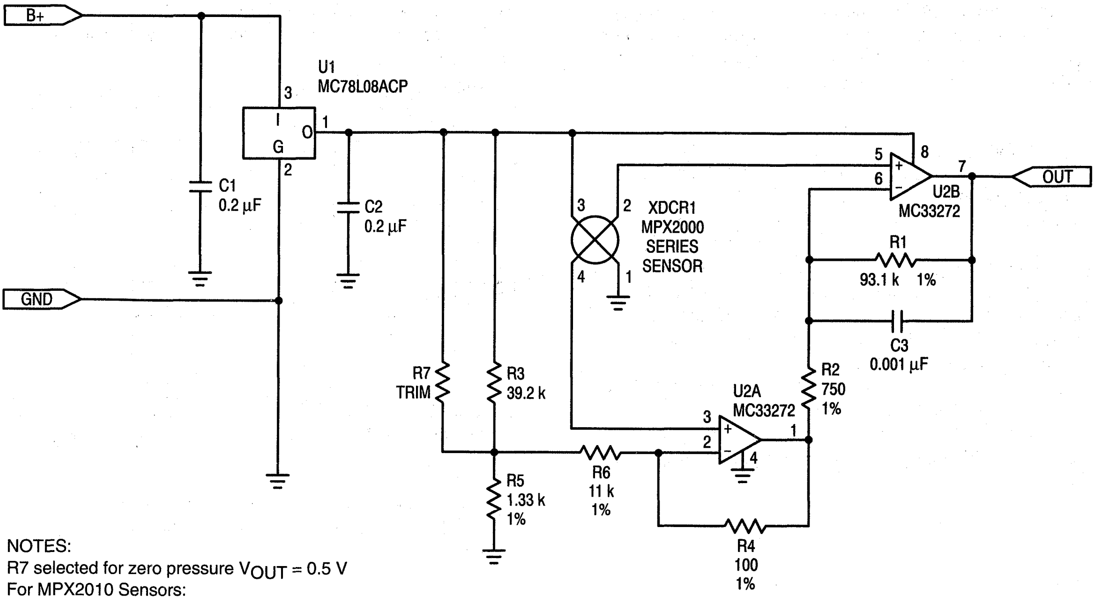
An analog output is supplied at the OUT terminal. The signal it provides is nominally 0.5 V at zero pressure and 4.5 V at full scale. This output is designed to be directly connected to a microcomputer A/D channel, such as one of the E ports on an MC68HC11.

GND:

The terminal labeled GND is intended for use as the power supply return. It is generally advisable to leave enough bare wire going into this terminal to conveniently provide a connection for instrumentation ground clips.

P1, P2:

Pressure and Vacuum ports P1 & P2 protrude from the sensor on the right side of the board. Pressure port P1 is on the top and vacuum port P2 is on the bottom. Neither port is labeled. Maximum safe pressure is 700 kPa.



NOTES:
R7 selected for zero pressure V_{OUT} = 0.5 V
For MPX2010 Sensors:
R1 = 150 k
R4 = 61.9 Ohms

Figure 2. Sensor Mini Block

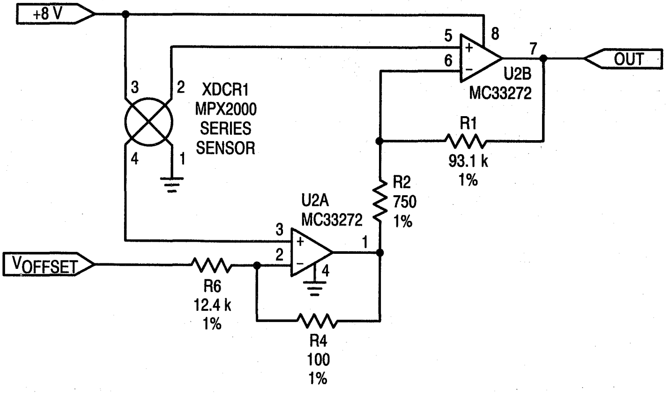


Figure 3. Simplified Schematic

DESIGN CONSIDERATIONS

When interfacing semiconductor pressure sensors to microcomputers, the design challenge is how to take a relatively small DC coupled differential signal and produce a ground referenced output that is suitable for driving A/D inputs. A very simple interface circuit that will do this job is shown in Figure 2. 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 in Figure 3, and assume V_{OFFSET} is zero. If the common mode voltage at pins 2 & 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. Assuming that the current in R4 isequal to the current in R6, 323 µA x 100 ohms 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 value for V_{OFFSET} other than zero into this calculation reveals that the zero pressure output voltage equals V_{OFFSET}. 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.

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 3 of U2A at 3.95 V, and pin 5 of U2B at 4.05 V. Therefore, 3.95 V is applied to R6, generating 319 µA. 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.

Returning to Figure 2, a 0.5 V V_{OFFSET} is generated by the divider consisting of R3, R5, and R7. To keep the input impedance looking into pin 2 of U2A at 12.4 k, R6 is chosen as 11 k. The divider impedance is then chosen to nominally be 1.4 k, providing a total of 12.4 k. For purposes of analysis, the complete circuit in Figure 2 is then equivalent to Figure 3 with a V_{OFFSET} input of 0.5 V.

The resulting 0.5 V to 4.5 V output from pin 7 of U2B is directly compatible with microprocessor A/D inputs. Over a zero to 50°C temperature range combined accuracy for the sensor and interface is ±5%.

APPLICATION

Using the Sensor Mini Block's analog output to provide pressure information to a microcomputer is very straightforward. The output voltage range which goes from 0.5 V at zero pressure to 4.5 V at full scale is designed to make optimum use of microcomputer A/D inputs. A direct connection from the evaluation board output to an A/D input is all that is required. Using the MC68HC11 as an example, the output is connected to any of the E ports, such as port E0.

CHANGING SENSORS

In order to change pressure ranges, MPX2050, MPX2100, MPX2200, and MPX2700 pressure sensors can be substituted directly for each other. When one of these sensors is substituted for another, the 4.5 V full scale output will remain the same and correspond to the new sensor's full scale pressure specification. For example, substituting an MPX2200 200 kPa sensor for an MPX2100 100 kPa unit will change the full scale output from 4.5 V at 100 kPa to 4.5 V at 200 kPa. To make this translation with an MPX2010 requires changing R1 from 93.1 k to 150 k and R4 from 100 ohms to 61.9 ohms. With R1 at 93.1 k and R4 at 100 ohms, full scale span for an MPX2010 is only 2.5 V, producing a nominal full scale output voltage of 3.0 V.

FURTHER SIMPLIFICATION

In non-demanding applications the 7 resistor topology that is shown in Figure 2 can be reduced to 5, by eliminating R6 & R7. Without R7 the zero pressure offset is untrimmed. However, in microprocessor based systems it is relatively easy to read the zero pressure offset voltage, store it, and calibrate in software. This can be done automatically when the unit powers up, or as a calibration procedure. R6 can be eliminated (reduced to zero ohms) by directly connecting the R3, R5 divider to pin 2. The output impedance of this divider then needs to be choosen such that its ratio with R4 = R1/R2, in other words [R3•R5/(R3+R5)]/R4 = R1/R2. Given the values in Figure 2, this would mean R3 = 200 k, R5 = 13.3 k, R6 = 0, and R7 is open. In an untrimmed system, there is no real disadvantage to doing this, provided that the ratios can be sufficiently matched with standard resistor values.

The other option is to eliminate R6 and trim R3 with R7. This situation is somewhat different. The trimming operation will throw the ratio off, and reduce common mode rejection. Typically several percent of any change in the sensor's common mode voltage will show up as an output error when this configuration is used.

CONCLUSION

Perhaps the most noteworthy aspect to the sensor amplifier described here is its simplicity. The interface between an MPX2000 series sensor and a microcomputer A/D consists of one dual op amp and a few resistors. The result is a simple and inexpensive circuit that is capable of measuring pressure, vacuum or differential pressure.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1325

Amplifiers for Semiconductor Pressure Sensors

Prepared by: Warren Schultz
Discrete Applications Engineering

INTRODUCTION

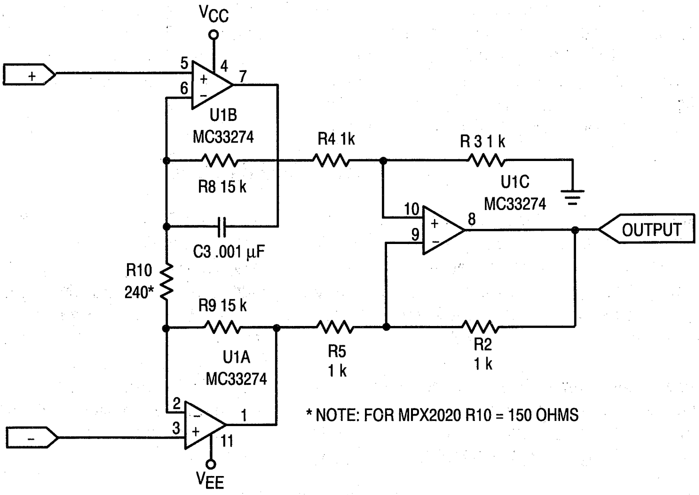
Amplifiers for interfacing Semiconductor Pressure Sensors to electronic systems have historically been based upon classic instrumentation amplifier designs. Instrumentation amplifiers have been widely used because they are well understood standard building blocks that also work reasonably well. For the 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 .3 – 1.0 V. Typical design targets are .5 V at zero pressure and enough gain to produce 4.5 V at full scale. The .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 .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.

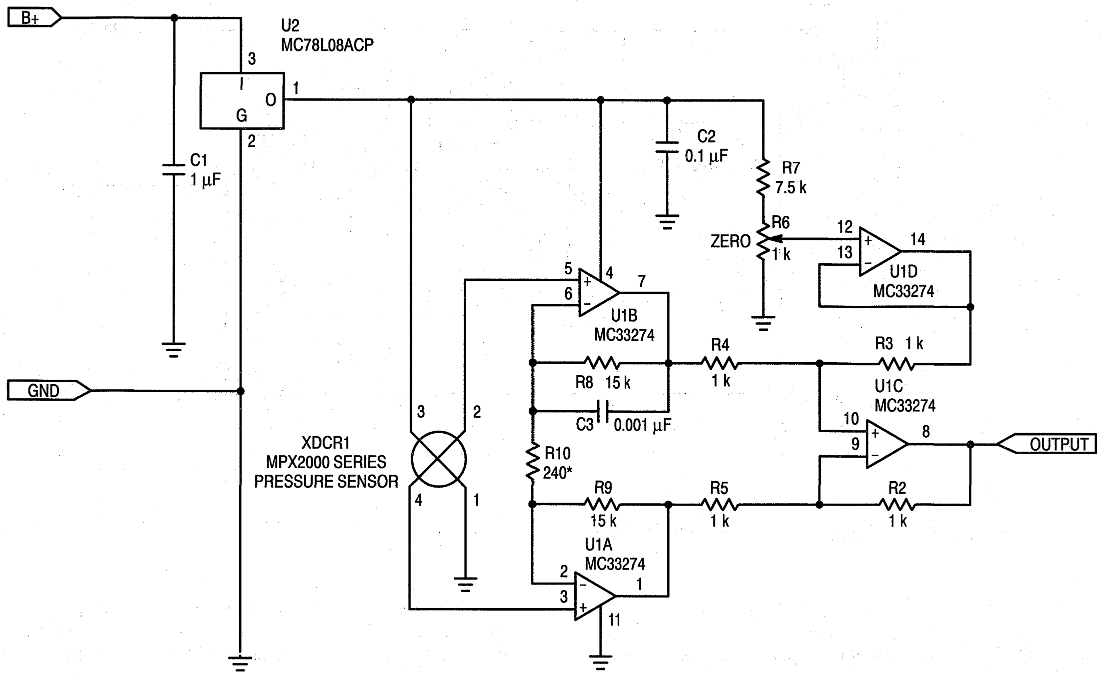
CLASSIC INSTRUMENTATION AMPLIFIER

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.



* NOTE: FOR MPX2020 R10 = 150 OHMS

Figure 1. Classic Instrumentation Amplifier



*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.

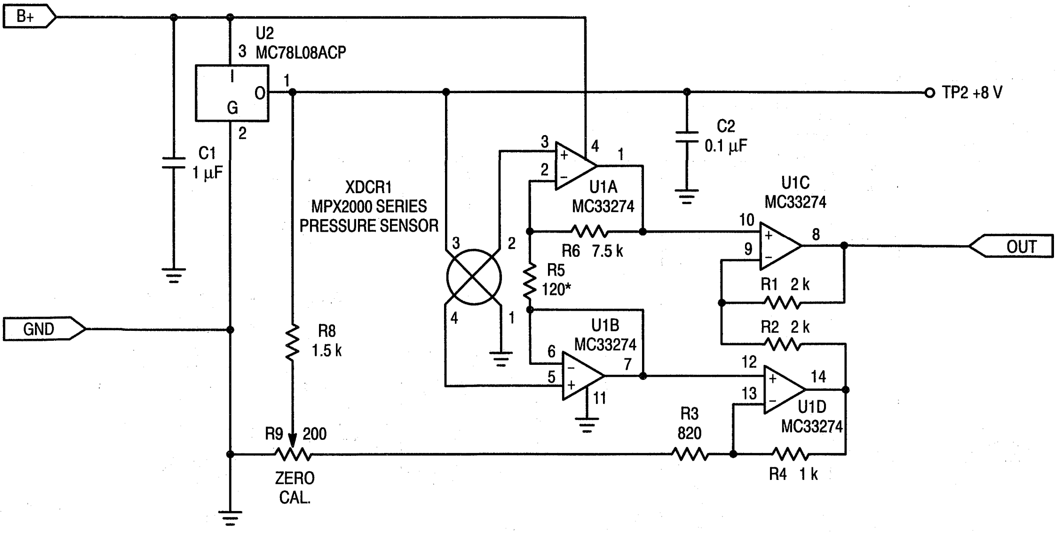
With R10 at 240 Ω gain is set for a nominal value of 125, providing a 4 V span for 32 mV of full scale sensor output. Setting the offset voltage to .75 V, results in a .75 V to 4.75 V output that is directly compatible with microprocessor A/D inputs.

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 .75 V zero pressure offset voltage, compared to .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 & 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 k Ω. 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 across R1, and the voltage at pin 8 is



*NOTE: FOR MPX2010 R5 = 75 OHMS

Figure 3. Sensor Specific Amplifier

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 .5 V results in an analog zero to full scale range of .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.

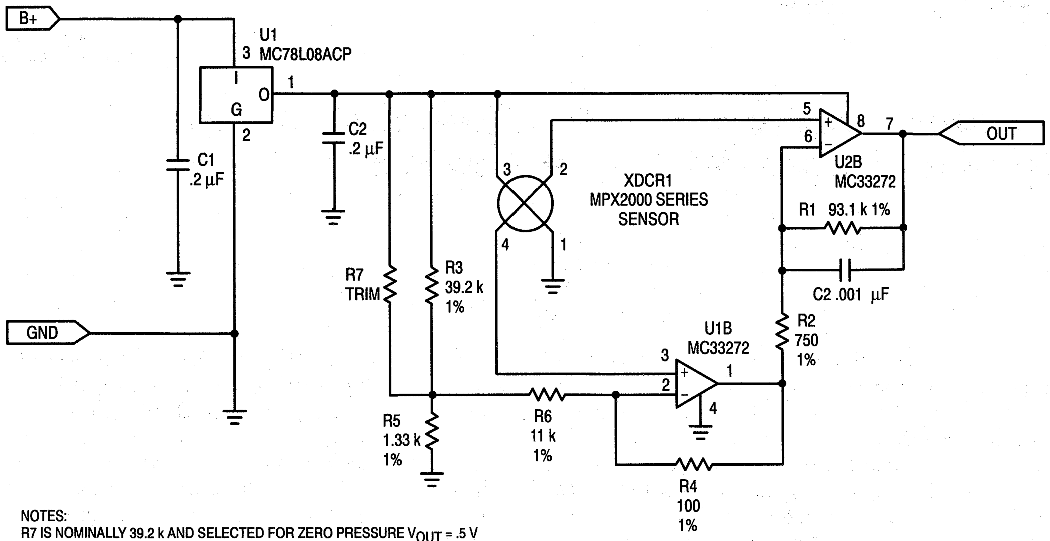
This approach to interface amplifier design is an improvement over the classic instrument amplifier in that it uses fewer resistors, is inherently more stable, and provides a zero pressure output voltage that can be targeted at .5 V. It has the same tolerance problem from matching discrete resistors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

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1326

Barometric Pressure Measurement Using Semiconductor Pressure Sensors

Prepared by: Chris Winkler and Jeff Baum
Discrete Applications Engineering

ABSTRACT

The most recent advances in silicon micromachining technology have given rise to a variety of low-cost pressure sensor applications and solutions. Certain applications had previously been hindered by the high-cost, large size, and overall reliability limitations of electromechanical pressure sensing devices. Furthermore, the integration of on-chip temperature compensation and calibration has allowed a significant improvement in the accuracy and temperature stability of the sensor output signal. This technology allows for the development of both analog and microcomputer-based systems that can accurately resolve the small pressure changes encountered in many applications. One particular application of interest is the combination of a silicon pressure sensor and a microcontroller interface in the design of a digital barometer. The focus of the following documentation is to present a low-cost, simple approach to designing a digital barometer system.

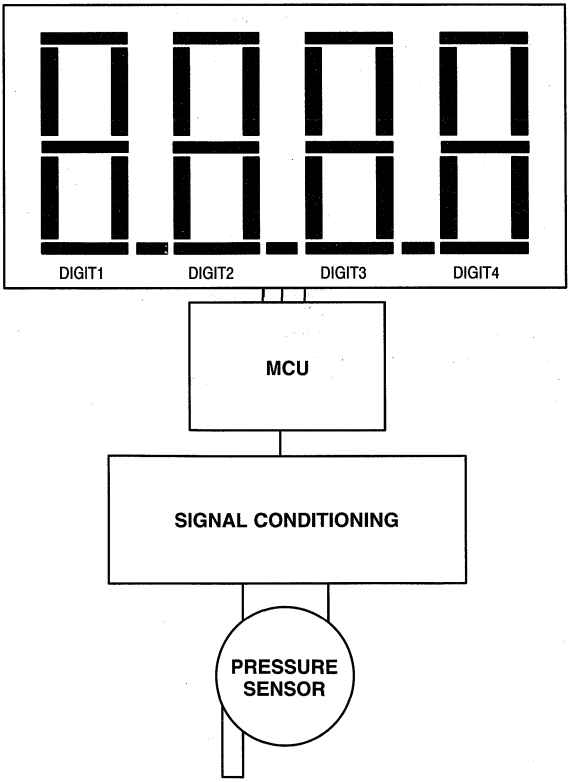


Figure 1. Barometer System

INTRODUCTION

Figure 1 shows the overall system architecture chosen for this application. This system serves as a building block, from which more advanced systems can be developed. Enhanced accuracy, resolution, and additional features can be integrated in a more complex design.

There are some preliminary concerns regarding the measurement of barometric pressure which directly affect the design considerations for this system. Barometric pressure refers to the air pressure existing at any point within the earth's atmosphere. This pressure can be measured as an absolute pressure, (with reference to absolute vacuum) or can be referenced to some other value or scale. The meteorology and avionics industries traditionally measure the absolute pressure, and then reference it to a sea level pressure value. This complicated process is used in generating maps of weather systems. The atmospheric pressure at any altitude varies due to changing weather conditions over time. Therefore, it can be difficult to determine the significance of a particular pressure measurement without additional information. However, once the pressure at a particular location and elevation is determined, the pressure can be calculated at any other altitude. Mathematically, atmospheric pressure is exponentially related to altitude. This particular system is designed to track variations in barometric pressure once it is calibrated to a known pressure reference at a given altitude.

For simplification, the standard atmospheric pressure at sea level is assumed to be 29.9 in-Hg. "Standard" barometric pressure is measured at particular altitude at the average weather conditions for that altitude over time. The system described in this text is specified to accurately measure barometric pressure variations up to altitudes of 15,000 ft. This altitude corresponds to a standard pressure of approximately 15.0 in-Hg. As a result of changing weather conditions, the standard pressure at a given altitude can fluctuate approximately ±1 in-Hg. in either direction. Table 1 indicates standard barometric pressures at several altitudes of interest.

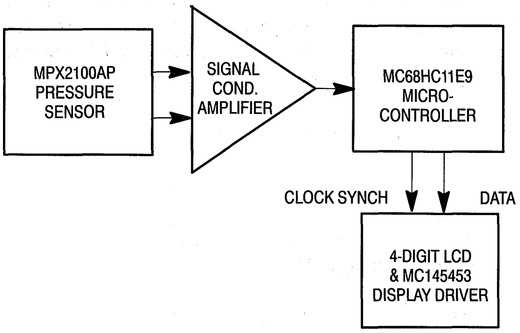


Figure 2. Barometer System Block Diagram

Table 1. Altitude versus Pressure Data

Altitude (Ft.)	Pressure (in-Hg)
0	29.92
500	29.38
1,000	28.85
6,000	23.97
10,000	20.57
15,000	16.86

SYSTEM OVERVIEW

In order to measure and display the correct barometric pressure, this system must perform several tasks. The measurement strategy is outlined below in Figure 2. First, pressure is applied to the sensor. This produces a proportional differential output voltage in the millivolt range. This signal must then be amplified and level-shifted to a single-ended, microcontroller (MCU) compatible level (0.5 – 4.5 V) by a signal conditioning circuit. The MCU will then sample the voltage at the analog-to-digital converter (A/D) channel input, convert the digital measurement value to inches of mercury, and then display the correct pressure via the LCD interface. This process is repeated continuously.

There are several significant performance features implemented into this system design. First, the system will digitally display barometric pressure in inches of mercury, with a resolution of approximately one-tenth of an inch of mercury. In order to allow for operation over a wide altitude range (0 – 15,000 ft.), the system is designed to display barometric pressures ranging from 30.5 in-Hg. to a minimum of 15.0 in-Hg. The display will read "lo" if the pressure measured is below 30.5 in-Hg. These pressures allow for the system to operate with the desired resolution in the range from sea-level to approximately 15,000 ft. An overview of these features is shown in Table 2.

Table 2. System Features Overview

Display Units	in-Hg
Resolution	0.1 in-Hg.
System Range	15.0 – 30.5 in-Hg.
Altitude Range	0 – 15,000 ft.

DESIGN OVERVIEW

The following sections are included to detail the system design. The overall system will be described by considering the subsystems depicted in the system block diagram, Figure 2. The design of each subsystem and its function in the overall system will be presented.

Pressure Sensor

The first and most important subsystem is the pressure transducer. This device converts the applied pressure into a proportional, differential voltage signal. This output signal will vary linearly with pressure. Since the applied pressure in this application will approach a maximum level of 30.5 in-Hg. (100 kPa) at sea level, the sensor output must have a linear output response over this pressure range. Also, the applied pressure must be measured with respect to a known reference pressure, preferably absolute zero pressure (vacuum). The device should also produce a stable output over the entire operating temperature range.

The desired sensor for this application is a temperature compensated and calibrated, semiconductor pressure transducer, such as the Motorola MPX2100A series sensor family. The MPX2000 series sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 200 kPa (30 psi). Furthermore, they are available in a variety of pressure configurations (gauge, differential, and absolute) and porting options. Because of the pressure ranges involved with barometric pressure measurement, this system will employ an MPX2100AP (absolute with single port). This device will produce a linear voltage output in the pressure range of 0 to 100 kPa. The ambient pressure applied to the single port will be measured with respect to an evacuated cavity (vacuum reference). The electrical characteristics for this device are summarized in Table 3.

Table 3. MPX2100AP Electrical Characteristics

Characteristic	Symbol	Minimum	Typical	Max	Unit
Pressure Range	P_{OP}	0		100	kPa
Supply Voltage	V_S		10	16	Vdc
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{off}			±1.0	mV
Sensitivity	S		0.4		mv/kPa
Linearity			0.05		%FSS
Temperature Effect on Span			0.5		%FSS
Temperature Effect on Offset			0.2		%FSS

As indicated in Table 3, the sensor can be operated at different supply voltages. The full-scale output of the sensor, which is specified at 40 mV nominally for a supply voltage of 10 Vdc, changes linearly with supply voltage. All non-digital circuitry is operated at a regulated supply voltage of 8 Vdc. Therefore, the full-scale sensor output (also the output of the sensor at sea level) will be approximately 32 mV.

$$\left(\frac{8}{10} \text{ x } 40 \text{ mV}\right)$$

The sensor output voltage at the systems minimum range (15 in-Hg.) is approximately 16.2 mV. Thus, the sensor output over the intended range of operations is expected to vary from 32 to 16.2 mV. These values can vary slightly for each sensor as the offset voltage and full-scale span tolerances indicate.

Signal Conditioning Circuitry

In order to convert the small-signal differential output signal of the sensor to MCU compatible levels, the next subsystem includes signal conditioning circuitry. The operational amplifier circuit is designed to amplify, level-shift, and ground reference the output signal. The signal is converted to a single-ended, 0.5 – 4.5 Vdc range. The schematic for this amplifier is shown in Figure 3.

This particular circuit is based on classic instrumentation amplifier design criteria. The differential output signal of the sensor is inverted, amplified, and then level-shifted by an adjustable offset voltage (through $R_{offset1}$). The offset voltage is adjusted to produce 0.5 volts at the maximum barometric pressure (30.5 in-Hg.). The output voltage will increase for decreasing pressure. If the output exceeds 5.1 V, a zener protection diode will clamp the output. This feature is included to protect the A/D channel input of the MCU. Using the transfer function for this circuit, the offset voltage and gain can be determined to provide 0.1 in-Hg of system resolution and the desired output voltage level. The calculation of these parameters is illustrated below.

In determining the amplifier gain and range of the trimmable offset voltage, it is necessary to calculate the number of steps used in the A/D conversion process to resolve 0.1 in-Hg.

$$(30.5 - 15.0)\text{in-Hg} * 10\,\frac{\text{steps}}{\text{Hg}} = 155 \text{ steps}$$

The span voltage can now be determined. The resolution provided by an 8-bit A/D converter with low and high voltage references of zero and five volts, respectively, will detect 19.5 mV of change per step.

$$V_{RH} = 5\text{ V},\ V_{RL} = 0\text{ V}$$

Sensor Output at 30.5 in-Hg = 32.44 mV
Sensor Output at 15.0 in-Hg = 16.26 mV
ΔSensor Output = ΔSO = 16.18 mV

$$\text{Gain} = \frac{3.04\text{ V}}{\Delta\text{SO}} \approx 187$$

Note: 30.5 in-Hg and 15.0 in-Hg are the assumed maximum and minimum absolute pressures, respectively.

This gain is then used to determine the appropriate resistor values and offset voltage for the amplifier circuit defined by the transfer function shown below.

$$V_{out} = -\left[\frac{R_2}{R_1}+1\right] * \Delta V + V_{off}$$

ΔV is the differential output of the sensor.

The gain of 187 can be implemented with:

$R_1 \approx R_3 = 121\ \Omega$
$R_2 \approx R_4 = 22.6\ k\ \Omega$.

Choosing $R_{offset1}$ to be 1 k Ω and $R_{offset2}$ to be 2.5 k Ω, V_{out} is 0.5 V at the presumed maximum barometric pressure of 30.5 in-Hg. The maximum pressure output voltage can be trimmed to a value other than 0.5 V, if desired via $R_{offset1}$. In addition, the trimmable offset resistor is incorporated to provide offset calibration if significant offset drift results from large weather fluctuations.

The circuit shown in Figure 3 employs an MC33272 (low-cost, low-drift) dual operational amplifier IC. In order to control large supply voltage fluctuations, an 8 Vdc regulator, MC78L08ACP, is used. This design permits use of a battery for excitation.

Microcontroller Interface

The low cost of MCU devices has allowed for their use as a signal processing tool in many applications. The MCU used in this application, the MC68HC11, demonstrates the power of incorporating intelligence into such systems. The on-chip resources of the MC68HC11 include: an 8 channel, 8-bit A/D, a 16-bit timer, an SPI (Serial Peripheral Interface – synchronous), and SCI (Serial Communications Interface – asynchronous), and a maximum of 40 I/O lines. This device is available in several package configurations and product variations which include additional RAM, EEPROM, and/or I/O capability. The software used in this application was developed using the MC68HC11 EVB development system.

The following software algorithm outlines the steps used to perform the desired digital processing. This system will convert the voltage at the A/D input into a digital value, convert this measurement into inches of mercury, and output this data serially to an LCD display interface (through the on-board SPI). This process is outlined in greater detail below:

1. Set up and enable A/D converter and SPI interface.
2. Initialize memory locations, initialize variables.
3. Make A/D conversion, store result.
4. Convert digital value to inches of mercury.
5. Determine if conversion is in system range.

6a. Convert pressure into decimal display digits.
6b. Otherwise, display range error message.

7. Output result via SPI to LCD driver device.

The signal conditioned sensor output signal is connected to pin PE5 (Port E-A/D Input pin). The MCU communicates to the LCD display interface via the SPI protocol. A listing of the assembly language source code to implement these tasks is included in the appendix. In addition, the software can be downloaded directly from the Motorola MCU Freeware Bulletin Board (in the MCU directory). Further information is included at the beginning of the appendix.

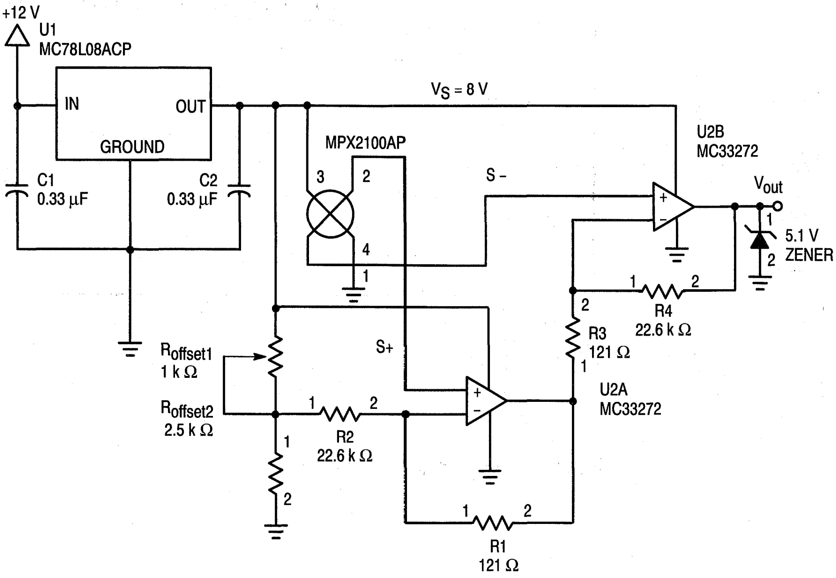


Figure 3. Signal Conditioning Circuit

LCD Interface

In order to digitally display the barometric pressure conversion, a serial LCD interface was developed to communicate with the MCU. This system includes an MC145453 CMOS serial interface/LCD driver, and a 4-digit, non-multiplexed LCD. In order for the MCU to communicate correctly with the interface, it must serially transmit six bytes for each conversion. This includes a start byte, a byte for each of the four decimal display digits, and a stop byte. For formatting purposes, decimal points and blank digits can be displayed through appropriate bit patterns. The control of display digits and data transmission is executed in the source code through subroutines BCDCONV, LOOKUP, SP12LCD, and TRANSFER. A block diagram of this interface is included below.

CONCLUSION

This digital barometer system described herein is an excellent example of a sensing system using solid state components and software to accurately measure barometric pressure. This system serves as a foundation from which more complex systems can be developed. The MPX2100A series pressure sensors provide the calibration and temperature compensation necessary to achieve the desired accuracy and interface simplicity for barometric pressure sensing applications.

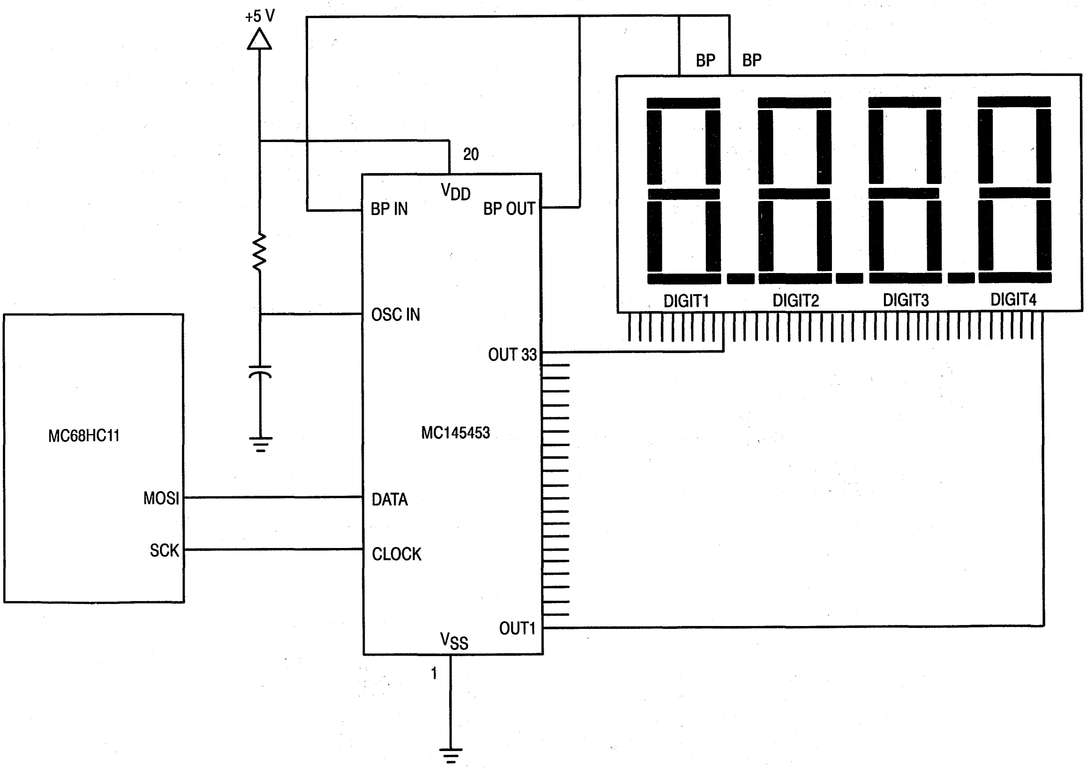


Figure 4. LCD Display Interface Diagram

APPENDIX

MC68HC11 Barometer Software Available on:

Motorola Electronic Bulletin Board
MCU Freeware Line
8–bit, no parity, 1 stop bit
1200/300 baud
(512) 891–FREE (3733)

```
* BAROMETER APPLICATIONS PROJECT   - Chris Winkler
* Developed: October 1st, 1992     - Motorola Discrete Applications
* This code will be used to implement an MC68HC11 Micro-Controller
* as a processing unit for a simple barometer system.
* The HC11 will interface with an MPX2100AP to monitor,store
* and display measured Barometric pressure via the 8-bit A/D channel
* The sensor output (32mv max) will be amplified to .5 - 2.5 V dc
* The processor will interface with a 4-digit LCD (FE202) via
* a Motorola LCD driver (MC145453) to display the pressure
* within +/- one tenth of an inch of mercury.
* The systems range is 15.0 - 30.5 in-Hg

*       A/D  & CPU Register Assignment
*       This code will use index addressing to access the
*       important control registers.  All addressing will be
*       indexed off of REGBASE, the base address for these registers.

REGBASE EQU     $1000           * register base of control register
ADCTL           EQU     $30             * offset of A/D control register
ADR2            EQU     $32             * offset of A/D results register
ADOPT           EQU     $39             * offset for A/D option register location
PORTB           EQU     $04             * Location of PORTB used for conversion
PORTD           EQU     $08             * PORTD Data Register Index
DDRD            EQU     $09             * offset of Data Direction Reg.
SPCR            EQU     $28             * offset of SPI Control Reg.
SPSR            EQU     $29             * offset of SPI Status Reg.
SPDR            EQU     $2A             * offset of SPI Data Reg.

*       User Variables
*       The following locations are used to store important measurements
*       and calculations used in determining the altitude.  They
*       are located in the lower 256 bytes of user RAM

DIGIT1  EQU     $0001           * BCD blank digit (not used)
DIGIT2  EQU     $0002           * BCD tens digit for pressure
DIGIT3  EQU     $0003           * BCD tenths digit for pressure
DIGIT4  EQU     $0004           * BCD ones digit for pressure
COUNTER EQU     $0005           * Variable to send 5 dummy bytes
POFFSET EQU     $0010           * Storage Location for max pressure offset
SENSOUT EQU     $0012           * Storage location for previous conversion
RESULT  EQU     $0014           * Storage of Pressure(in Hg) in hex format
FLAG            EQU     $0016           * Determines if measurement is within range

*       MAIN PROGRAM
*       The conversion process involves the following steps:
*
*                       1.              Set-Up SPI device-              SPI_CNFG
*                       2.              Set-Up A/D, Constants           SET_UP
*                       3.              Read A/D, store sample          ADCONV
*                       4.              Convert into in-Hg              IN_HG
*                       5.              Determine FLAG condition  IN_HG
*                               a.      Display error                   ERROR
*                               b.      Continue Conversion             INRANGE
*                       6.              Convert hex to BCD format BCDCONV
*                       7.              Convert LCD display digits      LOOKUP
*                       8.              Output via SPI to LCD           SPI2LCD

*       This process is continually repeated as the loop CONVERT
*       runs unconditionally through BRA (the BRANCH ALWAYS statement)
*       Repeats to step 3 indefinitely.
```

```
                ORG     $C000                   * DESIGNATES START OF MEMORY MAP FOR USER CODE
                LDX     #REGBASE        * Location of base register for indirect adr
                BSR     SPI_CNFG        * Set-up SPI Module for data X-mit to LCD
                BSR     SET_UP          * Power-Up A/D, initialize constants
CONVERT BSR     ADCONV          * Calls subroutine to make an A/D conversion
                BSR     DELAY                   * Delay routine to prevent LCD flickering
                BSR     IN_HG                   * Converts hex format to in of Hg

*       The value of FLAG passed from IN_HG is used to determine
*       If a range error has occurred.  The following logical
*       statements are used to either allow further conversion or jump
*       to a routine to display a range error message.

                LDAB    FLAG                    * Determines if an range Error has ocurred
                CMPB    #$80                    * If No Error detected (FLAG=$80) then
                BEQ     INRANGE         *   system will continue conversion process

                BSR     ERROR                   * If error occurs (FLAG<>80), branch to ERROR
                BRA     OUTPUT          * Branches to output ERROR code to display

*       No Error Detected, Conversion Process Continues

INRANGE JSR     BCDCONV         * Converts Hex Result to BCD
                JSR     LOOKUP          * Uses Look-Up Table for BCD-Decimal


OUTPUT  JSR     SPI2LCD         * Output transmission to LCD
                BRA     CONVERT         * Continually converts using Branch Always

*       Subroutine SPI_CNFG
*               Purpose is to initialize SPI for transmission
*               and clear the display before conversion.

SPI_CNFG BSET   PORTD,X #$20    * Set SPI SS Line High to prevent glitch
                LDAA    #$38                    * Initializing Data Direction for Port D
                STAA    DDRD,X          * Selecting SS, MOSI, SCK as outputs only


                LDAA    #$5D                    * Initialize SPI-Control Register
                STAA    SPCR,X          * selecting SPE,MSTR,CPOL,CPHA,CPRO

                LDAA    #$5                     * sets counter to X-mit 5 blank bytes
                STAA    COUNTER
                LDAA    SPSR,X          * Must read SPSR to clear SPIF Flag

                CLRA                            * Transmission of Blank Bytes to LCD

ERASELCD JSR    TRANSFER        * Calls subroutine to transmit
                DEC     COUNTER
                BNE     ERASELCD

                RTS

*       Subroutine SET_UP
*               Purpose is to initialize constants and to power-up A/D
*               and to initialize POFFSET used in conversion purposes.
SET_UP  LDAA    #$90                    * selects ADPU bit in OPTION register
                STAA    ADOPT,X         * Power-Up of A/D complete
                LDD     #$0131+$001A    * Initialize POFFSET
                STD     POFFSET         * POFFSET = 305 - 25 in hex
                LDAA    #$00                    * or Pmax + offset voltage (5 V)
                RTS

*       Subroutine DELAY
*               Purpose is to delay the conversion process
*               to minimize LCD flickering.

DELAY           LDA     #$FF                    * Loop for delay of display
OUTLOOP LDB     #$FF                    * Delay = clk/255*255
INLOOP  DECB
                BNE     INLOOP
                DECA
                BNE     OUTLOOP
                RTS

*       Subroutine ADCONV
*               Purpose is to read the A/D input, store the conversion into
*               SENSOUT. For conversion purposes later.

ADCONV  LDX     #REGBASE        * loads base register for indirect addressing
                LDAA    #$25
                STAA    ADCTL,X         * initializes A/D cont. register SCAN=1,MULT=0
```

```
WTCONV   BRCLR    ADCTL,X  #$80 WTCONV      * Wait for completion of conversion flag
                  LDAB     ADR2,X           * Loads conversion result into Accumulator
                  CLRA
                  STD      SENSOUT          * Stores conversion as SENSOUT

                  RTS

*        Subroutine IN_HG
*                 Purpose is to convert the measured pressure SENSOUT, into
*                 units of in-Hg, represented by a hex value of 305-150
*                 This represents the range 30.5 - 15.0 in-Hg
IN_HG             LDD      POFFSET          * Loads maximum offset for subtraction
                  SUBD     SENSOUT          * RESULT = POFFSET-SENSOUT in hex format
                  STD      RESULT           * Stores hex result for P, in Hg
                  CMPD     #305
                  BHI      TOHIGH

                  CMPD     #150
                  BLO      TOLOW

                  LDAB     #$80
                  STAB     FLAG
                  BRA      END_CONV

TOHIGH   LDAB     #$FF
                  STAB     FLAG
                  BRA      END_CONV

TOLOW             LDAB     #$00
                  STAB     FLAG
END_CONV RTS

*        Subroutine ERROR
*                          This subroutine sets the display digits to output
*                          an error message having detected an out of range
*                          measurement in the main program from FLAG

ERROR             LDAB     #$00                     * Initialize digits 1,4 to blanks
                  STAB     DIGIT1
                  STAB     DIGIT4

                  LDAB     FLAG                     * FLAG is used to determine
                  CMPB     #$00                     * if above or below range.
                  BNE      SET_HI           * If above range GOTO SET_HI

                  LDAB     #$0E                     * ELSE display LO on display
                  STAB     DIGIT2           * Set DIGIT2=L,DIGIT3=O
                  LDAB     #$7E
                  STAB     DIGIT3
                  BRA      END_ERR          * GOTO exit of subroutine

SET_HI   LDAB     #$37                      * Set DIGIT2=H,DIGIT3=1
                  STAB     DIGIT2
                  LDAB     #$30
                  STAB     DIGIT3

END_ERR  RTS


*        Subroutine BCDCONV
*                          Purpose is to convert ALTITUDE from hex to BCD
*                          uses standard HEX-BCD conversion scheme
*                          Divide HEX/10 store Remainder, swap Q & R, repeat
*                          process until remainder = 0.

BCDCONV  LDAA     #$00                      * Default Digits 2,3,4 to 0
                  STAA     DIGIT2
                  STAA     DIGIT3
                  STAA     DIGIT4
                  LDY      #DIGIT4          * Conversion starts with lowest digit
                  LDD      RESULT           * Load voltage to be converted
CONVLP   LDX      #$A                       * Divide hex digit by 10
                  IDIV                              * Quotient in X, Remainder in D
                  STAB     0,Y                      * stores 8 LSB's of remainder as BCD digit
                  DEY
                  CPX      #$0                      * Determines if last digit stored
                  XGDX                              * Exchanges remainder & quotient
                  BNE      CONVLP
                  LDX      #REGBASE         * Reloads BASE into main program
                  RTS

*        Subroutine LOOKUP
```

```
*                         Purpose is to implement a Look-Up conversion
*                         The BCD is used to index off of TABLE
*                         where the appropriate hex code to display
*                         that decimal digit is contained.
*                         DIGIT4,3,2 are converted only.

LOOKUP  LDX      #DIGIT1+4                  * Counter starts at 5
TABLOOP DEX                                 * Start with Digit4
                 LDY      #TABLE            * Loads table base into Y-pointer
                 LDAB     0,X                        * Loads current digit into B
                 ABY                                 * Adds to base to index off TABLE
                 LDAA     0,Y                        * Stores HEX segment result in A
                 STAA     0,X
                 CPX      #DIGIT2           * Loop condition complete, DIGIT2 Converted
                 BNE      TABLOOP

                 RTS


*       Subroutine SPI2LCD
*                         Purpose is to output digits to LCD via SPI
*                         The format for this is to send a start byte,
*                         four digits, and a stop byte. This system
*                         will have 3 significant digits: blank digit
*                         and three decimal digits.

*                                                    Sending LCD Start Byte

SPI2LCD LDX      #REGBASE
                 LDAA     SPSR,X            * Reads to clear SPIF flag
                 LDAA     #$02                       * Byte, no colon, start bit
                 BSR      TRANSFER          * Transmit byte

*                                                    Initializing decimal point & blank digit

                 LDAA     DIGIT3            * Sets MSB for decimal pt.
                 ORA      #$80                       * after digit 3
                 STAA     DIGIT3

                 LDAA     #$00                       * Set 1st digit as blank
                 STAA     DIGIT1

*                                                    Sending four decimal digits

                 LDY      #DIGIT1           * Pointer set to send 4 bytes
DLOOP            LDAA     0,Y                        * Loads digit to be x-mitted
                 BSR      TRANSFER          * Transmit byte
                 INY                                 * Branch until both bytes sent
                 CPY      #DIGIT4+1
                 BNE      DLOOP


*                                                    Sending LCD Stop Byte

                 LDAA     #$00                       * end byte requires all 0's
                 BSR      TRANSFER          * Transmit byte

                 RTS

*       Subroutine TRANSFER
*                Purpose is to send data bits to SPI
*                and wait for conversion complete flag bit to be set.

TRANSFER LDX     #REGBASE
                 BCLR     PORTD,X #$20      * Assert SS Line to start X-misssion
                 STAA     SPDR,X            * Load Data into Data Reg.,X-mit
XMIT             BRCLR    SPSR,X  #$80 XMIT* Wait for flag
                 BSET     PORTD,X #$20      * DISASSERT SS Line
                 LDAB     SPSR,X            * Read to Clear SPI Flag


                 RTS

*       Location for FCB memory for look-up table
*       There are 11 possible digits: blank, 0-9

TABLE            FCB      $7E,$30,$6D,$79,$33,$5B,$5F,$70,$7F,$73,$00

                 END
```

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1513

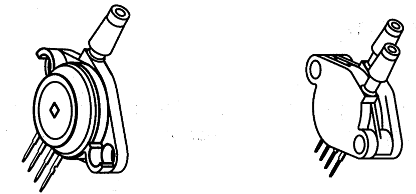
Mounting Techniques and Plumbing Options of Motorola's MPX Series Pressure Sensors

Prepared by: Brian Pickard
Sensor Products Division
Semiconductor Products Sector

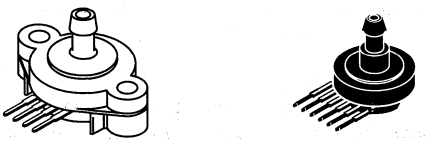
INTRODUCTION

Motorola offers a wide variety of ported, pressure sensing devices which incorporate a hose barb and mounting tabs. They were designed to give the widest range of design flexibility. The hose barbs are 1/8″ (≈3 mm) diameter and the tabs have #6 mounting holes. These sizes are very common and should make installation relatively simple. More importantly, and often overlooked, are the techniques used in mounting and adapting the ported pressure sensors. This application note provides some recommendations on types of fasteners for mounting, how to use them with Motorola sensors, and identifies some suppliers. This document also recommends a variety of hoses, hose clamps, and their respective suppliers.

This information applies to all Motorola MPX pressure sensors with ported packages, which includes the packages shown in Figure 1.



Single Side Port **Differential Port**



Axial Port **Stovepipe Port**

Figure 1. MPX Pressure Sensors with Ported Packages

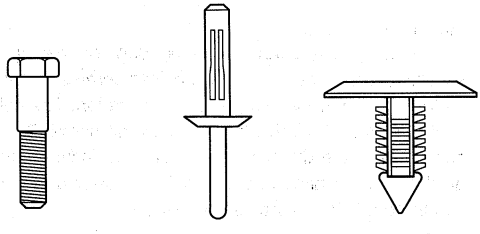
A review of recommended mounting hardware, mounting torque, hose applications, and hose clamps is also provided for reference.

MOUNTING HARDWARE

Mounting hardware is an integral part of package design. Different applications will call for different types of hardware. When choosing mounting hardware, there are three important factors:

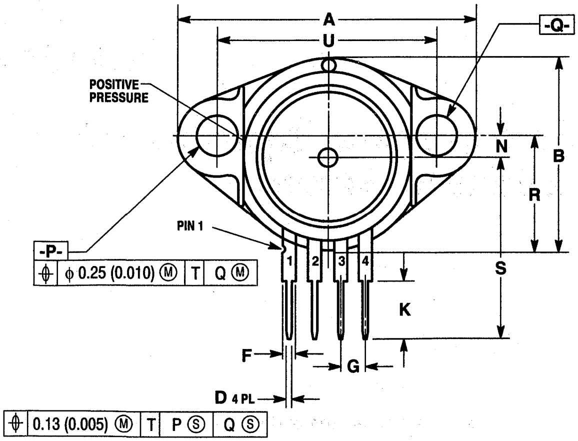
- permanent versus removable
- application
- cost

The purpose of mounting hardware is not only to secure the sensor in place, but also to remove the stresses from the sensor leads. In addition, these stresses can be high if the hose is not properly secured to the sensor port. Screws, rivets, push-pins, and clips are a few types of hardware that can be used. Refer to Figure 2.



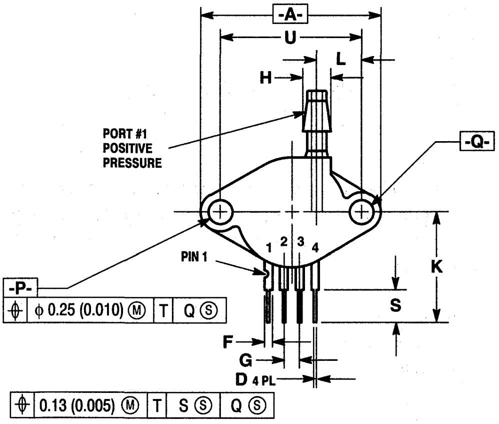
Screw **Rivet** **Push-Pin**

Figure 2. Mounting Hardware



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. 371D-01 OBSOLETE, NEW STANDARD 371D-02.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	27.94	30.48	1.100	1.200
B	18.80	19.30	0.740	0.760
C	16.13	16.51	0.635	0.650
D	0.41	0.50	0.016	0.020
E	4.06	4.57	0.160	0.180
F	1.22	1.32	0.048	0.052
G	2.54 BSC		0.100 BSC	
J	0.36	0.40	0.014	0.016
K	5.84 REF		0.230 REF	
N	1.78	2.03	0.070	0.080
P	3.81	4.06	0.150	0.160
Q	3.81	4.06	0.150	0.160
R	11.30	11.68	0.445	0.460
S	17.40	18.16	0.685	0.715
U	21.33	21.84	0.840	0.860
V	4.69	4.95	0.185	0.195



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982
2. CONTROLLING DIMENSION: INCH.
3. 350-01 OBSOLETE, NEW STANDARD 350-03.

	MILLIMETERS		INCHES	
DIM	MIN	MAX	MIN	MAX
A	28.95	29.97	1.140	1.180
B	17.39	18.16	0.685	0.715
C	7.74	8.15	0.305	0.321
D	0.40	0.50	0.016	0.020
F	1.21	1.32	0.048	0.052
G	2.54 BSC		0.100 BSC	
H	4.62	4.92	0.182	0.194
J	0.35	0.40	0.014	0.016
K	17.39	18.16	0.685	0.715
L	7.34	7.62	0.290	0.300
N	10.67	11.12	0.420	0.440
P	3.88	4.01	0.153	0.158
Q	3.88	4.01	0.153	0.158
R	5.86	6.35	0.231	0.250
S	5.84 REF		0.230 REF	
U	23.11 BSC		0.910 BSC	

Figure 3. Case Outline Drawings
Top: Case 371D
Bottom: Case 350-03

To mount any of the devices except Case 371-05/06 and 867E) to a flat surface such as a circuit board, the spacing and diameter for the mounting holes should be made according to Figure 3.

Mounting Screws

Mounting screws are recommended for making a very secure, yet removable connection. The screws can be either metal or nylon, depending on the application. The holes are 0.155″ diameter which fits a #6 machine screw. The screw can be threaded directly into the base mounting surface or go through the base and use a flat washer and nut (on a circuit board) to secure to the device.

MOUNTING TORQUE

The torque specifications are very important. The sensor package should not be over tightened because it can crack, causing the sensor to leak. The recommended torque specification for the sensor packages are as follows:

Port Style	Torque Range
Single side port:	
port side down	3–4 in–lb
port side up	6–7 in–lb
Differential port (dual port)	9–10 in–lb
Axial side port	9–10 in–lb

The torque range is based on installation at room temperature. Since the sensor thermoplastic material has a higher TCE (temperature coefficient of expansion) than common metals, the torque will increase as temperature increases. Therefore, if the device will be subjected to very low temperatures, the torque may need to be increased slightly. If a precision torque wrench is not available, these torques all work out to be roughly 1/2 of a turn past "finger tight" (contact) at room temperature.

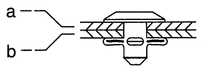
Tightening beyond these recommendations may damage the package, or affect the performance of the device.

Nylon Screws

Motorola recommends the use of #6–32 nylon screws as a hardware option. However, they should not be torqued excessively. The nylon screw will twist and deform under higher than recommended torque. These screws should be used with a nylon nut.

Rivets

Rivets are excellent fasteners which are strong and very inexpensive. However, they are a permanent connection. Plastic rivets are recommended because metal rivets may damage the plastic package. When selecting a rivet size, the most important dimension, besides diameter, is the grip range. The grip range is the combined thickness of the sensor package and the thickness of the mounting surface. Package thicknesses are listed below.

Port Style	Thickness, a	Grip Range = a + b
Single side port	0.321″ (8.15 mm)	
Dual side port	0.420″ (10.66 mm)	
Axial side port	0.321″ (8.15 mm)	
Stovepipe port	(Does not apply)	

Push-Pins

Plastic push pins or ITW FasTex "Christmas Tree" pins are an excellent way to make a low cost and easily removable connection. However, these fasteners should not be used for permanent connections. Remember, the fastener should take all of the static and dynamic loads off the sensor leads. This type of fastener does not do this completely.

HOSE APPLICATIONS

By using a hose, a sensor can be located in a convenient place away from the actual sensing location which could be a hazardous and difficult area to reach. There are many types of hoses on the market. They have different wall thicknesses, working pressures, working temperatures, material compositions, and media compatibilities. All of the hoses referenced here are 1/8″ inside diameter and 1/16″ wall thickness, which produces a 1/4″ outside diameter. Since all the port hose barbs are 1/8″, they require 1/8″ inside diameter hose. The intent is for use in air only and any questions about hoses for your specific application should be directed to the hose manufacturer. Four main types of hose are available:

- Vinyl
- Tygon
- Urethane
- Nylon

Vinyl hose is inexpensive and is best in applications with pressures under 50 psig and at room temperature. It is flexible and durable and should not crack or deteriorate with age. This type of hose should be used with a hose clamp such as those listed later in this application note. Two brands of vinyl hose are:

Hose	Wall Thickness	Max. Press. @ 70°F (24°C)	Max. Temp. (°F)/(°C)
Clippard #3814-1	1/16″	105	100/(38)
Herco Clear #0500-037	1/16″	54	180/(82)

Tygon tubing is slightly more expensive than vinyl, but it is the most common brand, and it is also very flexible. It also is recommended for use at room temperature and applications below 50 psig. This tubing is also recommended for applications where the hose may be removed and reattached several times. This tubing should also be used with a hose clamp.

Tubing	Wall Thickness	Max. Press. @ 73°F (25°C)	Max. Temp. (°F)/(°C)
Tygon B-44-3	1/16″	62	165/(74)

Urethane tubing is the most expensive of the four types described herein. It can be used at higher pressures (up to 100 psig) and temperatures up to 100°F (38°C). It is flexible, although its flexibility is not as good as vinyl or Tygon. Urethane tubing is very strong and it is not necessary to use a hose clamp, although it is recommended.

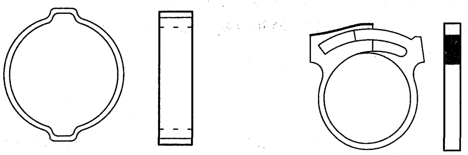
Two brands of urethane hose are:

Hose	Wall Thickness	Max. Press. @ 70°F (24°C)	Max. Temp. (°F)/(°C)
Clippard #3814-6	1/16″	105	120/(49)
Herco Clear #0585-037	1/16″	105	225/(107)

Nylon tubing does not work well with Motorola's sensors. It is typically used in high pressure applications with metal fittings (such as compressed air).

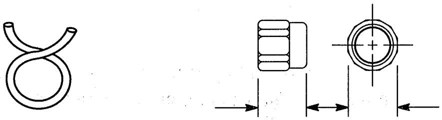
HOSE CLAMPS

Hose clamps should be employed for use with all hoses listed above. They provide a strong connection with the sensor which prevents the hose from working itself off, and also reduces the chance of leakage. There are many types of hose clamps that can be used with the ported sensors. Here are some of the most common hose clamps used with hoses.



Crimp-on Clamp

Nylon Snap



Spring Wire

Screw-on

Figure 4. Hose Clamps

The two clamps most recommended by Motorola are the crimp-on clamp and the screw-on, Clippard reusable clamp. The crimp-on type clamp is offered from both Ryan Herco (#0929-007) and Clippard (#5000-2). Once crimped in place, it provides a very secure hold, but it is not easily removed and is not reusable. The Clippard, reusable hose clamp is a brass, self-threading clamp, which provides an equally strong grip as the crimp-on type just described. The drawback is the reusable clamp is considerably more expensive. The nylon snap is also reusable, however the size options do not match the necessary outside diameter. The spring wire clamp, common in the automotive industry, and known for its very low cost and ease of use, also has a size matching problem. Custom fit spring wire clamps may provide some cost savings in particular applications.

SUPPLIER LIST

Hoses

Norton-Performance Plastics
Worldwide Headquarters
150 Dey Road, Wayne, NJ 07470-4599 USA
(201) 596-4700
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MOTOROLA
SEMICONDUCTOR
TECHNICAL DATA

AN1516

Liquid Level Control Using a Motorola Pressure Sensor

Prepared by: JC Hamelain
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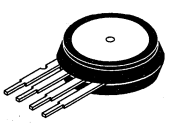
INTRODUCTION

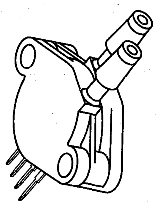
Motorola Discrete Products provides a complete solution for designing a low cost system for direct and accurate liquid level control using an ac powered pump or solenoid valve. This circuit approach which exclusively uses Motorola semiconductor parts, incorporates a piezoresistive pressure sensor with on-chip temperature compensation and a new solid-state relay with an integrated power triac, to drive directly the liquid level control equipment from the domestic 110/220 V 50/60 Hz ac main power line.

PRESSURE SENSOR DESCRIPTION

The MPX2000 Series pressure sensor integrates on-chip, laser-trimmed resistors for offset calibration and temperature compensation. The pressure sensitive element is a patented, single piezoresistive implant which replaces the four resistor Wheatstone bridge traditionally used by most pressure sensor manufacturers.



**BASIC CHIP
CARRIER ELEMENT
CASE 344**



**DIFFERENTIAL
PORT OPTION
CASE 352**

Depending on the application and pressure range, the sensor may be chosen from the following portfolio. For this application the MPX2010DP was selected.

Device	Pressure Range	Application Sensitivity*
MPX2010DP	0 to 10 kPa	± 0.01 kPa (1 mm H_2O)
MPX2050DP	0 to 50 kPa	± 0.05 kPa (5 mm H_2O)
MPX2100DP	0 to 100 kPa	± 0.1 kPa (10 mm H_2O)
MPX2200DP	0 to 200 kPa	± 0.2 kPa (20 mm H_2O)

* after proper gain adjustment

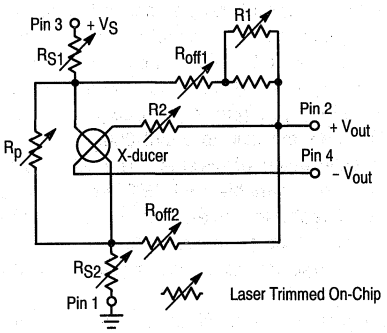
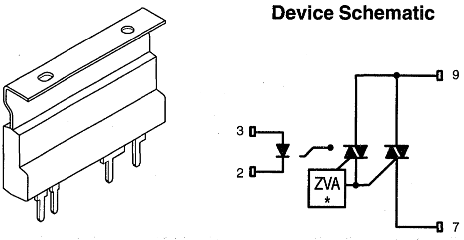


Figure 1. Pressure Sensor MPX2000 Series

1/94

POWER OPTO ISOLATOR MOC2A60 DESCRIPTION

The MOC2A60 is a new Motorola POWER OPTO™ isolator and consists of a gallium arsenide, infrared emitting diode, which is optically coupled to a zero-cross triac driver and a power triac. It is capable of driving a load of up to 2 A (rms) directly from a line voltage of 220 V (50/60 Hz).



CASE 417
PLASTIC
PACKAGE

* Zero Voltage Activate Circuit

1, 4, 5, 6, 8. No Pin
2. LED Cathode
3. LED Anode
7. Main Terminal
9. Main Terminal

Figure 2. MOC2A60 POWER OPTO Isolator

SIGNAL CONDITIONING

When a full range pressure is applied to the MPX2010DP, it will provide an output of about 20 mV (at an 8 V supply). Therefore, for an application using only a few percent of the pressure range, the available signal may be as low as a few hundred microvolts. To be useful, the sensor signal must be amplified. This is achieved via a true differential amplifier (A1 and A2) as shown in Figure 4. The GAIN ADJ (500 ohm) resistor, R_G, sets the gain to about 200.

The differential output of this stage is amplified by a second stage (A3) with a variable OFFSET resistor. This stage performs a differential to single-ended output conversion and references this output to the adjustable offset voltage. This output is then compared to a voltage (V_{REF} = 4 V at TP2) at the input of the third stage (A4).

This last amplifier is used as an inverted comparator amplifier with hysteresis (Schmitt trigger) which provides a logic signal (TP3) within a preset range variation of about 10% of the input (selected by the ratio R9/(R9 + R7).

If the pressure sensor delivers a voltage to the input of the Schmitt trigger (pin 13) lower than the reference voltage (pin 12), then the output voltage (pin 14) is high and the drive current for the power stage MOC2A60 is provided. When the sensor output increases above the reference voltage, the output at pin 14 goes low and no drive current is available.

The amplifier used is a Motorola MC33179. This is a quad amplifier with large current output drive capability (more than 80 mA).

OUTPUT POWER STAGE

For safety reasons, it is important to prevent any direct contact between the ac main power line and the liquid environment or the tank. In order to maintain full isolation between the sensor circuitry and the main power, the solid-state relay is placed between the low voltage circuit (sensor and amplifier) and the ac power line used by the pump and compressor.

The output of the last stage of the MC33179 is used as a current source to drive the LED (light emitting diode). The series resistor, R8, limits the current into the LED to approximately 15 mA and guarantees an optimum drive for the power opto-triac. The LD1 (MFOE76), which is an infrared light emitting diode, is used as an indicator to detect when the load is under power.

The MOC2A60 works like a switch to turn ON or OFF the pump's power source. This device can drive up to 2 A for an ac load and is perfectly suited for the medium power motors (less than 500 watts) used in many applications. It consists of an opto-triac driving a power triac and has a zero-crossing detection to limit the power line disturbance problems when fast switching selfic loads. An RC network, placed in parallel with the output of the solid-state relay is not required, but it is good design practice for managing large voltage spikes coming from the inductive load commutation. The load itself (motor or solenoid valve) is connected in series with the solid-state relay to the main power line.

EXAMPLE OF APPLICATION: ACCURATE LIQUID LEVEL MONITORING

The purpose of the described application is to provide an electronic system which maintains a constant liquid level in a tank (within ± 5 mm H_2O). The liquid level is kept constant in the tank by an ac electric pump and a pressure sensor which provides the feedback information. The tank may be of any size. The application is not affected by the volume of the tank but only by the difference in the liquid level. Of course, the maximum level in the tank must correspond to a pressure within the operating range of the pressure sensor.

LIQUID LEVEL SENSORS

Motorola has developed a piezoresistive pressure sensor family which is very well adapted for level sensing, especially when using an air pipe sensing method. These devices may also be used with a bubbling method or equivalent.

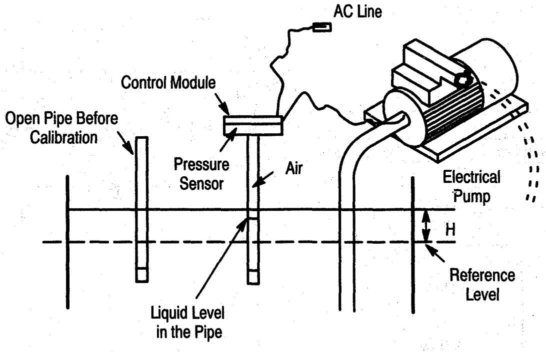


Figure 2. Figure 3. Liquid Level Monitoring

LEVEL SENSING THEORY

If a pipe is placed vertically, with one end dipped into a liquid and the other end opened, the level in the pipe will be exactly the same as the level in the tank. However, if the upper end of the pipe is closed off and some air volume is trapped, the pressure in the pipe will vary proportionally with the liquid level change in the tank.

For example, if we assume that the liquid is water and that the water level rises in the tank by 10 mm, then the pressure in the pipe will increase by that same value (10 mm of water).

A gauge pressure sensor has one side connected to the pipe (pressure side) and the other side open to ambient (in this case, atmospheric) pressure. The pressure difference which corresponds to the change in the tank level is measured by the pressure sensor.

PRESSURE SENSOR CHOICE

In this example, a level sensing of 10 mm of water is desired. The equivalent pressure in kilo pascals is 0.09806 kPa. In this case, Motorola's temperature compensated 0–10 kPa, MPX2010 is an excellent choice. The sensor output, with a pressure of 0.09806 kPa applied, will result in 2.0 mV/kPa x 0.09806 = 0.196 mV.

The sensing system is designed with an amplifier gain of about 1000. Thus, the conditioned signal voltage given by the module is 1000 x 0.196 mV = 0.196 V with 10 mm – H_2O pressure.

Table 1. Liquid Level Sensors

METHOD	SENSOR	ADVANTAGE	DISADVANTAGES
Liquid weight	Magnetoresitive	Low power, no active electronic	Low resolution, range limited
	Magnetoresitive	Very high resolution	Complex electronic
	Ultrasonic	Easy to install	Need high power, low accuracy
Liquid resistivity	No active electronic	No active electronic	Low resolution, liquid dependent
String potentiometer	Potentiometer	Low power, no active electronic	Poor linearity, corrosion
Pressure	Silicon sensors	Inexpensive good resolution, wide range measurements	Active electronic, need power

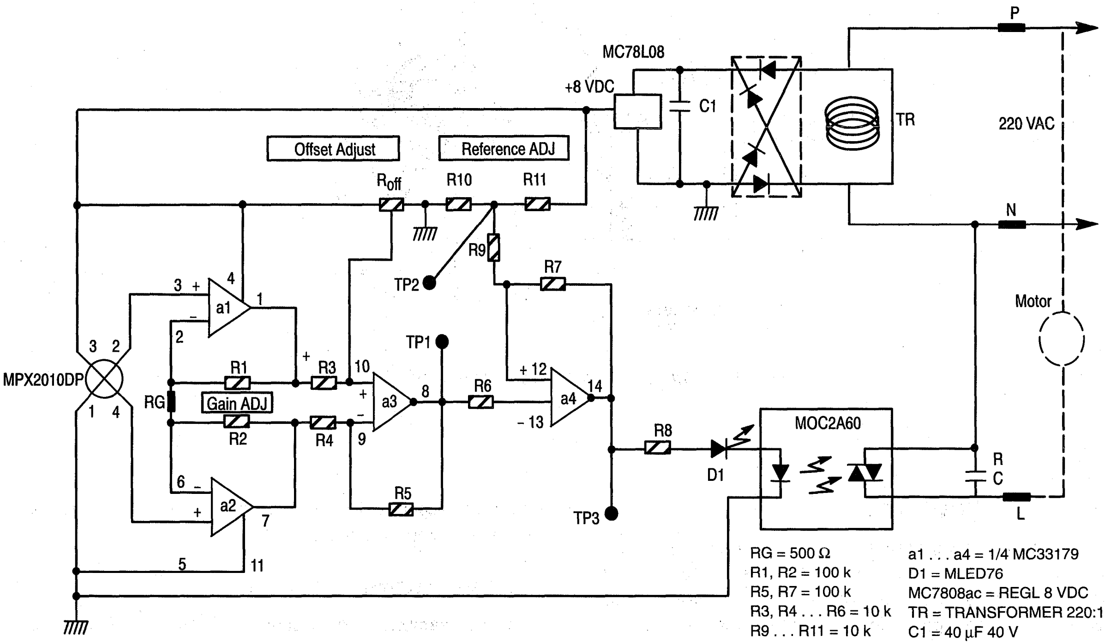
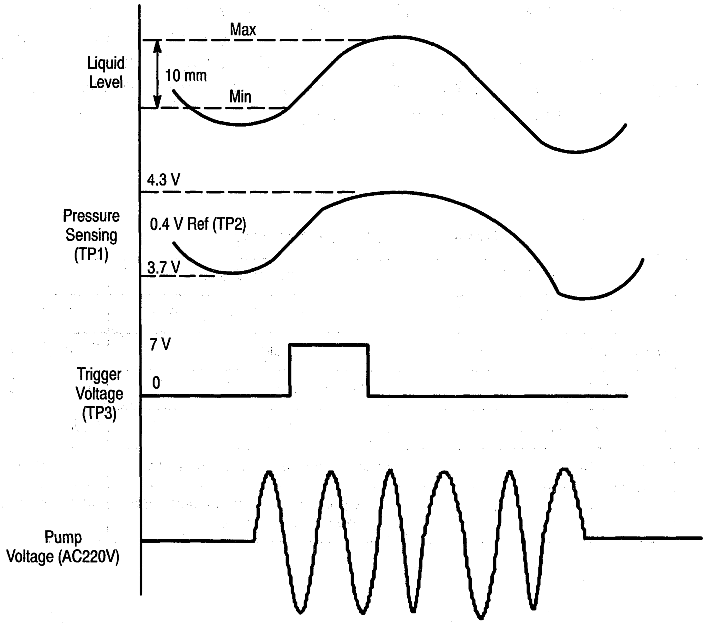


Figure 4. Electrical Circuit

RG = 500 Ω
R1, R2 = 100 k
R5, R7 = 100 k
R3, R4 . . . R6 = 10 k
R9 . . . R11 = 10 k
R8 = 100
R_{off} = 25 k var

a1 . . . a4 = 1/4 MC33179
D1 = MLED76
MC7808ac = REGL 8 VDC
TR = TRANSFORMER 220:12 V
C1 = 40 µF 40 V



Sensing for minimum level (pumping into the tank)

The sensing probe is tied to the positive pressure port of the sensor. The pump is turned on to fill the tank when the minimum level is reached.

Figure 5. Functional Diagram

LEVEL CONTROL MODES

This application describes two ways to keep the liquid level constant in the tank; first, by pumping the water out if the liquid level rises above the reference, or second, by pumping the water in if the liquid level drops below the reference.

If pumping water out, the pump must be OFF when the liquid level is below the reference level. To turn the pump ON, the sensor signal must be decreased to drop the input to the Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the NEGATIVE pressure port (back or vacuum side) of the sensor. In the condition when the pressure increases (liquid level rises), the sensor voltage will decrease and the pump will turn ON when the sensor output crosses the referenced level. As pumping continues, the level in the tank decreases (thus the pressure on the sensor decreases) and the sensor signal increases back up to the trigger point where the pump was turned OFF.

In the case of pumping water into the tank, the pump must be OFF when the liquid level is above the reference level. To turn ON the pump, the sensor signal must be decreased to drive the input Schmitt trigger below the reference voltage. To do this, the sensing pipe must be connected to the POSITIVE pressure port (top side) of the sensor. In this configuration when the pressure on the sensor decreases, (liquid level drops) the sensor voltage also decreases and the pump is turned ON when the signal exceeds the reference. As pumping continues, the water level increases and when the maximum level is reached, the Schmitt trigger turns the pump OFF.

ADJUSTMENTS

The sensing tube is placed into the water at a distance below the minimum limit level anywhere in the tank. The other end of the tube is opened to atmosphere. When the tank is filled to the desired maximum (or minimum) level, the pressure sensor is connected to the tube with the desired port configuration for the application. Then the water level in the tank is the reference.

After connecting the tube to the pressure sensor, the module must be adjusted to control the water level. The output voltage at TP1 is preadjusted to about 4 V (half of the supply voltage). When the sensor is connected to the tube, the module output is ON (lighted) or OFF. By adjusting the offset adjust potentiometer the output is just turned into the other state: OFF, if it was ON or the reverse, ON, if it was OFF, (the change in the tank level may be simulated by moving the sensing tube up or down).

The reference point TP2 shows the ON/OFF reference voltage, and the switching point of the module is reached when the voltage at TP1 just crosses the value of the TP2 voltage. The module is designed for about 10 mm of difference level between ON and OFF (hysteresis).

CONCLUSION

This circuit design concept may be used to evaluate Motorola pressure sensors used as a liquid level switch. This basic circuit may be easily modified to provide an analog signal of the level within the controlled range. It may also be easily modified to provide tighter level control (±2 mm H_2O) by increasing the gain of the first amplifier stage (decreasing RG resistor).

The circuit is also a useful tool to evaluate the performance of the power optocoupler MOC2A60 when driving ac loads directly.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1517

Pressure Switch Design with Semiconductor Pressure Sensors

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INTRODUCTION

The Pressure Switch concept is simple, as are the additions to conventional signal conditioning circuitry required to provide a pressure threshold (or thresholds) at which the output switches logic state. This logic-level output may be input to a microcontroller, drive an LED, control an electronic switch, etc. The user-programmed threshold (or reference voltage) determines the pressure at which the output state will switch. An additional feature of this minimal component design is an optional user-defined hysteresis setting that will eliminate multiple output transitions when the pressure sensor voltage is comparable to the threshold voltage.

This paper presents the characteristics and design criteria for each of the major subsystems of the pressure switch design: the pressure sensor, the signal conditioning (gain) stage, and the comparator output stage. Additionally, an entire section will be devoted to comparator circuit topologies which employ comparator ICs and/or operational amplifiers. A window comparator design (high and low thresholds) is also included. This section will discuss the characteristics and design criteria for each comparator circuit, while evaluating them in overall performance (i.e., switching speed, logic-level voltages, etc.).

BASIC SENSOR OPERATION

Motorola's MPX2000 Series sensors are temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges from 10 kPa (1.5 psi) to 700 kPa (100 psi). Although the specifications (see Table 1) in the data sheets apply only to a 10 V supply voltage, the output of these devices is ratiometric with the supply voltage. For example, at the absolute maximum supply voltage rating, 16 V, the sensor will produce a differential output voltage of 64 mV at the rated full-scale pressure of the given sensor. One exception to this is that the full-scale span of the MPX2010 (10 kPa sensor) will be only 40 mV due to the device's slightly lower sensitivity. Since the maximum supply voltage produces the most output voltage, it is evident that even the best case scenario will require some signal conditioning to obtain a usable voltage level. For this specific design, an MPX2100 and 5.0 V supply is used to provide a maximum sensor output of 20 mV. The sensor output is then signal conditioned to obtain a four volt signal swing (span).

Table 1. MPX2100 Electrical Characteristics for V_S = 10 V, T_A = 25°C

Characteristic	Symbol	Minimum	Typical	Max	Unit
Pressure Range	P_{OP}	0		100	kPa
Supply Voltage	V_S		10	16	Vdc
Full Scale Span	V_{FSS}	38.5	40	41.5	mV
Zero Pressure Offset	V_{off}		0.05	0.1	mV
Sensitivity	S		0.4		mV/kPa
Linearity			0.05		%FSS
Temperature Effect on Span			0.5		%FSS
Temperature Effect on Offset			0.2		%FSS

THE SIGNAL CONDITIONING

The amplifier circuitry, shown in Figure 1, is composed of two op-amps. This interface circuit has a much lower component count than conventional quad op amp instrumentation amplifiers. The two op amp design offers the high input impedance, low output impedance, and high gain desired for a transducer interface, while performing a differential to single-ended conversion. The gain is set by the following equation:

$$\text{GAIN} = 1 + \frac{R6}{R5}$$

where R6 = R3 and R4 = R5.

For this specific design, the gain is set to 201 by setting R6 = 20 kΩ and R5 = 100 Ω. Using these values and setting R6 = R3 and R4 = R5 gives the desired gain without loading the reference voltage divider formed by R1 and R_{off}. The offset voltage is set via this voltage divider by choosing the value of R_{off}. This enables the user to adjust the offset for each application's requirements.

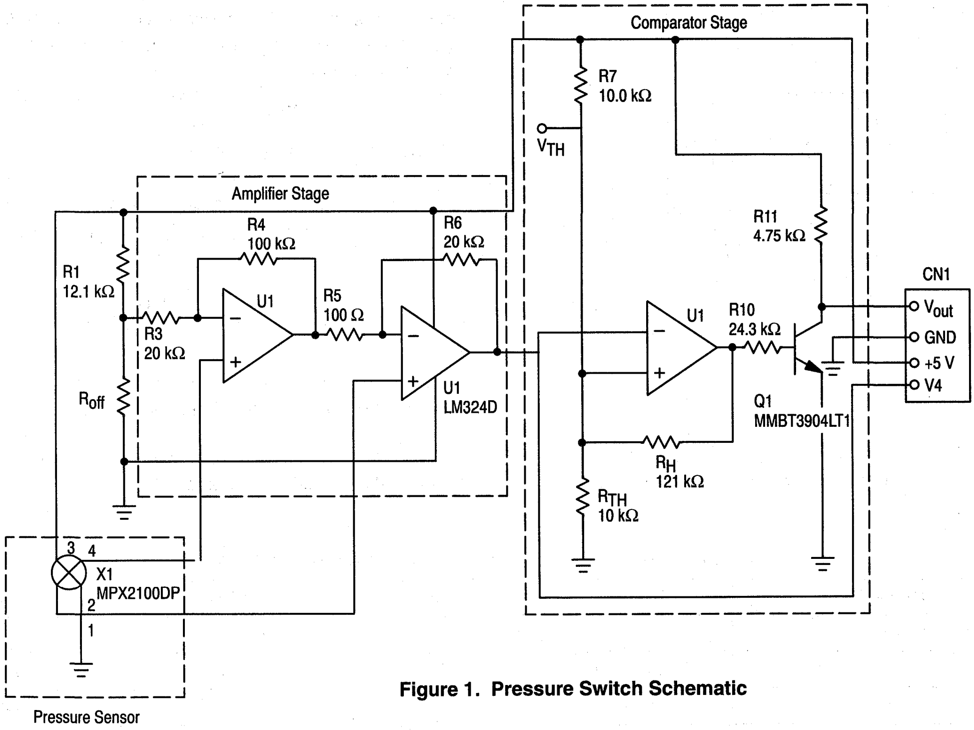

Figure 1. Pressure Switch Schematic

THE COMPARISON STAGE

The comparison stage is the "heart" of the pressure switch design. This stage converts the analog voltage output to a digital output, as dictated by the comparator's threshold. The comparison stage has a few design issues which must be addressed:

- The threshold for which the output switches must be programmable. The threshold is easily set by dividing the supply voltage with resistors R7 and R_{TH}. In Figure 1, the threshold is set at 2.5 V for R7 = R_{TH} = 10 kΩ.
- A method for providing an appropriate amount of hysteresis should be available. Hysteresis prevents multiple transitions from occurring when slow varying signal inputs oscillate about the threshold. The hysteresis can be set by applying positive feedback. The amount of hysteresis is determined by the value of the feedback resistor, R_H (refer to equations in the following section).
- It is ideal for the comparator's logic level output to swing from one supply rail to the other. In practice, this is not possible. Thus, the goal is to swing as high and low as possible for a given set of supplies. This offers the greatest difference between logic states and will avoid having a microcontroller read the switch level as being in an indeterminate state.
- In order to be compatible with CMOS circuitry and to avoid microcontroller timing delay errors, the comparator must switch sufficiently fast.
- By using two comparators, a window comparator may be implemented. The window comparator may be used to monitor when the applied pressure is within a set range. By adjusting the input thresholds, the window width can be customized for a given application. As with the single threshold design, positive feedback can be used to provide

hysteresis for both switching points. The window comparator and the other comparator circuits will be explained in the following section.

EXAMPLE COMPARATOR CIRCUITS

Several comparator circuits were built and evaluated. Comparator stages using the LM311 comparator, LM358 Op-Amp (with and without an output transistor stage), and LM339 were examined. Each comparator was evaluated on output voltage levels (dynamic range), transition speed, and the relative component count required for the complete pressure switch design. This comparison is tabulated in Table 2.

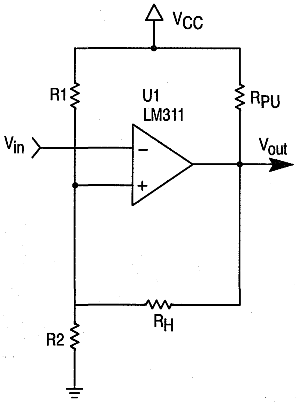

Figure 2. LM311 Comparator Circuit Schematic

LM311 Used in a Comparator Circuit

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. Additionally, the LM311 is a reverse logic circuit; that is, for an input lower than the reference voltage, the output is high. Likewise, when the input voltage is higher than the reference voltage, the output is low. Figure 2 shows a schematic of the LM311 stage with threshold setting resistor divider, hysteresis resistor, and the open-collector pull-up resistor. Table 2 shows the comparator's performance. Based on its performance, this circuit can be used in many types of applications, including interface to microprocessors.

The amount of hysteresis can be calculated by the following equations:

$$V_{REF} = \frac{R2}{R1 + R2} V_{CC},$$

neglecting the effect of R_H.

$$V_{REFH} = \frac{R1R2 + R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$V_{REFL} = \frac{R2R_H}{R1R2 + R1R_H + R2R_H} V_{CC}$$

$$\text{HYSTERESIS} = V_{REF} - V_{REFL}$$

when the normal state is below V_{REF}, or

$$\text{HYSTERESIS} = V_{REFH} - V_{REF}$$

when the normal state is above V_{REF}.

Table 2. Comparator Circuits Performance Characteristics

Characteristic	LM311	LM358	LM358 w/ Trans.	Unit
Switching Speeds				
Rise Time	1.40	5.58	2.20	µs
Fall Time	0.04	6.28	1.30	µs
Output Levels				
V_{OH}	4.91	3.64	5.00	V
V_{OL}	61.1	38.0	66.0	mV
Circuit Logic Type	NEGATIVE	NEGATIVE	POSITIVE	

The initial calculation for V_{REF} will be slightly in error due to neglecting the effect of R_H. To establish a precise value for V_{REF} (including R_H in the circuit), recompute R1 taking into account that V_{REF} depends on R1, R2, and R_H. It turns out that when the normal state is below V_{REF}, R_H is in parallel with R1:

$$V_{REF} = \frac{R2}{R1 \parallel R_H + R2} V_{CC}$$

(which is identical to the equation for V_{REFH})

Alternately, when the normal state is above V_{REF}, R_H is in parallel with R2:

$$V_{REF} = \frac{R2 \parallel R_H}{R1 + R2 \parallel R_H} V_{CC}$$

(which is identical to the equation for V_{REFL})

These two additional equations for V_{REF} can be used to calculate a more precise value for V_{REF}.

The user should be aware that V_{REF}, V_{REFH} and V_{REFL} are chosen for each application, depending on the desired switching point and hysteresis values. Also, the user must specify which range (either above or below the reference voltage) is the desired normal state (see Figure 3). Referring to Figure 3, if the normal state is below the reference voltage then V_{REFL} (V_{REFH} is only used to calculate a more precise value for V_{REF} as explained above) is below V_{REF} by the desired amount of hysteresis (use V_{REFL} to calculate R_H). Alternately, if the normal state is above the reference voltage then V_{REFH} (V_{REFL} is only used to calculate a more precise value for V_{REF}) is above V_{REF} by the desired amount of hysteresis (use V_{REFH} to calculate R_H).

An illustration of hysteresis and the relationship between these voltages is shown in Figure 3.

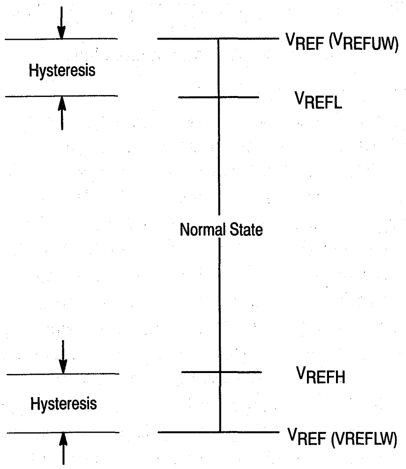

Figure 3. Setting the Reference Voltages

LM358 Op Amp Used in a Comparator Circuit

Figure 4 shows the schematic for the LM358 op amp comparator stage, and Table 2 shows its performance. Since the LM358 is an operational amplifier, it does not have the fast slew-rate of a comparator IC nor the open collector output. Comparing the LM358 and the LM311 (Table 2), the LM311 is better for logic/switching applications since its output nearly extends from rail to rail and has a sufficiently high switching speed. The LM358 will perform well in applications where the switching speed and logic-state levels are not critical (LED output, etc.). The design of the LM358 comparator is accomplished by using the same equations and procedure presented for the LM311. This circuit is also reverse logic.

LM358 Op Amp With a Transistor Output Stage Used in a Comparator Circuit

The LM358 with a transistor output stage is shown in Figure 5. This circuit has similar performance to the LM311 comparator: its output reaches the upper rail and its switching speed is comparable to the LM311's. This enhanced performance does, however, require an additional transistor and base resistor. Referring to Figure 1, note that this comparator topology was chosen for the pressure switch design. The LM324 is a quad op amp that has equivalent amplifier characteristics to the LM358.

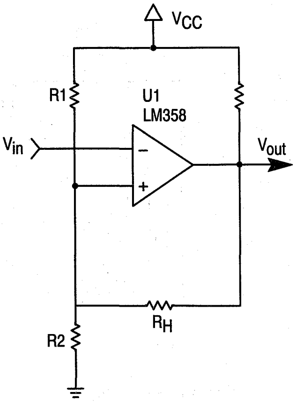

Figure 4. LM358 Comparator Circuit Schematic

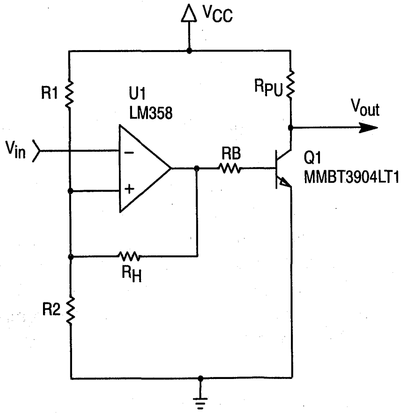

Figure 5. LM358 with a Transistor Output Stage Comparator Circuit Schematic

Like the other two circuits, this comparator circuit can be designed with the same equations and procedure. The values for R_B and R_{PU} are chosen to give a 5:1 ratio in Q1's collector current to its base current, in order to insure that Q1 is well-saturated (V_{out} can pull down very close to ground when Q1 is on). Once the 5:1 ratio is chosen, the actual resistance values determine the desired switching speed for turning Q1 on and off. Also, R_{PU} limits the collector current to be within the maximum specification for the given transistor (see example values in Figure 1). Unlike the other two circuits, this circuit is positive logic due to the additional inversion created at the output transistor stage.

LM339 Used in a Window Comparator Circuit

Using two voltage references to detect when the input is within a certain range is another possibility for the pressure switch design. The window comparator's schematic is shown in Figure 6. The LM339 is a quad comparator IC (it has open collector outputs), and its performance will be similar to that of the LM311.

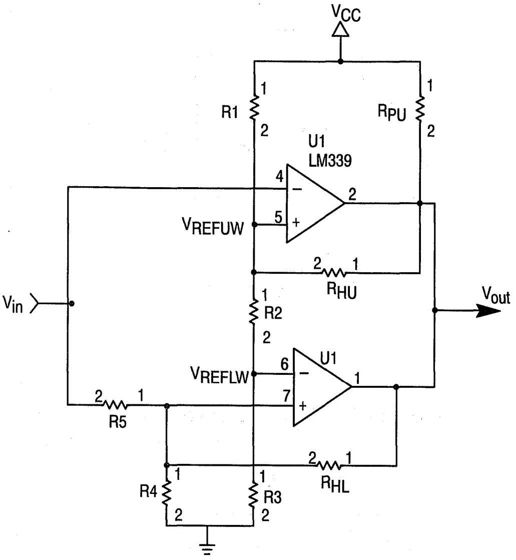

Figure 6. LM339 Window Comparator Circuit Schematic

Obtaining the correct amount of hysteresis and the input reference voltages is slightly different than with the other circuits. The following equations are used to calculate the hysteresis and reference voltages. Referring to Figure 3, V_{REFUW} is the upper window reference voltage and V_{REFLW} is the lower window reference voltage. Remember that reference voltage and threshold voltage are interchangeable terms.

For the upper window threshold:

Choose the value for V_{REFUW} and R1 (e.g., 10 kΩ). Then, by voltage division, calculate the total resistance of the combination of R2 and R3 (named R23 for identification) to obtain the desired value for V_{REFUW}, neglecting the effect of R_{HU}:

$$V_{REFUW} = \frac{R23}{R1 + R23} V_{CC}$$

The amount of hysteresis can be calculated by the following equation:

$$V_{REFL} = \frac{R23R_{HU}}{R1R23 + R1R_{HU} + R23R_{HU}} V_{CC}$$

Notice that the upper window reference voltage, V_{REFUW}, is now equal to its V_{REFL} value, since at this moment, the input voltage is above the normal state.

$$\text{HYSTERESIS} = V_{REFUW} - V_{REFL},$$

where VREFL is chosen to give the desired amount of hysteresis for the application.

The initial calculation for V_{REFUW} will be slightly in error due to neglecting the effect of R_{HU}. To establish a precise value for V_{REFUW} (including R_{HU} in the circuit), recompute R1 taking into account that V_{REFUW} depends on R2 and R3 and the parallel combination of R1 and R_{HU}. This more precise value is calculated with the following equation:

$$V_{REFUW} = \frac{R23}{R1 \parallel R_{HU} + R23} V_{CC}$$

for the lower window threshold choose the value for V_{REFLW}.

$$\text{Set } V_{REFLW} = \frac{R3}{R1 \parallel R_{HU} + R2 + R3} V_{CC},$$

where R2 + R3 = R23 from above calculation.

To calculate the hysteresis resistor:

The input to the lower comparator is one half V_{in} (since R4 = R5) when in the normal state. When V_{REFLW} is above one half of V_{in} (i.e., the input voltage has fallen below the window), R_{HL} parallels R4, thus loading down V_{in}. The resulting input to the comparator can be referred to as V_{INL} (a lower input voltage). To summarize, when the input is within the window, the output is high and only R4 is connected to ground from the comparator's positive terminal. This establishes one half of V_{in} to be compared with V_{REFLW}. When the input voltage is below V_{REFLW}, the output is low, and R_{HL} is effectively in parallel with R4. By voltage division, less of the input voltage will fall across the parallel combination of R4 and R_{HL}, demanding that a higher input voltage at V_{in} be required to make the noninverting input exceed V_{REFLW}.

Therefore the following equations are established:

$$\text{HYSTERESIS} = V_{REFLW} - V_{INL}$$

Choose R4 = R5 to simplify the design.

$$R_{HL} = \frac{R4R5\,(V_{REFLW} - V_{INL} - V_{CC})}{(R4 + R5)(V_{INL} - V_{REFLW})}$$

IMPORTANT NOTE:

As explained above, because the input voltage is divided in half by R4 and R5, all calculations are done relative to the one half value of V_{in}. Therefore, for a hysteresis of 200 mV (relative to V_{in}), the above equations must use one half this hysteresis value (100 mV). Also, if a V_{REFLW} value of 2.0 V is desired (relative to V_{in}), then 1.0 V for its value should be used in the above equations. The value for V_{INL} should be scaled by one half also.

The window comparator design can also be designed using operational amplifiers and the same equations as for the LM339 comparator circuit. For the best performance, however, a transistor output stage should be included in the design.

TEST/CALIBRATION PROCEDURE

1. Before testing the circuit, the user-defined values for R_{TH}, R_H and R_{off} should be calculated for the desired application.

The sensor offset voltage is set by

$$V_{off} = \frac{R_{off}}{R1 + R_{off}} V_{CC}.$$

Then, the amplified sensor voltage corresponding to a given pressure is calculated by

$$V_{sensor} = 201 \times 0.0002 \times \text{APPLIED PRESSURE} + V_{off},$$

where 201 is the gain, 0.0002 is in units of V/kPa and APPLIED PRESSURE is in kPa.

The threshold voltage, V_{TH}, at which the output changes state is calculated by determining V_{sensor} at the pressure that causes this change of state:

$$V_{TH} = V_{sensor}\text{ (@ pressure threshold)} = \frac{R_{TH}}{R7 + R_{TH}} V_{CC}.$$

If hysteresis is desired, refer to the LM311 Used in a Comparator section to determine R_H.

2. To test this design, connect a +5 volt supply between pins 3 and 4 of the connector CN1.
3. Connect a volt meter to pins 1 and 4 of CN1 to measure the output voltage and amplified sensor voltage, respectively.
4. Connect an additional volt meter to the V_{TH} probe point to verify the threshold voltage.
5. Turn on the supply voltage.
6. With no pressure applied, check to see that V_{off} is correct by measuring the voltage at the output of the gain stage (the volt meter connected to Pin 4 of CN1). If desired, V_{off} can be fine tuned by using a potentiometer for R_{off}.
7. Check to see that the volt meter monitoring V_{TH} displays the desired voltage for the output to change states. Use a potentiometer for R_{TH} to fine tune V_{TH}, if desired.
8. Apply pressure to the sensor. Monitor the sensor's output via the volt meter connected to pin 4 of CN1. The output will switch from low to high when this pressure sensor voltage reaches or exceeds the threshold voltage.
9. If hysteresis is used, with the output high (pressure sensor voltage greater than the threshold voltage), check to see if V_{TH} has dropped by the amount of hysteresis desired. A potentiometer can be used for R_H to fine tune the amount of hysteresis.

CONCLUSION

The pressure switch design uses a comparator to create a logic level output by comparing the pressure sensor output voltage and a user-defined reference voltage. The flexibility of this minimal component, high performance design makes it compatible with many different applications. The design presented here uses an op amp with a transistor output stage, yielding excellent logic-level outputs and output transition speeds for many applications. Finally, several other comparison stage designs, including a window comparator, are evaluated and compared for overall performance.

MOTOROLA
SEMICONDUCTOR
APPLICATION NOTE

AN1518

Using a Pulse Width Modulated Output with Semiconductor Pressure Sensors

Prepared by: Eric Jacobsen and Jeff Baum
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INTRODUCTION

For remote sensing and noisy environment applications, a frequency modulated (FM) or pulse width modulated (PWM) output is more desirable than an analog voltage. FM and PWM outputs inherently have better noise immunity for these types of applications. Generally, FM outputs are more widely accepted than PWM outputs, because PWM outputs are restricted to a fixed frequency. However, obtaining a stable FM output is difficult to achieve without expensive, complex circuitry.

With either an FM or PWM output, a microcontroller can be used to detect edge transitions to translate the time-domain signal into a digital representation of the analog voltage signal. In conventional voltage-to-frequency (V/F) conversions, a voltage-controlled oscillator (VCO) may be used in conjunction with a microcontroller. This use of two time bases, one analog and one digital, can create additional inaccuracies. With either FM or PWM outputs, the microcontroller is only concerned with detecting edge transitions. If a programmable frequency, stable PWM output could be obtained with simple, inexpensive circuitry, a PWM output would be a cost-effective solution for noisy environment/remote sensing applications while incorporating the advantages of frequency outputs.

The Pulse Width Modulated Output Pressure Sensor design (Figure 1) utilizes simple, inexpensive circuitry to create an output waveform with a duty cycle that is linear to the applied pressure. Combining this circuitry with a single digital time base to create and measure the PWM signal, results in a stable, accurate output. Two additional advantages of this design are 1) an A/D converter is not required, and 2) since the PWM output calibration is controlled entirely by software, circuit-to-circuit variations due to component tolerances can be nullified.

The PWM Output Sensor system consists of a Motorola MPX5000 series pressure sensor, a ramp generator (transistor switch, constant current source, and capacitor), a comparator, and an MC68HC05P9 microcontroller. These subsystems are explained in detail below.

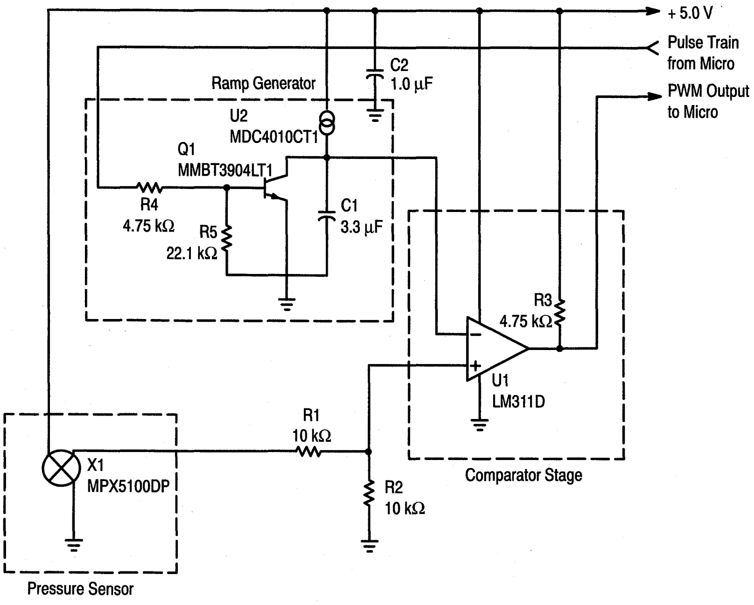


Figure 1. PWM Output Pressure Sensor Schematic

1/94

PRESSURE SENSOR

Motorola's MPX5000 series sensors are signal conditioned (amplified), temperature compensated and calibrated (i.e., offset and full-scale span are precision trimmed) pressure transducers. These sensors are available in full-scale pressure ranges of 50 kPa (7.3 psi) and 100 kPa (14.7 psi). With the recommended 5.0 V supply, the MPX5000 series produces an output of 0.5 V at zero pressure to 4.5 V at full scale pressure. Referring to the schematic of the system in Figure 1, note that the output of the pressure sensor is attenuated to one-half of its value by the resistor divider comprised of resistors R1 and R2. This yields a span of 2.0 V ranging from 0.25 V to 2.25 V at the non-inverting terminal of the comparator. Table 1 shows the electrical characteristics of the MPX5100.

Table 1. MPX5100DP Electrical Characteristics

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	0	—	100	kPa
Supply Voltage	V_S	—	5.0	6.0	Vdc
Full Scale Span	V_{FSS}	3.9	4.0	4.1	V
Zero Pressure Offset	V_{off}	0.4	0.5	0.6	V
Sensitivity	S	—	40	—	mV/kPa
Linearity	—	– 0.5	—	0.5	%FSS
Temperature Effect on Span	—	–1.0	—	1.0	%FSS
Temperature Effect on Offset	—	– 50	0.2	50	mV

THE RAMP GENERATOR

The ramp generator is shown in the schematic in Figure 1. A pulse train output from a microcontroller drives the ramp generator at the base of transistor Q1. This pulse can be accurately controlled in frequency as well as pulse duration via software (to be explained in the microcontroller section).

The ramp generator uses a constant current source to charge the capacitor. It is imperative to remember that this current source generates a stable current only when it has approximately 2.5 V or more across it. With less voltage across the current source, insufficient voltage will cause the current to fluctuate more than desired; thus, a design constraint for the ramp generator will dictate that the capacitor can be charged to only approximately 2.5 V, when using a 5.0 V supply.

The constant current charges the capacitor linearly by the following equation:

$$\Delta V = \frac{I\Delta t}{C} \tag{1}$$

where Δt is the capacitor's charging time and C is the capacitance.

Referring to Figure 2, when the pulse train sent by the microcontroller is low, the transistor is off, and the current source charges the capacitor linearly. When the pulse sent by the microcontroller is high, the transistor turns on into saturation, discharging the capacitor. The duration of the high part of the pulse train determines how long the capacitor discharges, and thus to what voltage it discharges. This is how the dc offset of the ramp waveform may be accurately controlled. Since the transistor saturates at approximately 60 mV, very little offset is needed to keep the capacitor from discharging completely.

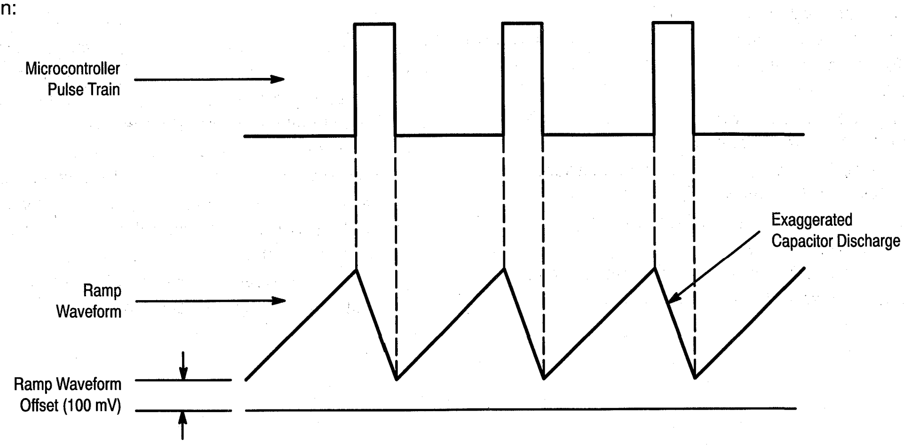


Figure 2. Ideal Ramp Waveform for the PWM Output Pressure Sensor

The PWM output is most linear when the ramp waveform's period consists mostly of the rising voltage edge (see Figure 2). If the capacitor were allowed to completely discharge (see Figure 3), a flat line at approximately 60 mV would separate the ramps, and these "flat spots" may result in non-linearities of the resultant PWM output (after comparing it to the sensor voltage). Thus, the best ramp waveform is produced when one ramp cycle begins immediately after another, and a slight dc offset disallows the capacitor from discharging completely.

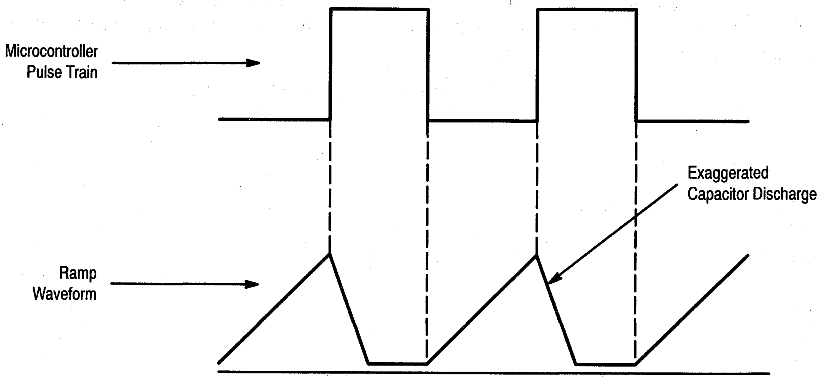


Figure 3. Non Ideal Ramp Waveform for the PWM Output Pressure Sensor

The flexibility of frequency control of the ramp waveform via the pulse train sent from the microcontroller allows a programmable-frequency PWM output. Using Equation 1 the frequency (inverse of period) can be calculated with a given capacitor so that the capacitor charges to a maximum ΔV of approximately 2.5 V (remember that the current source needs approximately 2.5 V across it to output a stable current). The importance of software control becomes evident here since the selected capacitor may have a tolerance of ± 20%. By adjusting the frequency and positive width of the pulse train, the desired ramp requirements are readily obtainable; thus, nullifying the effects of component variances.

For this design, the ramp spans approximately 2.4 V from 0.1 V to 2.5 V. At this voltage span, the current source is stable and results in a linear ramp. This ramp span was used for reasons which will become clear in the next section.

In summary, complete control of the ramp is achieved by the following adjustments of the microcontroller-created pulse train:

- Increase Frequency: Span of ramp decreases. The dc offset decreases slightly.
- Decrease Frequency: Span of ramp increases. The dc offset increases slightly.
- Increase Pulse Width: The dc offset decreases. Span decreases slightly.
- Decrease Pulse Width: The dc offset increases. Span increases slightly.

THE COMPARATOR STAGE

The LM311 chip is designed specifically for use as a comparator and thus has short delay times, high slew rate, and an open-collector output. A pull-up resistor at the output is all that is needed to obtain a rail-to-rail output. As Figure 1 shows, the pressure sensor output voltage is input to the non-inverting terminal of the op amp and the ramp is input to the inverting terminal. Therefore, when the pressure sensor voltage is higher than a given ramp voltage, the output is high; likewise, when the pressure sensor voltage is lower than a given ramp voltage, the output is low (refer to Figure 5). As mentioned in the Pressure Sensor section, resistors R1 and R2 of Figure 1 comprise the voltage divider that attenuates the pressure sensor's signal to a 2.0 V span ranging from 0.25 V to 2.25 V.

Since the pressure sensor voltage does not reach the ramp's minimum and maximum voltages, there will be a finite minimum and maximum pulse width for the PWM output. These minimum and maximum pulse widths are design constraints dictated by the comparator's slew rate. The system design ensures a minimum positive and negative pulse width of 20 μs to avoid nonlinearities at the high and low pressures where the positive duty cycle of the PWM output is at its extremes (refer to Figure 4). Depending on the speed of the microcontroller used in the system, the minimum required pulse width may be larger. This will be explained in the next section.

THE MICROCONTROLLER

The microcontroller for this application requires input capture and output compare timer channels. The output capture pin is programmed to output the pulse train that drives the ramp generator, and the input capture pin detects edge transitions to measure the PWM output pulse width.

Since software controls the entire system, a calibration routine may be implemented that allows an adjustment of the frequency and pulse width of the pulse train until the desired ramp waveform is obtained. Depending on the speed of the microcontroller, additional constraints on the minimum and maximum PWM output pulse widths may apply. For this design, the software latency incurred to create the pulse train at the output compare pin is approximately 40 μs. Consequently, the microcontroller cannot create a pulse train with a positive pulse width of less than 40 μs. Also, the software that measures the PWM output pulse width at the input capture pin requires approximately 20 μs to execute. Referring to Figure 5, the software interrupt that manipulates the pulse train always occurs near an edge detection on the input capture pin (additional software interrupt). Therefore, the minimum PWM output pulse width that can be accurately detected is approximately 60 μs (20 μs + 40 μs). This constrains the minimum and maximum pulse widths more than the slew rate of the comparator which was discussed earlier (refer to Figure 4).

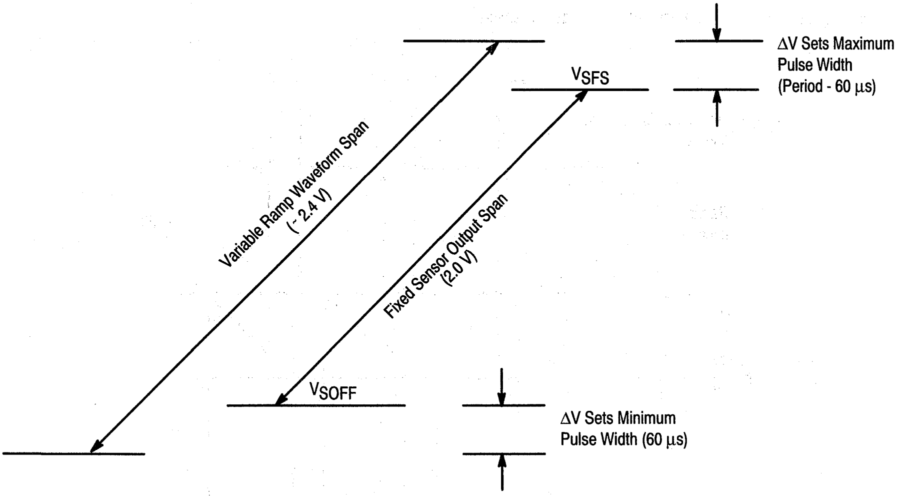


Figure 4. Desired Relationship Between the Ramp Waveform and Pressure Sensor Voltage Spans

An additional consideration is the resolution of the PWM output. The resolution is directly related to the maximum frequency of the pulse train. In our design, 512 μs are required to obtain at least 8-bit resolution. This is determined by the fact that a 4 MHz crystal yields a 2 MHz clock speed in the microcontroller. This, in turn, translates to 0.5 μs per clock tick. There are four clock cycles per timer count. This results in 2 μs per timer count. Thus, to obtain 256 timer counts (or 8-bit resolution), the difference between the zero pressure and full scale pressure PWM output pulse widths must be at least 512 μs (2 μs x 256). But since an additional 60 μs is needed at both pressure extremes of the output waveform, the total period must be at least 632 μs. This translates to a maximum frequency for the pulse train of approximately 1.6 kHz. With this frequency, voltage span of the ramp generator, and value of current charging the capacitor, the minimum capacitor value may be calculated with Equation 1.

To summarize:

The MC68HC705P9 runs off a 4 MHz crystal. The microcontroller internally divides this frequency by two to yield an internal clock speed of 2 MHz.

$$\frac{1}{2\ \text{MHz}} => \frac{0.5\ \mu\text{s}}{\text{clock cycle}}$$

And,

4 clock cycles = 1 timer count.

Therefore,

$$\frac{4\ \text{clock cycles}}{\text{timer count}} \times \frac{0.5\ \mu\text{s}}{\text{clock cycle}} = \frac{2\ \mu\text{s}}{\text{timer count}}$$

For 8-bit resolution,

$$\frac{2\ \mu\text{s}}{\text{timer count}} \times 256\ \text{counts} = 512\ \mu\text{s}$$

Adding a minimum of 60 μs each for the zero and full scale pressure pulse widths yields

$$512\ \mu\text{s} + 60\ \mu\text{s} + 60\ \mu\text{s} = 632\ \mu\text{s},$$

which is the required minimum pulse train period to drive the ramp generator.

Translating this to frequency, the maximum pulse train frequency is thus

$$\frac{1}{632\ \mu\text{s}} = 1.58\ \text{kHz}.$$

CALIBRATION PROCEDURE AND RESULTS

The following calibration procedure will explain how to systematically manipulate the pulse train to create a ramp that meets the necessary design constraints. The numbers used here are only for this design example. Figure 6 shows the linearity performance achieved by following this calibration procedure and setting up the ramp as indicated by Figures 4 and 5.

1. Start with a pulse train that has a pulse width and frequency that creates a ramp with about 100 mV dc offset and a span smaller than required. In this example the initial pulse width is 84 μs and the initial frequency is 1.85 kHz.
2. **Decrease** the **frequency** of the pulse train until the ramp span increases to approximately 2.4 V. The ramp span of 2.4 V will ensure that the maximum pulse width at full scale pressure will be at least 60 μs less than the total period. Note that by **decreasing** the **frequency** of the pulse train, a dc offset will begin to appear. This may result in the ramp looking nonlinear at the top.
3. If the ramp begins to become nonlinear, **increase** the **pulse width** to decrease the dc offset.
4. Repeat steps 2 and 3 until the ramp spans 2.4 V and has a dc offset of approximately 100 mV. The dc offset value is not critical, but the bottom of the ramp should have a "crisp" point at which the capacitor stops discharging and begins charging. Simply make sure that the minimum pulse width at zero pressure is at least 60 μs. Refer to Figures 4 and 5 to determine if the ramp is sufficient for the application.

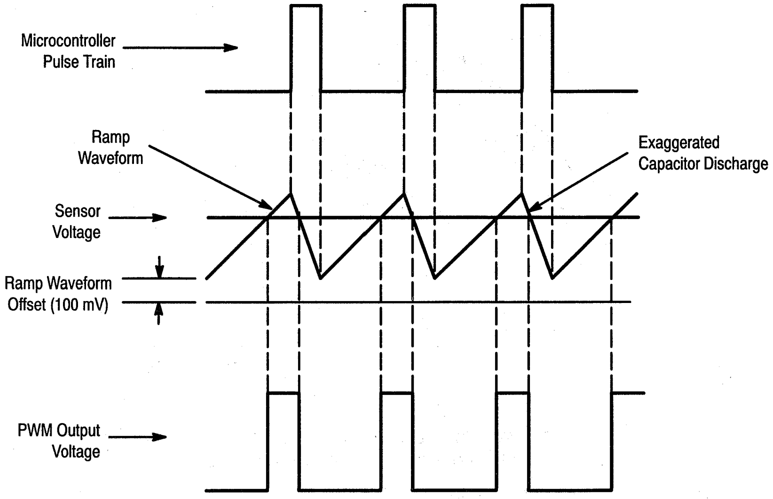


Figure 5. Relationships Between the PWM Output Pressure Sensor Voltages

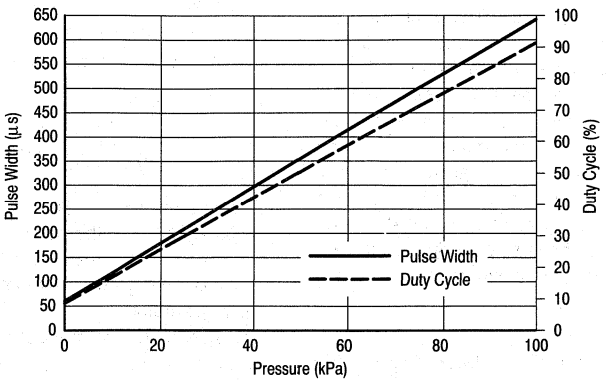
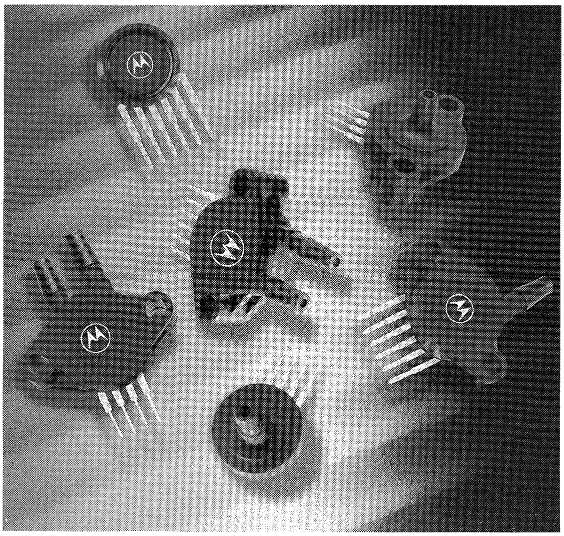


Figure 6. PWM Output Pressure Sensor Linearity Data

CONCLUSION

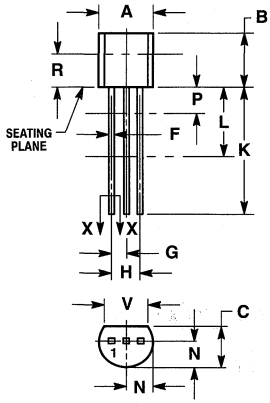
The Pulse Width Modulated Output Pressure Sensor uses a ramp generator to create a linear ramp which is compared to the amplified output of the pressure sensor at the input of a comparator. The resulting output is a digital waveform with a duty cycle that is linearly proportional to the input pressure. Although the pressure sensor output has a fixed offset and span, the ramp waveform is adjustable in frequency, dc offset, and voltage span. This flexibility enables the effect of component tolerances to be nullified and ensures that ramp span encompasses the pressure sensor output range. The ramp's span can be set to allow for the desired minimum and maximum duty cycle to guarantee a linear dynamic range.

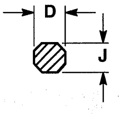


Section Six

Package Outline Dimensions

Package Outline Dimensions





SECTION X-X

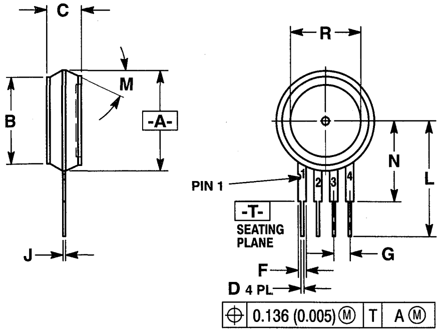
STYLE 1:
PIN 1. EMITTER
2. BASE
3. COLLECTOR

NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. CONTOUR OF PACKAGE BEYOND DIM R IS UNCONTROLLED.
4. DIM F APPLIES BETWEEN P AND L. DIM D AND J APPLIES BETWEEN L AND K MINIMUM. LEAD DIM IS UNCONTROLLED IN P AND BEYOND DIM K MINIMUM.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.175	0.205	4.45	5.20
B	0.170	0.210	4.32	5.33
C	0.125	0.165	3.18	4.19
D	0.016	0.022	0.41	0.55
F	0.016	0.019	0.41	0.48
G	0.045	0.055	1.15	1.39
H	0.095	0.105	2.42	2.66
J	0.015	0.020	0.39	0.50
K	0.500	—	12.70	—
L	0.250	—	6.35	—
N	0.080	0.105	2.04	2.66
P	—	0.100	—	2.54
R	0.115	—	2.93	—
V	0.135	—	3.43	—

CASE 29-04

SILICON TEMPERATURE SENSOR



STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

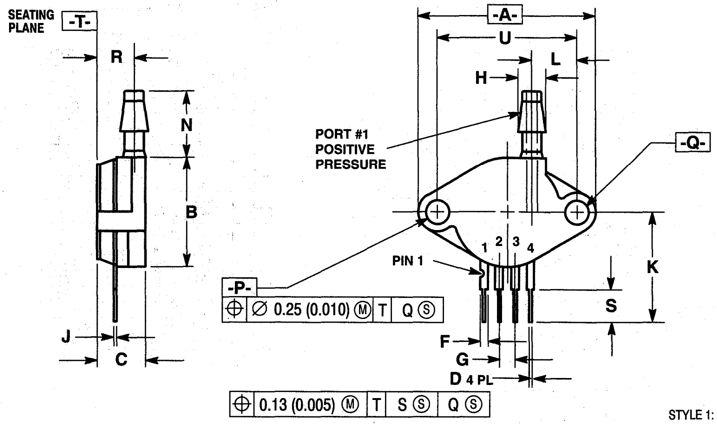
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.590	0.615	14.99	15.62
B	0.505	0.525	12.83	13.34
C	0.195	0.225	4.95	5.72
D	0.016	0.020	0.41	0.51
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.685	0.715	17.40	18.16
M	30° NOM		30° NOM	
N	0.480	0.500	12.19	12.70
R	0.420	0.450	10.67	11.43

CASE 344-08

BASIC ELEMENT (A, D)

PACKAGE OUTLINE DIMENSIONS (continued)



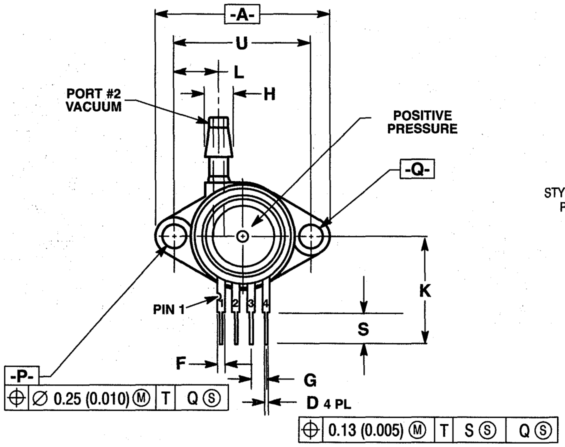
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.39	18.16
C	0.305	0.321	7.74	8.15
D	0.016	0.020	0.40	0.50
F	0.048	0.052	1.21	1.32
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.92
J	0.014	0.016	0.35	0.40
K	0.685	0.715	17.39	18.16
L	0.290	0.300	7.34	7.62
N	0.420	0.440	10.67	11.12
P	0.153	0.158	3.88	4.01
Q	0.153	0.158	3.88	4.01
R	0.231	0.250	5.86	6.35
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 350-03

PRESSURE SIDE PORTED (AP, GP)



STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

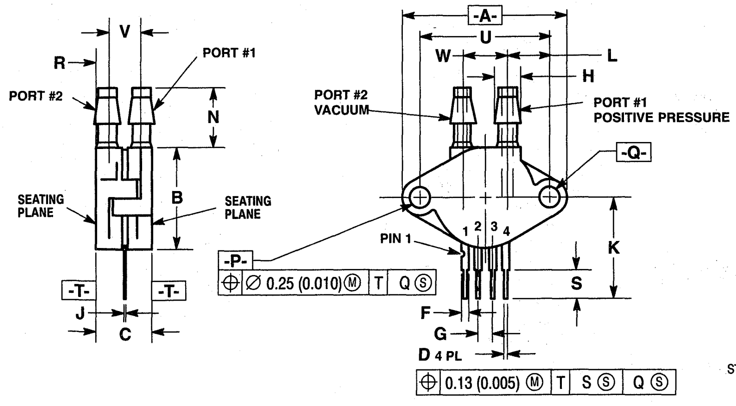
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.39	18.16
C	0.305	0.321	7.74	8.15
D	0.016	0.020	0.40	0.50
F	0.048	0.052	1.21	1.32
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.92
J	0.014	0.016	0.35	0.40
K	0.685	0.715	17.39	18.16
L	0.290	0.300	7.34	7.62
N	0.420	0.430	10.67	10.92
P	0.153	0.158	3.88	4.01
Q	0.153	0.158	3.88	4.01
R	0.231	0.250	5.86	6.35
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	

CASE 350-04

VACUUM SIDE PORTED (GVP)

PACKAGE OUTLINE DIMENSIONS (continued)



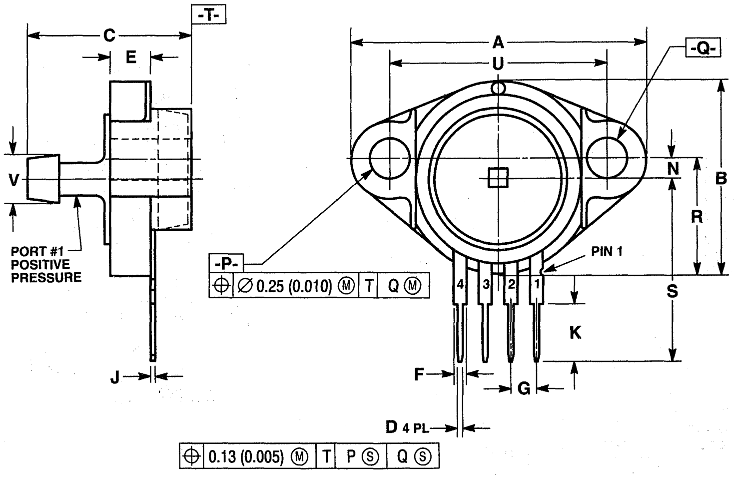
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.39	18.16
C	0.380	0.420	9.65	10.66
D	0.016	0.020	0.40	0.50
F	0.048	0.052	1.21	1.32
G	0.100 BSC		2.54 BSC	
H	0.182	0.194	4.62	4.92
J	0.014	0.016	0.35	0.40
K	0.685	0.715	17.39	18.16
L	0.290	0.300	7.34	7.62
N	0.420	0.430	10.67	10.92
P	0.153	0.158	3.88	4.01
Q	0.153	0.158	3.88	4.01
R	0.063	0.083	1.60	2.10
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	
V	0.243	0.273	6.17	6.93
W	0.310	0.330	7.87	8.38

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

CASE 352-02

PRESSURE AND VACUUM SIDES PORTED (DP)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

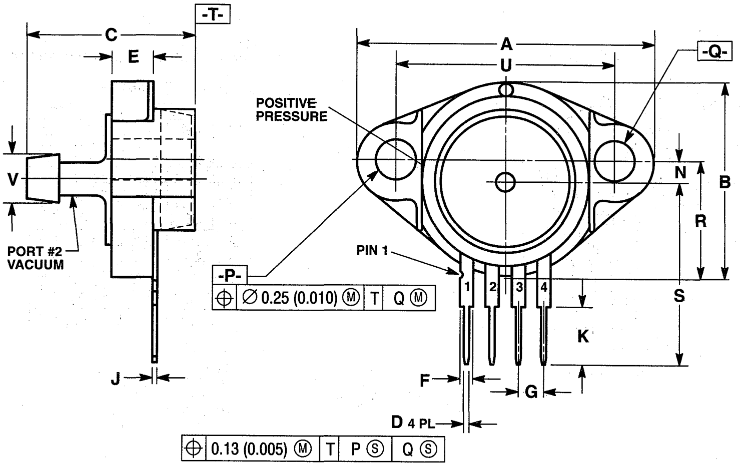
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	1.100	1.200	27.94	30.48
B	0.740	0.760	18.80	19.30
C	0.635	0.650	16.13	16.51
D	0.016	0.020	0.41	0.50
E	0.160	0.180	4.06	4.57
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.230 REF		5.84 REF	
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.445	0.460	11.30	11.68
S	0.685	0.715	17.40	18.16
U	0.840	0.860	21.33	21.84
V	0.185	0.195	4.69	4.95

STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (–) OUT

CASE 371C-02

PRESSURE SIDE PORTED (ASX, GSX)

PACKAGE OUTLINE DIMENSIONS (continued)



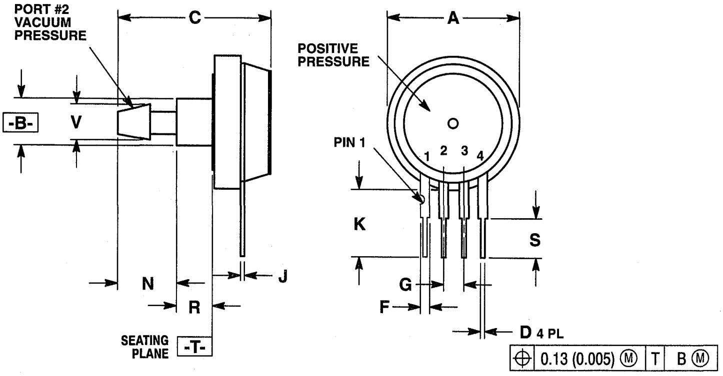
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.100	1.200	27.94	30.48
B	0.740	0.760	18.80	19.30
C	0.635	0.650	16.13	16.51
D	0.016	0.020	0.41	0.50
E	0.160	0.180	4.06	4.57
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.230 REF		5.84 REF	
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.445	0.460	11.30	11.68
S	0.685	0.715	17.40	18.16
U	0.840	0.860	21.33	21.84
V	0.185	0.195	4.69	4.95

STYLE 1:
PIN 1. GROUND
2. V (+) OUT
3. V SUPPLY
4. V (-) OUT

CASE 371D-02

VACUUM SIDE PORTED (GVSX)



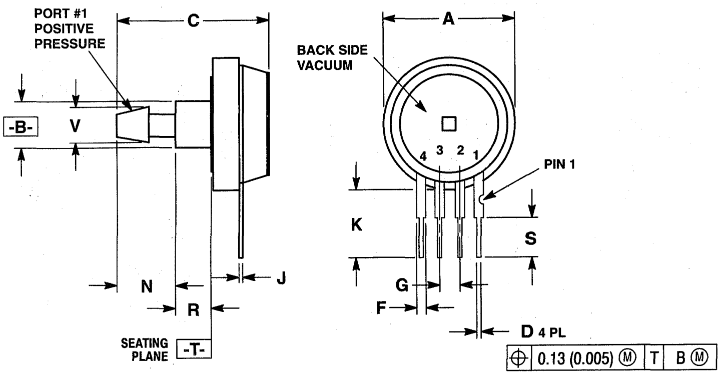
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.247	0.253	6.28	6.42
C	0.780	0.820	19.81	20.82
D	0.016	0.020	0.41	0.50
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.335	0.365	8.51	9.27
N	0.305	0.315	7.75	8.00
R	0.178	0.185	4.53	4.69
S	0.230 REF		5.84 REF	
V	0.182	0.194	4.63	4.92

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. - OUTPUT

CASE 371-05

VACUUM SIDE PORTED (GVS)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

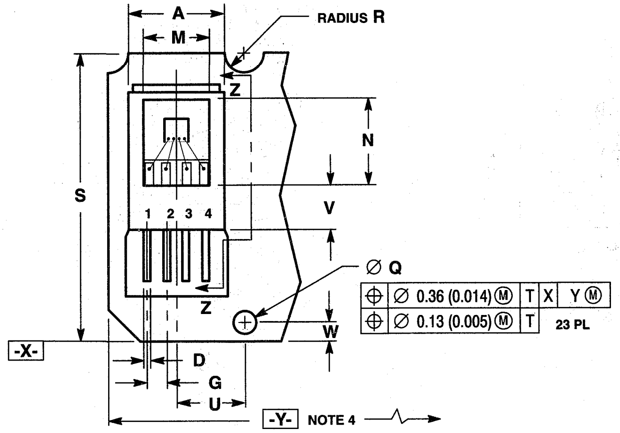
DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.247	0.253	6.28	6.42
C	0.780	0.820	19.81	20.82
D	0.016	0.020	0.41	0.50
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.335	0.365	8.51	9.27
N	0.305	0.315	7.75	8.00
R	0.178	0.185	4.53	4.69
S	0.230 REF		5.84 REF	
V	0.182	0.194	4.63	4.92

STYLE 1:
PIN 1. GROUND
2. + OUTPUT
3. + SUPPLY
4. – OUTPUT

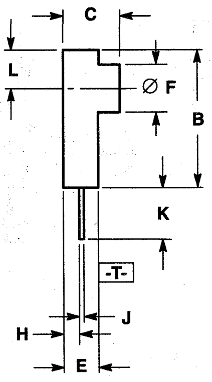
CASE 371-06

PRESSURE SIDE PORTED (AS, GS)

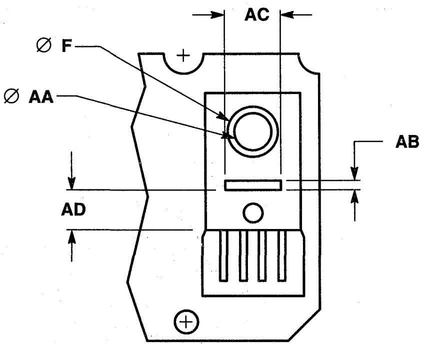
PACKAGE OUTLINE DIMENSIONS (continued)



FRONT VIEW



SECTION Z-Z



BACK VIEW

STYLE 1:
PIN 1. V_{CC}
2. +OUT
3. -OUT
4. GROUND

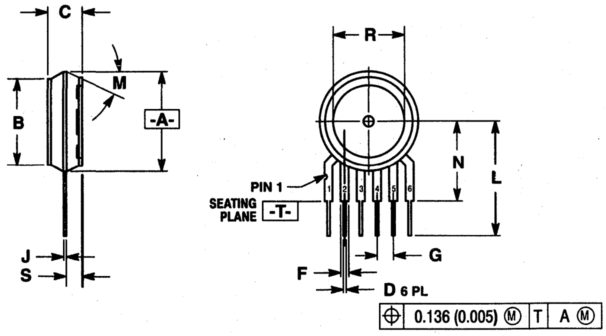
NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.
3. 24 UNITS PER STRIP AT 8.89 (0.350) PITCH.
4. OVERALL LENGTH OF STRIP EQUALS 212.7-214.00 (8.375-8.425).

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.240	0.260	6.10	6.60
B	0.350	0.370	8.89	9.40
C	0.140	0.150	3.56	3.81
D	0.012	0.020	0.30	0.51
E	0.088	0.102	2.24	2.59
F	0.123	0.128	3.12	3.25
G	0.045	0.055	1.14	1.40
H	0.037	0.047	0.94	1.19
J	0.007	0.011	0.18	0.28
K	0.120	0.140	3.05	3.56
L	0.095	0.105	2.41	2.67
M	0.165	0.175	4.19	4.45
N	0.223	0.239	5.66	6.07
Q	0.055	0.065	1.40	1.65
R	0.048	0.052	1.22	1.32
S	0.745	0.755	18.92	19.18
U	0.175 BSC		4.44 BSC	
V	0.105	0.115	2.67	2.92
W	0.050 BSC		1.27 BSC	
AA	0.095	0.107	2.41	2.72
AB	0.015	0.035	0.38	0.89
AC	0.120	0.175	3.05	4.45
AD	0.100	0.115	2.54	2.92

CASE 423-03

PACKAGE OUTLINE DIMENSIONS (continued)



NOTES:

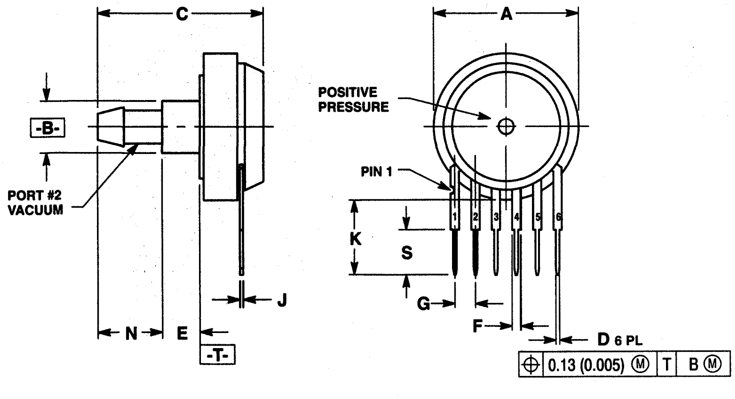
5. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
6. CONTROLLING DIMENSION: INCH.
7. DIMENSION A DOES NOT INCLUDE MOLDED FLASH RING. MOLDED FLASH RING NOT TO EXCEED 16.00 (0.630).

	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.590	0.615	14.99	15.62
B	0.505	0.525	12.83	13.34
C	0.195	0.225	4.95	5.72
D	0.027	0.033	0.68	0.84
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
L	0.685	0.715	17.40	18.16
M	30° NOM		30° NOM	
N	0.490	0.510	12.45	12.95
R	0.420	0.450	10.67	11.43
S	0.090	0.105	2.29	2.66

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867-04

BASIC ELEMENT (A, D)



NOTES:

1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

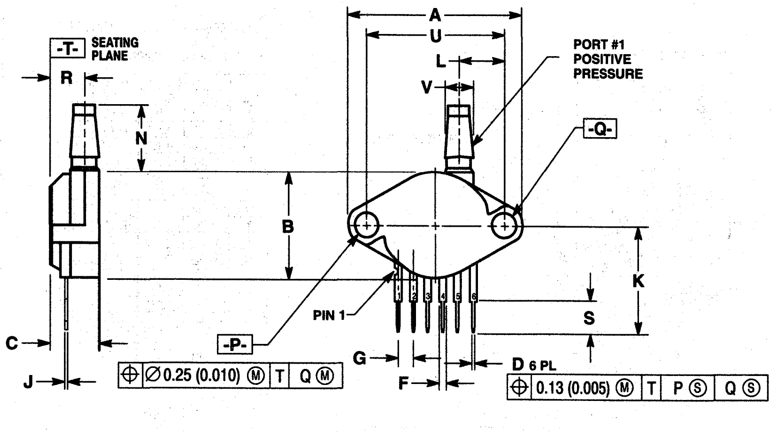
	INCHES		MILLIMETERS	
DIM	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.247	0.253	6.28	6.42
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.68	0.84
E	0.178	0.185	4.52	4.69
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.335	0.360	8.51	9.14
N	0.305	0.315	7.75	8.00
S	0.220	0.240	5.59	6.10

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867A-03

VACUUM SIDE PORTED (GVS)

PACKAGE OUTLINE DIMENSIONS (continued)



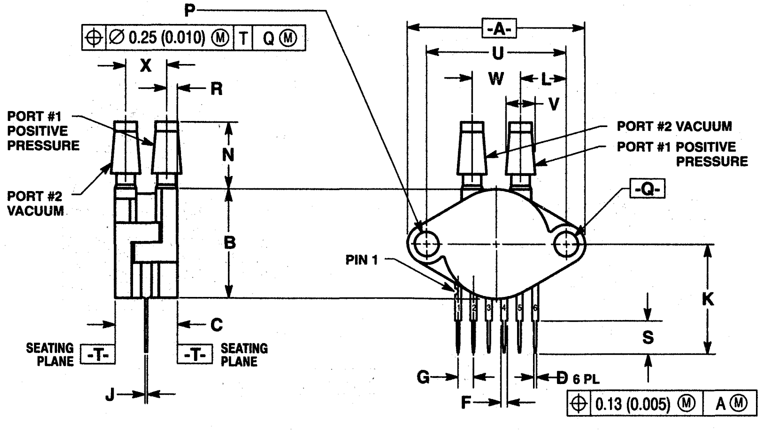
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.40	18.16
C	0.310	0.325	7.87	8.26
D	0.027	0.033	0.68	0.84
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.680	0.710	17.27	18.03
L	0.290	0.300	7.34	7.62
N	0.420	0.440	10.67	11.12
P	0.153	0.159	3.89	4.03
Q	0.153	0.159	3.89	4.03
R	0.231	0.250	5.87	6.35
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867B-03

PRESSURE SIDE PORTED (AP, GP)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

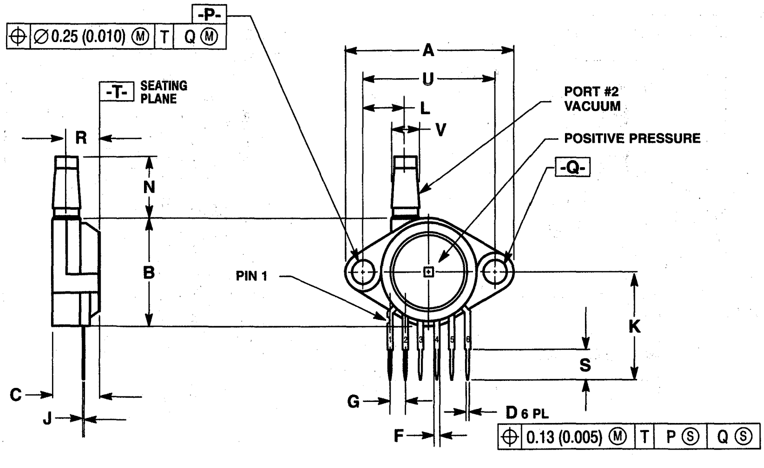
DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.40	18.16
C	0.380	0.420	9.65	10.60
D	0.027	0.033	0.68	0.84
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.680	0.710	17.27	18.03
L	0.290	0.300	7.34	7.62
N	0.420	0.440	10.67	11.12
P	0.153	0.159	3.89	4.03
Q	0.153	0.159	3.89	4.03
R	0.063	0.083	1.60	2.11
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93
W	0.310	0.330	7.87	8.38
X	0.248	0.278	6.30	7.06

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867C-03

PRESSURE AND VACUUM SIDES PORTED (DP)

PACKAGE OUTLINE DIMENSIONS (continued)



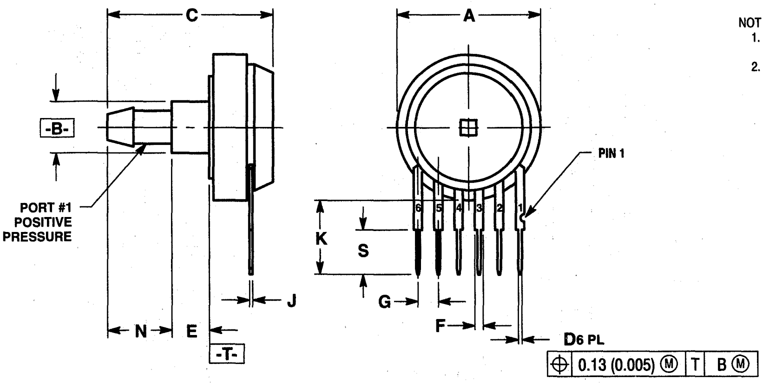
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.140	1.180	28.95	29.97
B	0.685	0.715	17.40	18.16
C	0.310	0.325	7.87	8.26
D	0.027	0.033	0.68	0.84
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.41
K	0.680	0.710	17.27	18.03
L	0.290	0.300	7.34	7.62
N	0.420	0.440	10.67	11.12
P	0.153	0.159	3.89	4.03
Q	0.153	0.159	3.89	4.03
R	0.231	0.250	5.87	6.35
S	0.230 REF		5.84 REF	
U	0.910 BSC		23.11 BSC	
V	0.182	0.194	4.62	4.93

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867D-03

VACUUM SIDE PORTED (GVP)



NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

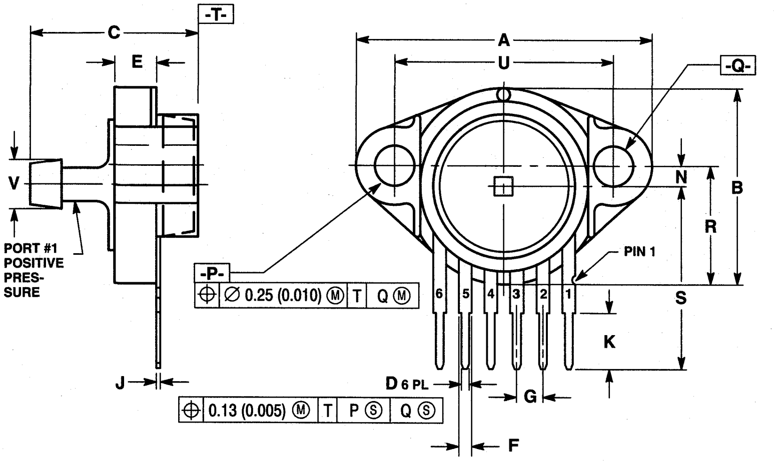
DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.690	0.720	17.53	18.28
B	0.247	0.253	6.28	6.42
C	0.780	0.820	19.81	20.82
D	0.027	0.033	0.68	0.84
E	0.178	0.185	4.52	4.69
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.335	0.360	8.51	9.14
N	0.305	0.315	7.75	8.00
S	0.220	0.240	5.59	6.10

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867E-02

PRESSURE SIDE PORTED (AS, GS)

PACKAGE OUTLINE DIMENSIONS (continued)



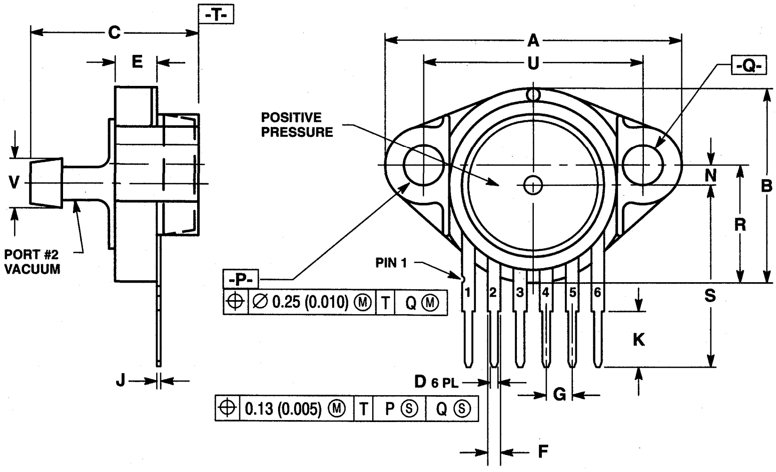
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.075	1.130	27.30	28.70
B	0.740	0.760	18.80	19.30
C	0.635	0.670	16.13	17.02
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.230 REF		5.84 REF	
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.445	0.460	11.30	11.68
S	0.685	0.715	17.40	18.16
U	0.840	0.860	21.33	21.84
V	0.185	0.195	4.69	4.95

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867F-02

PRESSURE SIDE PORTED (ASX, GSX)



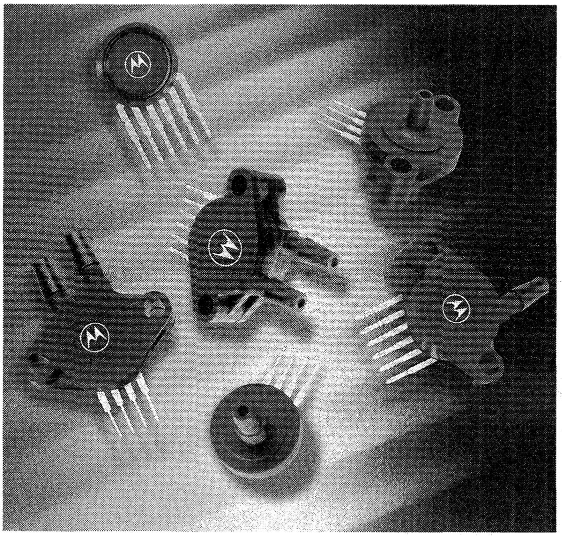
NOTES:
1. DIMENSIONING AND TOLERANCING PER ANSI Y14.5M, 1982.
2. CONTROLLING DIMENSION: INCH.

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	1.075	1.130	27.30	28.70
B	0.740	0.760	18.80	19.30
C	0.635	0.670	16.13	17.02
D	0.027	0.033	0.68	0.84
E	0.160	0.180	4.06	4.57
F	0.048	0.052	1.22	1.32
G	0.100 BSC		2.54 BSC	
J	0.014	0.016	0.36	0.40
K	0.220	0.240	5.59	6.10
N	0.070	0.080	1.78	2.03
P	0.150	0.160	3.81	4.06
Q	0.150	0.160	3.81	4.06
R	0.445	0.460	11.30	11.68
S	0.685	0.715	17.40	18.16
U	0.840	0.860	21.33	21.84
V	0.185	0.195	4.69	4.95

STYLE 1:
PIN 1. V_{OUT}
2. GROUND
3. V_{CC}
4. V1
5. V2
6. V_{EX}

CASE 867G-02

VACUUM SIDE PORTED (GVSX)



Section Seven

Appendices

Appendix 1

Appendix 2

Appendix 3

Appendix 4

Appendix 5

Appendix 6

Appendix 7

Appendix 8

Appendix 9

Appendix 10

Appendix 11

Appendix 12

APPENDIX 1

Device Numbering System for Pressure Sensors

MPX 2 100 DP

PORTING OPTIONS

A	Absolute, basic element
AP	Absolute, ported
AS	Absolute, stovepipe ported
ASX	Absolute, axial ported
D	Differential, basic element
DP	Differential, dual ported
GP	Gauge ported
GVP	Gauge vacuum ported
GS	Gauge stovepipe ported
GVS	Gauge vacuum ported
GSX	Gauge vacuum ported, axial
GVSX	Gauge vacuum ported, axial

PRESSURE RANGE IN kPa

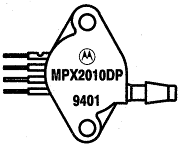
VERSION NUMBER

No Designator	Uncompensated
2	Temperature Compensated/Calibrated
4	Manifold Absolute Pressure
5	Signal Conditioning
7	High Impedance

MOTOROLA PRESSURE X-DUCER

APPENDIX 2

Marking Information for Pressure Sensor Products



Device No.	Marking
MPX10D	MPX10D
MPX10DP	MPX10DP
MPX10GP	MPX10GP
MPX10GVP	MPX10GVP
MPX10GS	MPX10D
MPX10GVS	MPX10D
MPX10GSX	MPX10D
MPX10GVSX	MPX10D
MPX12D	MPX12D
MPX12DP	MPX12DP
MPX12GP	MPX12GP
MPX12GVP	MPX12GVP
MPX12GS	MPX12D
MPX12GVS	MPX12D
MPX12GSX	MPX12D
MPX12GVSX	MPX12D
MPX50D	MPX50D
MPX50DP	MPX50DP
MPX50GP	MPX50GP
MPX50GVP	MPX50GVP
MPX50GS	MPX50D
MPX50GVS	MPX50D
MPX50GSX	MPX50D
MPX50GVSX	MPX50D
MPX100A	MPX100A
MPX100AP	MPX100AP
MPX100AS	MPX100A
MPX100ASX	MPX100A
MPX100D	MPX100D
MPX100DP	MPX100DP
MPX100GP	MPX100GP
MPX100GVP	MPX100GVP
MPX100GS	MPX100D
MPX100GVS	MPX100D
MPX100GSX	MPX100D
MPX100GVSX	MPX100D
MPX200A	MPX200A
MPX200AP	MPX200AP
MPX200AS	MPX200A
MPX200ASX	MPX200A
MPX200D	MPX200D
MPX200DP	MPX200DP
MPX200GP	MPX200GP
MPX200GVP	MPX200GVP

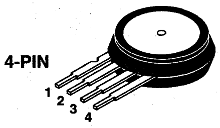
Device No.	Marking
MPX200GS	MPX200D
MPX200GVS	MPX200D
MPX200GSX	MPX200D
MPX200GVSX	MPX200D
MPX700D	MPX700D
MPX700DP	MPX700DP
MPX700GP	MPX700GP
MPX700GVP	MPX700GVP
MPX700GS	MPX700D
MPX700GVS	MPX700D
MPX700GSX	MPX700D
MPX700GVSX	MPX700D
MPX2010D	MPX2010D
MPX2010DP	MPX2010DP
MPX2010GP	MPX2010GP
MPX2010GVP	MPX2010GVP
MPX2010GS	MPX2010D
MPX2010GVS	MPX2010D
MPX2010GSX	MPX2010D
MPX2010GVSX	MPX2010D
MPX2050D	MPX2050D
MPX2050DP	MPX2050DP
MPX2050GP	MPX2050GP
MPX2050GVP	MPX2050GVP
MPX2050GS	MPX2050D
MPX2050GVS	MPX2050D
MPX2050GSX	MPX2050D
MPX2050GVSX	MPX2050D
MPX2052D	MPX2052D
MPX2052DP	MPX2052DP
MPX2052GP	MPX2052GP
MPX2052GVP	MPX2052GVP
MPX2052GS	MPX2052D
MPX2052GVS	MPX2052D
MPX2052GSX	MPX2052D
MPX2052GVSX	MPX2052D
MPX2100A	MPX2100A
MPX2100AP	MPX2100AP
MPX2100AS	MPX2100A
MPX2100ASX	MPX2100A
MPX2100D	MPX2100D
MPX2100DP	MPX2100DP
MPX2100GP	MPX2100GP
MPX2100GVP	MPX2100GVP

Device No.	Marking
MPX2100GS	MPX2100D
MPX2100GVS	MPX2100D
MPX2100GSX	MPX2100D
MPX2100GVSX	MPX2100D
MPX2200A	MPX2200A
MPX2200AP	MPX2200AP
MPX2200AS	MPX2200A
MPX2200ASX	MPX2200A
MPX2200D	MPX2200D
MPX2200DP	MPX2200DP
MPX2200GP	MPX2200GP
MPX2200GVP	MPX2200GVP
MPX2200GS	MPX2200D
MPX2200GVS	MPX2200D
MPX2200GSX	MPX2200D
MPX2200GVSX	MPX2200D
MPX4100A	MPX4100A
MPX4100AP	MPX4100AP
MPX4100AS	MPX4100A
MPX4100ASX	MPX4100A
MPX4101A	MPX4101A
MPX4101AP	MPX4101AP
MPX4101AS	MPX4101A
MPX4101ASX	MPX4101A
MPX4115A	MPX4115A
MPX4115AP	MPX4115AP
MPX4115ASX	MPX4115A
MPX5050D	MPX5050D
MPX5050DP	MPX5050DP
MPX5050GP	MPX5050GP
MPX5050GVP	MPX5050GVP
MPX5050GS	MPX5050D
MPX5050GVS	MPX5050D
MPX5050GSX	MPX5050D
MPX5050GVSX	MPX5050D
MPX5100A	MPX5100A
MPX5100AP	MPX5100AP
MPX5100AS	MPX5100A
MPX5100ASX	MPX5100A
MPX5100D	MPX5100D
MPX5100DP	MPX5100DP
MPX5100GP	MPX5100GP
MPX5100GVP	MPX5100GVP
MPX5100GS	MPX5100D

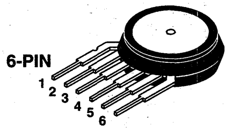
Device No.	Marketing
MPX5100GVS	MPX5100D
MPX5100GSX	MPX5100D
MPX5100GVSX	MPX5100D
MPX7050D	MPX7050D
MPX7050DP	MPX7050DP
MPX7050GP	MPX7050GP
MPX7050GVP	MPX7050GVP
MPX7050GS	MPX7050D
MPX7050GVS	MPX7050D
MPX7050GSX	MPX7050D
MPX7050GVSX	MPX7050D
MPX7100A	MPX7100A
MPX7100AP	MPX7100AP
MPX7100AS	MPX7100A
MPX7100ASX	MPX7100A
MPX7100D	MPX7100D
MPX7100DP	MPX7100DP
MPX7100GP	MPX7100GP
MPX7100GVP	MPX7100GVP
MPX7100GS	MPX7100D
MPX7100GVS	MPX7100D
MPX7100GSX	MPX7100D
MPX7100GVSX	MPX7100D
MPX7200A	MPX7200A
MPX7200AP	MPX7200AP
MPX7200AS	MPX7200A
MPX7200ASX	MPX7200A
MPX7200D	MPX7200D
MPX7200DP	MPX7200DP
MPX7200GP	MPX7200GP
MPX7200GVP	MPX7200GVP
MPX7200GS	MPX7200D
MPX7200GVS	MPX7200D
MPX7200GSX	MPX7200D
MPX7200GVSX	MPX7200D

APPENDIX 3

Pinout Diagrams for Pressure and Temperature Sensors



CASE 344, Style 1



CASE 867, Style 1

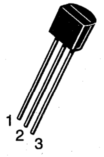
PRESSURE SENSORS

Case Type	Package Style	PIN STYLE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6
344	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
344	4 PIN Unibody	2	V_S	$-V_{out}$	$+V_{out}$	Ground	—	—
350-03	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
352	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
371-05	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
371C	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
371D	4 PIN Unibody	1	Ground	$+V_{out}$	V_S	$-V_{out}$	—	—
867	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867A	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867B	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867C	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867D	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867E	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867F	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C
867G	6 PIN Unibody	1	V_{out}	Ground	V_S	*N/C	*N/C	*N/C

* Note: Pins 4, 5 and 6 are internal device connections. Do not connect to external circuitry or ground.

TEMPERATURE SENSORS

Case Type	Package Style	PIN 1	PIN 2	PIN 3
29-04	TO-226AA	Emitter	Base	Collector



Temperature Sensor

APPENDIX 4

Reference Tables

FLOW EQUIVALENTS							
1 Cu. Ft./Hr.		**1 Cu. Ft./Min.**		**1 CC/Min.**		**1 CC/Hr.**	
.0166	Cu. Ft./Min	60	Cu. Ft./Min	60	CC/Hr.	.0167	CC/Min.
.4719	LPM	28.316	LPM	.000035	Cu. Ft./Min	.0000005	Cu. Ft./Min.
28.316	LPH	1699	LPH	.0021	Cu. Ft./Hr.	.00003	Cu. Ft./Hr.
471.947	CC/Min.	28317	CC/Min.	.001	LPM	.000017	LPM
28317	CC/Hr.	1,699,011	CC/Hr.	.06	LPH	.001	LPH
.1247	Gal/Min.	7.481	Gal/Min.	.00026	Gal/Min.	.000004	Gal/Min.
7.481	Gal/Hr.	448.831	Gal/Hr.	.0159	Gal/Hr.	.00026	Gal/Hr.
1 LPM		**1 LPH**		**1 Gal/Min.**		**1 Gal/Hr.**	
60	LPH	.0166	LPM	60	Gal/Hr.	.0167	Gal/Min.
.035	Cu. Ft./Min.	.00059	Cu. Ft./Min.	.1337	Cu. Ft./Min.	.002	Cu. Ft./Min.
2.1189	Cu. Ft./Hr.	.035	Cu. Ft./Hr.	8.021	Cu. Ft./Hr.	.1337	Cu. Ft./Hr.
1000	CC/Min.	16.667	CC/Min.	3.785	LPM	.063	LPM
60,002	CC/Hr.	1000	CC/Hr.	227.118	LPH	3.785	LPH
.264	Gal/Min.	.004	Gal/Min.	3,785.412	CC/Min.	63.069	CC/Min.
15.851	Gal/Hr.	.264	Gal/Hr.	227,125	CC/Hr.	3785	CC/Hr.

Airspeed			
Knots	**Inches of Mercury**	**Knots**	**Inches of Mercury**
60	0.1727	400	8.3850
80	0.3075	425	9.5758
100	0.4814	450	10.8675
110	0.5832	475	12.2654
120	0.6950	500	13.7756
130	0.8168	525	15.4045
140	0.9488	550	17.1590
150	1.0910	575	19.0465
175	1.4918	600	21.0749
200	1.9589	650	25.5893
225	2.4943	700	30.7642
250	3.1002	750	36.5662
275	3.7792	800	42.9378
300	4.5343	850	49.8423
325	5.3687	900	57.2554
350	6.2859	1,000	73.5454
375	7.2900		

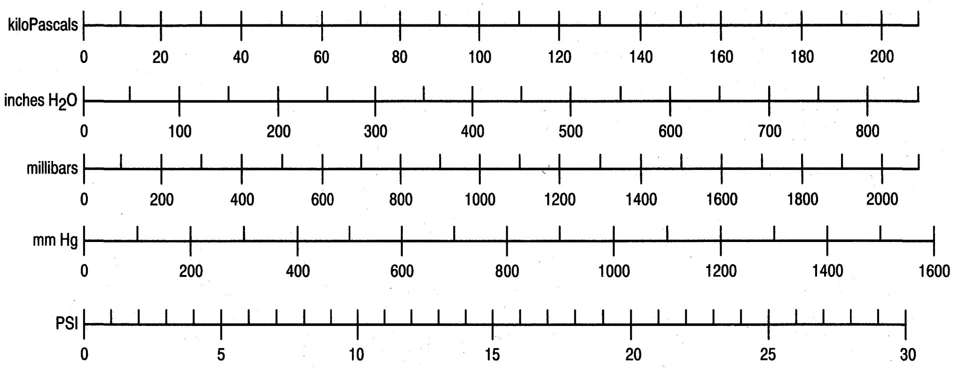
Altitude (Feet)	Equivalent Pressure (inches of Mercury)	Altitude (Feet)	Equivalent Pressure (inches of Mercury)
–1,000	31.0185	14,000	17.5774
–900	30.9073	16,000	16.2164
0	29.9213	18,000	14.9421
500	29.3846	20,000	13.7501
1,000	28.8557	22,000	12.6363
1,500	28.3345	25,000	11.1035
2,000	27.8210	30,000	8.88544
3,000	26.8167	35,000	7.04062
4,000	25.8418	40,000	5.53802
6,000	23.9782	45,000	4.35488
8,000	22.2250	49,900	3.44112 (EST)
10,000	20.5770	50,000	3.42466
12,000	19.0294		

Appendix 4 — Reference Tables (continued)

Conversion Table for Common Units of Pressure

	kiloPascals	mm Hg	millibars	inches H_2O	PSI
1 atm	101.325	760.000	1013.25	406.795	14.6960
1 kiloPascal	1.00000	7.50062	10.0000	4.01475	0.145038
1 mm Hg	0.133322	1.00000	1.33322	0.535257	0.0193368
1 millibar	0.100000	0.750062	1.00000	0.401475	0.0145038
1 inch H_2O	0.249081	1.86826	2.49081	1.00000	0.0361
1 PSI	6.89473	51.7148	68.9473	27.6807	1.00000
1 hectoPascal	0.100000	0.75006	1.00000	0.401475	0.0145038
1 cm H_2O	0.09806	0.7355	9.8×10^{-7}	0.3937	0.014223

Quick Conversion Chart for Common Units of Pressure



APPENDIX 5

Mounting and Handling Suggestions

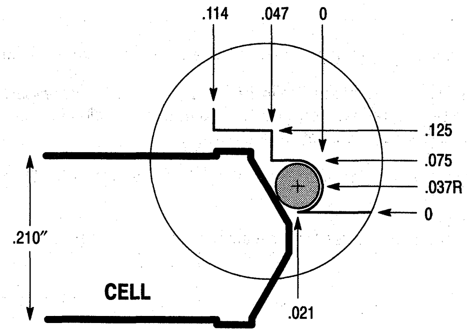
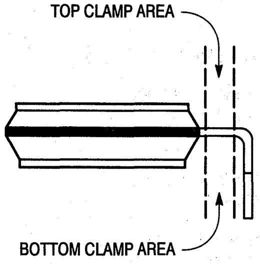


Figure 1.



Leads should be securely clamped top and bottom in the area between the plastic body and the form being sure that no stress is being put on plastic body. The area between dotted lines represents surfaces to be clamped.

Figure 3. Leadforming

Custom Port Adaptor Installation Techniques

The Motorola MPX silicon pressure sensor is available in a basic chip carrier cell which is adaptable for attachment to customer specific housings/ports (Case 344 for 4-pin devices and Case 867 for 6-pin devices). The basic cell has chamfered shoulders on both sides which will accept an O-ring such as Parker Seal's silicone O-ring (p/n#2-015-S-469-40). Refer to Figure 1 for the recommended O-ring to sensor cell interface dimensions.

The sensor cell may also be glued directly to a custom housing or port using many commercial grade epoxies or RTV adhesives which adhere to grade Valox 420, reinforced polyester resin plastic polysulfone (MPX2040D only). The epoxy should be dispensed in a continuous bead around the cell-to-port interface shoulder. Refer to Figure 2. Care must be taken to avoid gaps or voids in the adhesive bead to help ensure that a complete seal is made when the cell is joined to the port. After cure, a simple test for gross leaks should be performed to ensure the integrity of the cell to port bond. Submerging the device in water for 5 seconds with full rated pressure applied to the port nozzle and checking for air bubbles will provide a good indication. Be sure device is thoroughly dried after this test.

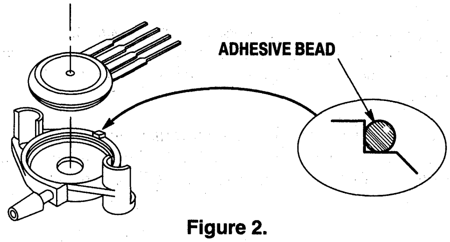


Figure 2.

Standard Port Attach Connection

Motorola also offers standard port options designed to accept readily available silicone, vinyl, nylon or polyethylene tubing for the pressure connection. The inside dimension of the tubing selected should provide a snug fit over the port nozzle. Dimensions of the ports may be found in the case outline drawings. Installation and removal of tubing from the port nozzle must be parallel to the nozzle to avoid undue stress which may break the nozzle from the port base. Whether sensors are used with Motorola's standard ports or customer specific housings, care must be taken to ensure that force is uniformly distributed to the package or offset errors may be induced.

Electrical Connection

The MPX series pressure sensor is designed to be installed on a printed circuit board (standard 0.100″ lead spacing) or to accept an appropriate connector if installed on a baseplate. The leads of the sensor may be formed at right angles for assembly to the circuit board, but one must ensure that proper leadform techniques and tools are employed. Hand or "needlenose" pliers should never be used for leadforming unless they are specifically designed for that purpose. Industrial leadform tooling is available from various companies including *Janesville Tool & Manufacturing* (608-868-4925). Refer to Figure 3 for the recommended leadform technique. It is also important that once the leads are formed, they should not be straightened and reformed without expecting reduced durability. The recommended connector for off-circuit board applications may be supplied by JST Corp. (1-800-292-4243) in Mount Prospect, IL. The part numbers for the housing and pins are:

4 Pin Housing: SMP-04V-BC
6 Pin Housing: SMP-06V-BC
Pin: SHF-01T-0.8SS
The crimp tool part number is: YC12.

APPENDIX 6

Glossary of Terms

Absolute Pressure Sensor	A sensor which measures input pressure in relation to a zero pressure (a total vacuum on one side of the diaphragm) reference.
Analog Output	An electrical output from a sensor that changes proportionately with any change in input pressure.
Accuracy — also see Pressure Error	A comparison of the actual output signal of a device to the true value of the input pressure. The various errors (such as linearity, hysteresis, repeatability and temperature shift) attributing to the accuracy of a device are usually expressed as a percent of full scale output (FSO).
Altimetric Pressure Transducer	A barometric pressure transducer used to determine altitude from the pressure-altitude profile.
Barometric Pressure Transducer	An absolute pressure sensor that measures the local ambient atmospheric pressure.
Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
Calibration	A process of modifying sensor output to improve output accuracy.
Chip	A die (unpackaged semiconductor device) cut from a silicon wafer, incorporating semiconductor circuit elements such as resistors, diodes, transistors, and/or capacitors.
Compensation	Added circuitry or materials designed to counteract known sources of error.
Diaphragm	The membrane of material that remains after etching a cavity into the silicon sensing chip. Changes in input pressure cause the diaphragm to deflect.
Differential Pressure Sensor	A sensor which is designed to accept simultaneously two independent pressure sources. The output is proportional to the pressure difference between the two sources.
Diffusion	A thermochemical process whereby controlled impurities are introduced into the silicon to define the piezoresistor. Compared to ion implantation, it has two major disadvantages: 1) the maximum impurity concentration occurs at the surface of the silicon rendering it subject to surface contamination, and making it nearly impossible to produce buried piezoresistors; 2) control over impurity concentrations and levels is about one thousand times poorer than obtained with ion implantation.
Drift	An undesired change in output over a period of time, with constant input pressure applied.
End Point Straight Line Fit	Motorola's method of defining linearity. The maximum deviation of any data point on a sensor output curve from a straight line drawn between the end data points on that output curve.
Error	The algebraic difference between the indicated value and the true value of the input pressure. Usually expressed in percent of full scale span, sometimes expressed in percent of the sensor output reading.
Error Band	The band of maximum deviations of the output values from a specified reference line or curve due to those causes attributable to the sensor. Usually expressed as "± % of full scale output." The error band should be specified as applicable over at least two calibration cycles, so as to include repeatability, and verified accordingly.
Excitation Voltage (Current) — see Supply Voltage (Current)	The external electrical voltage and/or current applied to a sensor for its proper operation (often referred to as the supply circuit or voltage). Motorola specifies constant voltage operation only.
Full Scale Output	The output at full scale pressure at a specified supply voltage. This signal is the sum of the offset signal plus the full scale span.
Full Scale Span	The change in output over the operating pressure range at a specified supply voltage. The SPAN of a device is the output voltage variation given between zero differential pressure and any given pressure. FULL SCALE SPAN is the output variation between zero differential pressure and when the maximum recommended operating pressure is applied.
Hysteresis — also see Pressure Hysteresis and Temperature Hysteresis	HYSTERESIS refers to a transducer's ability to reproduce the same output for the same input, regardless of whether the input is increasing or decreasing. PRESSURE HYSTERESIS is measured at a constant temperature while TEMPERATURE HYSTERESIS is measured at a constant pressure in the operating pressure range.

Appendix 6 — Glossary of Terms (continued)

Input Impedance (Resistance)	The impedance (resistance) measured between the positive and negative (ground) input terminals at a specified frequency with the output terminals open. For Motorola X-ducer this is a resistance measurement only.
Ion Implantation	A process whereby impurity ions are accelerated to a specific energy level and impinged upon the silicon wafer. The energy level determines the depth to which the impurity ions penetrate the silicon. Impingement time determines the impurity concentration. Thus, it is possible to independently control these parameters, and buried piezoresistors are easily produced. Ion implantation is increasingly used throughout the semiconductor industry to provide a variety of products with improved performance over those produced by diffusion.
Laser Trimming (Automated)	A method for adjusting the value of thin film resistors using a computer-controlled laser system.
Leakage Rate	The rate at which a fluid is permitted or determined to leak through a seal. The type of fluid, the differential pressure across the seal, the direction of leakage, and the location of the seal must be specified.
Linearity Error	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
Load Impedance	The impedance presented to the output terminals of a sensor by the associated external circuitry.
Null	The condition when the pressure on each side of the sensing diaphragm is equal.
Null Offset	The electrical output present, when the pressure sensor is at null.
Null Temperature Shift	The change in null output value due to a change in temperature.
Null Output	See ZERO PRESSURE OFFSET
Offset	See ZERO PRESSURE OFFSET
Operating Pressure Range	The range of pressures between minimum and maximum pressures at which the output will meet the specified operating characteristics.
Operating Temperature Range	The range of temperature between minimum and maximum temperature at which the output will meet the specified operating characteristics.
Output Impedance	The impedance measured between the positive and negative (ground) output terminals at a specified frequency with the input open.
Overpressure	The maximum specified pressure which may be applied to the sensing element of a sensor without causing a permanent change in the output characteristics.
Piezoresistance	A resistive element that changes resistance relative to the applied stress it experiences (e.g., strain gauge).
Pressure Error	The maximum difference between the true pressure and the pressure inferred from the output for any pressure in the operating pressure range.
Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
Pressure Range — also see Operating Pressure Range	The pressure limits over which the pressure sensor is calibrated or specified.
Pressure Sensor	A device that converts an input pressure into an electrical output.
Proof Pressure	See OVERPRESSURE
Ratiometric	Ratiometricity refers to the ability of the transducer to maintain a constant sensitivity, at a constant pressure, over a range of supply voltage values.
Ratiometric (Ratiometricity Error)	At a given supply voltage, sensor output is a proportion of that supply voltage. Ratiometricity error is the change in this proportion resulting from any change to the supply voltage. Usually expressed as a percent of full scale output.

Appendix 6 — Glossary of Terms (continued)

Range	See OPERATING PRESSURE RANGE
Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
Resolution	The maximum change in pressure required to give a specified change in the output.
Response Time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
Room Conditions	Ambient environmental conditions under which sensors most commonly operate.
Sensing Element	That part of a sensor which responds directly to changes in input pressure.
Sensitivity	The change in output per unit change in pressure for a specified supply voltage or current.
Sensitivity Shift	A change in sensitivity resulting from an environmental change such as temperature.
Stability	The maximum difference in the output at any pressure in the operating pressure range when this pressure is applied consecutively under the same conditions and from the same direction.
Storage Temperature Range	The range of temperature between minimum and maximum which can be applied without causing the sensor to fail to meet the specified operating characteristics.
Strain Gauge	A sensing device providing a change in electrical resistance proportional to the level of applied stress.
Supply Voltage (Current)	The voltage (current) applied to the positive and negative (ground) input terminals.
Temperature Coefficient of Full Scale Span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature.
Temperature Coefficient of Resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature.
Temperature Error	The maximum change in output at any pressure in the operating pressure range when the temperature is changed over a specified temperature range.
Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
Thermal Offset Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thermal Span Shift	See TEMPERATURE COEFFICIENT OF FULL SCALE SPAN
Thermal Zero Shift	See TEMPERATURE COEFFICIENT OF OFFSET
Thin Film	A technology using vacuum deposition of conductors and dielectric materials onto a substrate (frequently silicon) to form an electrical circuit.
Vacuum	A perfect vacuum is the absence of gaseous fluid.
Zero Pressure Offset	The output at zero pressure (absolute or differential, depending on the device type) for a specified supply voltage or current.

APPENDIX 7

Symbols, Terms & Definitions

The following are the most commonly used letter symbols, terms and definitions associated with solid state silicon pressure sensors.

P_{burst}	Burst Pressure	The maximum pressure that can be applied to a transducer without rupture of either the sensing element or transducer case.
I_O	supply current	The current drawn by the sensor from the voltage source.
I_{O+}	output source current	The current sourcing capability of the pressure sensor.
kPa	kilopascals	Unit of pressure. 1 kPa = .145038 PSI.
—	Linearity	The maximum deviation of the output from a straight line relationship with pressure over the operating pressure range, the type of straight line relationship (end point, least square approximation, etc.) should be specified.
mm Hg	millimeters of mercury	Unit of pressure. 1 mmHg = .0193368 PSI.
P_{max}	overpressure	The maximum specified pressure which may be applied to the sensing element without causing a permanent change in the output characteristics.
P_{OP}	operating pressure range	The range of pressures between minimum and maximum temperature at which the output will meet the specified operating characteristics.
—	Pressure Hysteresis	The difference in the output at any given pressure in the operating pressure range when this pressure is approached from the minimum operating pressure and when approached from the maximum operating pressure at room temperature.
PSI	pounds per square inch	Unit of pressure. 1 PSI = 6.89473 kPa.
—	Repeatability	The maximum change in output under fixed operating conditions over a specified period of time.
R_O	input resistance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open.
T_A	operating temperature	The temperature range over which the device may safely operate.
TCR	temperature coefficient of resistance	The percent change in the DC input impedance per unit change in temperature relative to the DC input impedance at a specified temperature (typically +25°C).
TCV_{FSS}	temperature coefficient of full scale span	The percent change in full scale span per unit change in temperature relative to the full scale span at a specified temperature (typically +25°C).
TCV_{off}	temperature coefficient of offset	The percent change in offset per unit change in temperature relative to the offset at a specified temperature (typically +25°C).
T_{stg}	storage temperature	The temperature range at which the device, without any power applied, may be stored.
t_R	response time	The time required for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
—	Temperature Hysteresis	The difference in output at any temperature in the operating temperature range when the temperature is approached from the minimum operating temperature and when approached from the maximum operating temperature with zero pressure applied.
V_{FSS}	full scale span voltage	The change in output over the operating pressure range at a specified supply voltage.
V_{off}	offset voltage	The output with zero differential pressure applied for a specified supply voltage or current.
V_S	supply voltage dc	The dc excitation voltage applied to the sensor. For precise circuit operation, a regulated supply should be used.
$V_{S\,max}$	maximum supply voltage	The maximum supply voltage that may be applied to a circuit or connected to the sensor.
Z_{in}	input impedance	The resistance measured between the positive and negative input terminals at a specified frequency with the output terminals open. For Motorola X-ducer this is a resistance measurement only.
Z_{out}	output impedance	The resistance measured between the positive and negative output terminals at a specified frequency with the input terminals open.
$\Delta V/\Delta P$	sensitivity	The change in output per unit change in pressure for a specified supply voltage.

APPENDIX 8

Pressure/Vacuum Side Identification

Motorola designates the two sides of the pressure sensor as the Pressure (top) side and the Vacuum Pressure (back) side. The Pressure side is the side containing silicone gel which protects the die from harsh media. The Motorola MPX pressure sensor is designed to operate with positive differential pressure applied (i.e. top side pressure is greater than or equal to back side pressure). The Pressure side may be identified by using the example tables below:

Part Number	Case Type 4 PIN	Positive Pressure Side Identifier
MPXxxxxA	344	Stainless Steel Cap
MPXxxxxD	344	Stainless Steel Cap
MPXxxxxDP	352	Side with Part Marking
MPXxxxxAP	350	Side with Port Attached
MPXxxxxGP	350	Side with Port Attached
MPXxxxxGVP	350-04	Stainless Steel Cap
MPXxxxxAS	371-06	Side with Port Attached
MPXxxxxGS	371-06	Side with Port Attached
MPXxxxxGVS	371-05	Stainless Steel Cap
MPXxxxxASX	371C	Side with Port Attached
MPXxxxxGSX	371C	Side with Port Attached
MPXxxxxGVSX	371D	Stainless Steel Cap
Part Number	**Case Type 6 PIN**	**Positive Pressure Side Identifier**
MPXxxxxA	867	Stainless Steel Cap
MPXxxxxD	867	Stainless Steel Cap
MPXxxxxDP	867C	Side with Part Marking
MPXxxxxAP	867B	Side with Port Attached
MPXxxxxGP	867B	Side with Port Attached
MPXxxxxGVP	867D	Stainless Steel Cap
MPXxxxxAS	867E	Side with Port Attached
MPXxxxxGS	867E	Side with Port Attached
MPXxxxxGVS	867A	Stainless Steel Cap
MPXxxxxASX	867F	Side with Port Attached
MPXxxxxGSX	867F	Side with Port Attached
MPXxxxxGVSX	867G	Stainless Steel Cap

APPENDIX 9

Connectors for MPX Pressure Sensors

In some applications connectors are used to interface with the MPX pressure sensor. The following manufacturer can provide off-the-shelf connectors which interface to both 4-pin and 6-pin pressure sensor packages.

Manufacturer: JS Terminal
Mount Prospect, IL
708-803-3300

Housing information:

4-pin	SMP-04V-BC
6-pin	SMP-06V-BC
Pins:	SHF-01T-0.8SS
Crimping tool:	YC12

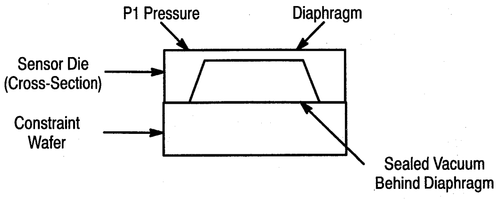
APPENDIX 10

Pressure Measurement

What is the difference between an absolute, differential and guage pressure sensor?

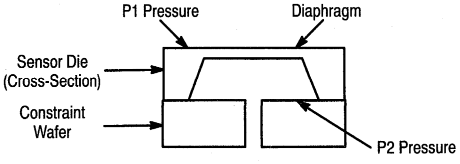
Absolute Pressure

An absolute pressure sensor is a sensor which measures external pressure relative to a zero pressure reference sealed inside the cavity of the chip. The output is proportional to the pressure difference between this reference and pressure applied externally.



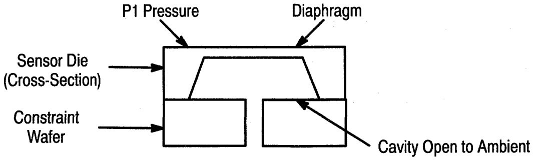
Differentail Pressure

A differential pressure sensor is a sensor which is designed to accept simultaneously two independent pressure sources. The output is proportional to the pressure difference between the two sources.



Gauge Pressure

A guage pressure sensor is a special case of differential pressure sensor. One side of the sensor is open to atmosphere.



APPENDIX 11

How The X-ducer Works

What is the X-ducer and how does it work?

The X-ducer is a patented single element silicon piezoresistor which constitutes a shear stress strain gauge when implanted at a critical point on the edge of a thin silicon micromachined diaphragm.

Applying pressure to the diaphragm results in a resistance change in the strain gauge. Unlike the widely used Wheatstone Bridge which is a network of four closely matched and precisely aligned resistors, the X-ducer is highly manufacturable, and it produces extremely accurate and repeatable outputs. The X-ducer optimizes important device characteristics such as linearity and hysteresis. Since the strain gauge is an integral part of the silicon diaphragm, there are no temperature effects due to differences in thermal expansion as in other devices. While the output parameters are temperature dependent, the single element X-ducer greatly simplifies compensation techniques required when the device is operated over extensive temperature ranges.

APPENDIX 12

Standard Warranty Clause

Seller warrants that its products sold hereunder will at the time of shipment be free from defects in material and workmanship, and will conform to Seller's approved specifications. If products are not as warranted, Seller shall, at its option and as Buyer's exclusive remedy, either refund the purchase price, or repair, or replace the product, provided proof of purchase and written notice of nonconformance are received within the applicable periods noted below and provided said nonconforming products are, with Seller's written authorization, returned in protected shipping containers FOB Seller's plant within thirty (30) days after expiration of the warranty period unless otherwise specified herein. If product does not conform to this warranty, Seller will pay for the reasonable cost of transporting the goods to and from Seller's plant. This warranty shall not apply to any products Seller determines have been, by Buyer or otherwise, subjected to improper testing, or have been the subject of mishandling or misuse.

THIS WARRANTY EXTENDS TO BUYER ONLY AND MAY BE INVOKED BY BUYER ONLY FOR ITS CUSTOMERS. SELLER WILL NOT ACCEPT WARRANTY RETURNS DIRECTLY FROM BUYER'S CUSTOMERS OR USERS OF BUYER'S PRODUCTS. THIS WARRANTY IS IN LIEU OF ALL OTHER WARRANTIES WHETHER EXPRESS, IMPLIED OR STATUTORY INCLUDING IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

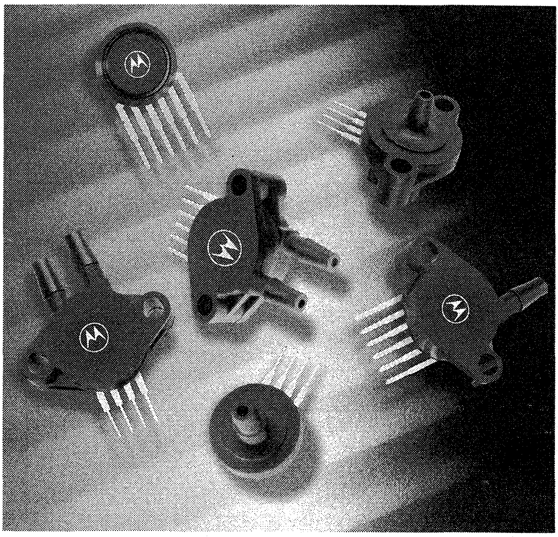
Seller's warranty shall not be enlarged, and no obligation or liability shall arise out of Seller's rendering of technical advice and/or assistance.

A. Time periods, products, exceptions and other restrictions applicable to the above warranty are:

    (1) Unless otherwise stated herein, products are warranted for a period of one (1) year from date of shipment.

    (2) Device Chips/Wafers. Seller warrants that device chips or wafers have, at shipment, been subjected to electrical test/probe and visual inspection. Warranty shall apply to products returned to Seller within ninety (90) days from date of shipment. This warranty shall not apply to any chips or wafers improperly removed from their original shipping container and/or subjected to testing or operational procedures not approved by Seller in writing.

B. Development products and Licensed Programs are licensed on an "AS IS" basis. IN NO EVENT SHALL SELLER BE LIABLE FOR ANY INCIDENTAL OR CONSEQUENTIAL DAMAGES.



Section Eight

Device Sample Kits

Sensor Sample Kits

Order No.	Pressure Range	Description	Cost
KITNOK29/D	1.5 PSI	One MPX2010DP, Temperature Compensated, Dual Ported Sensor with Spec Sheet and Literature.	FREE
KITNOK32/D	100 PSI	One MPX700DP, Uncompensated, Dual Ported Sensor with Spec Sheet and Literature.	FREE
KITMPX5100A/D	15 PSI	One MPX5100AP, Absolute, Signal Conditioned, Single Ported Sensor with Spec Sheet and Literature.	FREE
KITMPX5100D/D	15 PSI	One MPX5100DP, Differential, Signal Conditioned, Dual Ported Sensor with Spec Sheet and Literature.	FREE
KITMPX7100D/D	15 PSI	One MPX7100DP, Differential, High Impedance Dual Ported Sensor with Spec Sheet and Literature.	FREE
KITMPX7200D/D	30 PSI	One MPX7200DP, Differential, High Impedance Dual Ported Sensor with Spec Sheet and Literature.	FREE

Sensor Sample Kits Order Form

Kit Number	Kit Title	Availability	Price	Qty	Amount
KITNOK29/D	MPX2010DP Sample Kit	Now	FREE		
KITNOK32/D	MPX700DP Sample Kit	Now	FREE		
KITMPX5100A/D	MPX5100AP Sample Kit	Now	FREE		
KITMPX5100D/D	MPX5100DP Sample Kit	Now	FREE		
KITMPX7100D/D	MPX7100DP Sample Kit	Now	FREE		
KITMPX7200D/D	MPX7200DP Sample Kit	Now	FREE		
				SUBTOTAL	$
				POSTAGE AND HANDLING	$
				GRAND TOTAL	$

Postage and Handling:

United States — Surface	$5.00
Air	$7.50
DHL World Mail — Air	$20.00

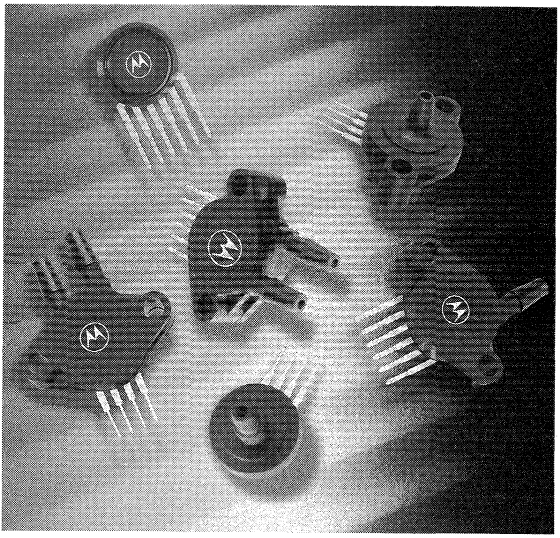
Prices are subject to change. Documents will be sent best way surface unless specified for air delivery. Allow 2 to 3 weeks for delivery.

Motorola offers three convenient ways to order these kits, check or money order, purchase orders if credit line has previously been established, and credit card (Master Card, Visa and American Express).

Credit Card # ____________________ Exp. Date ____________
NAME ____________________ PHONE ____________
COMPANY ____________________ TITLE ____________
ADDRESS ________________________________
CITY ____________________ STATE ________ ZIP ________

Mail with remittance to:
MOTOROLA SEMICONDUCTOR PRODUCTS INC.
P.O. Box 20912
Phoenix, Arizona, U.S.A. 85036-0924

For immediate service call:
(800) 441-2447
Fax: (602) 994-6430



Section Nine

Distributors and Sales Offices

12/1/93

MOTOROLA DISTRIBUTOR AND WORLDWIDE SALES OFFICES

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	Future Electronics	(205)830-2322
	Hamilton Hallmark	(205)837-8700
	Newark	(205)837-9091
	Time Electronics	(205)721-1133

Arizona

City	Distributor	Phone
Phoenix	Future Electronics	(602)968-7140
	Hamilton Hallmark	(602)437-1200
	Newark Electronics	(602)864-9905
	Wyle Laboratories	(602)437-2088
Tempe	Arrow/Schweber Electronics	(602)431-0030
	Time Electronics	(602)967-2000

CALIFORNIA

City	Distributor	Phone
Agoura Hills	Time Electronics Corporate	(818)707-2890
Belmont	Richardson Electronics	(415)592-9225
Calabassas	Arrow/Schweber Electronics	(818)880-9686
	Wyle Laboratories	(818)880-9000
Chatsworth	Future Electronics	(818)772-6240
	Time Electronics	(818)998-7200
Costa Mesa	Hamilton Hallmark	(714)641-4100
Culver City	Hamilton Hallmark	(213)558-2000
Irvine	Arrow/Schweber Electronics	(714)587-0404
	Future Electronics	(714)250-4141
	Wyle Laboratories Corporate	(714)753-9953
	Wyle Laboratories	(714)863-9953
Mountain View	Richardson Electronics	(415)960-6900
Orange	Newark	(714)634-8224
Rocklin	Hamilton Hallmark	(916)624-9781
Sacramento	Newark	(916)721-1633
	Wyle Laboratories	(916)638-5282
San Diego	Arrow/Schweber Electronics	(619)565-4800
	Future Electronics	(619)625-2800
	Hamilton Hallmark	(619)571-7540
	Newark	(619)569-9877
	Wyle Laboratories	(619)565-9171
San Francisco	Newark	(415)571-5300
San Jose	Arrow/Schweber Electronics	(408)441-9700
	Arrow/Schweber Electronics	(408)428-6400
	Future Electronics	(408)434-1122
Santa Clara	Wyle Laboratories	(408)727-2500
Sunnyvale	Hamilton Hallmark	(408)743-3300
	Time Electronics	(408)734-9888
Torrance	Time Electronics	(310)320-0880
Tustin	Time Electronics	(714)669-0100
West Hills	Newark	(818)888-3718
Woodland Hills	Hamilton Hallmark	(818)594-0404
	Richardson Electronics	(615)594-5600

COLORADO

City	Distributor	Phone
Lakewood	Future Electronics	(303)232-2008
Colorado Springs	Newark	(719)592-9494
Denver	Newark	(303)757-3351
Englewood	Arrow/Schweber Electronics	(303)799-0258
	Hamilton Hallmark	(303)790-1662
	Time Electronics	(303)721-8882
Thornton	Wyle Laboratories	(303)457-9953

CONNECTICUT

City	Distributor	Phone
Chesire	Future Electronics	(203)250-0083
	Hamilton Hallmark	(203)271-2844
Southbury	Time Electronics	(203)271-3200
Wallingfort	Arrow/Schweber Electronics	(203)265-7741
Windsor	Newark	(203)683-8860

FLORIDA

City	Distributor	Phone
Altamonte Springs	Future Electronics	(407)767-8414
Clearwater	Future Electronics	(813)530-1222
Deerfield Beach	Arrow/Schweber Electronics	(305)429-8200
Ft. Lauderdale	Future Electronics	(305)351-0660
	Hamilton Hallmark	(305)767-6377
	Time Electronics	(305)484-1778
Lake Mary	Arrow/Schweber Electronics	(407)333-9300
Largo/Tampa/St. Petersburg	Hamilton Hallmark	(813)541-7440
	Newark	(813)287-1578
	Time Electronics	(407)841-6565
Orlando	Newark	(407)896-8350
	Time Electronics	(407)841-6565
Plantation	Newark	(305)424-4400
Winter Park	Richardson Electronics	(407)644-1453
	Hamilton Hallmark	(407)657-3800

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City	Distributor	Phone
Atlanta	Time Electronics	(404)351-3545
Duluth	Arrow/Schweber Electronics	(404)497-1300
	Hamilton Hallmark	(404)623-5475
Norcross	Future Electronics	(404)441-7676
	Newark	(404)448-1300
	Time Electronics	(404)368-0969

ILLINOIS

City	Distributor	Phone
Bensenville	Hamilton Hallmark	(708)860-7780
Chicago	Newark Electronics Corp.	(312)784-5100
Hoffman Estates	Future Electronics	(708)882-1255
Itasca	Arrow/Schweber Electronics	(708)250-0500
LaFox	Richardson Electronics	(708)208-2401
Schaumburg	Newark	(708)310-8980
	Time Electronics	(708)303-3000

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City	Distributor	Phone
Indianapolis	Arrow/Schweber Electronics	(317)299-2071
	Hamilton Hallmark	(317)872-8875
	Newark	(317)259-0085
	Time Electronics	(708)303-3000
Ft. Wayne	Newark	(219)484-0766

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City	Distributor	Phone
Cedar Rapids	Newark	(319)393-3800
	Time Electronics	(314)391-6444

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City	Distributor	Phone
Lenexa	Arrow/Schweber Electronics	(913)541-9542
	Hamilton Hallmark	(913)888-4747
Overland Park	Future Electronics	(913)649-1531
	Newark	(913)677-0727
	Time Electronics	(314)391-6444

MARYLAND

City	Distributor	Phone
Beltsville	Newark	(301)604-1700
Columbia	Arrow/Schweber Electronics	(301)596-7800
	Future Electronics	(410)290-0600
	Hamilton Hallmark	(410)988-9800
	Time Electronics	(301)964-3090

MASSACHUSETTS

City	Distributor	Phone
Boston	Arrow/Schweber Electronics	(508)658-0900
Bolton	Future Corporate	(508)779-3000
Burlington	Wyle Laboratories	(617)272-7300
Methuen	Newark	(508)683-0913
Norwell	Richardson Electronics	(617)871-5162
Peabody	Time Electronics	(508)532-9900
	Hamiltion Hallmark	(508)532-3701

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Detroit	Newark	(313)967-0600
Grand Rapids	Future Electronics	(616)698-6800
Livonia	Arrow/Schweber Electronics	(313)462-2290
	Future Electronics	(313)261-5270
	Hamilton Hallmark	(313)416-5800
	Time Electronics	(614)794-3301

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City	Distributor	Phone
Eden Prairie	Arrow/Schweber Electronics	(612)941-5280
	Future Electronics	(612)944-2200
	Hamilton Hallmark	(612)881-2600
	Time Electronics	(612)943-2433
Minneapolis	Newark	(612)331-6350

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Cherry Hill	Hamilton Hallmark	(609)424-0100
Fairfield	Newark	(201)882-0300
Marlton	Arrow/Schweber Electronics	(609)596-8000
	Future Electronics	(609)596-4080
Pinebrook	Arrow/Schweber Electronics	(201)227-7880
Parsippany	Future Electronics	(201)299-0400
	Hamilton Hallmark	(201)515-1641
Wayne	Time Electronics	(201)785-8250

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Albuquerque	Alliance Electronics	(505)292-3360
	Hamilton Hallmark	(505)828-0360
	Newark	(505)828-1878

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Commack	Newark	(516)499-1216
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Hauppauge	Arrow/Schweber Electronics	(516)231-1000
	Future Electronics	(516)234-4000
Konkoma	Hamilton Hallmark	(516)737-0600
Pittsford	Newark	(716)381-4244
Rochester	Arrow/Schweber Electronics	(716)427-0300
	Future Electronics	(716)272-1120
	Hamilton Hallmark	(716)292-0730
	Richardson Electronics	(716)264-1100
	Time Electronics	(315)432-0355
Rockville Centre	Richardson Electronics	(516)872-4400
Syracuse	Future Electronics	(315)451-2371
	Time Electronics	(315)432-0355

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Charlotte	Future Electronics	(704)455-9030
	Richardson Electronics	(704)548-9042
Greensboro	Newark	(919)292-7240
Raleigh	Arrow/Schweber Electronics	(919)876-3132
	Future Electronics	(919)790-7111
	Hamilton Hallmark	(919)872-0712
	Time Electronics	(919)693-5166

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Centerville	Arrow/Schweber Electronics	(513)435-5563
Cleveland	Newark	(216)391-9330
	Time Electronics	(614)794-3301
Columbus	Newark	(614)431-0809
	Time Electronics	(614)794-3301
Dayton	Future Electronics	(513)439-5700
	Newark	(513)294-8980
	Time Electronics	(614)794-3301
Mayfield Heights	Future Electronics	(216)449-6996
Solon	Arrow/Schweber Electronics	(216)248-3990
	Hamilton Hallmark	(216)498-1100
Worthington	Hamilton Hallmark	(614)888-3313

OKLAHOMA

Tulsa	Hamilton Hallmark	(918)254-6110
	Newark	(918)252-5070

OREGON

Beaverton	Arrow/Almac Electronics Corp.	(503)629-8090
	Future Electronics	(503)645-9454
	Wyle Laboratories	(503)643-7900
	Hamilton Hallmark	(503)526-6200
Portland	Newark	(503)297-1984
	Time Electronics	(503)626-2979

PENNSYLVANIA

King of Prussia	Newark	(215)265-0933
Montgomeryville	Richardson Electronics	(215)628-0805
Philadelphia	Time Electronics	(609)596-6700
Pittsburgh	Arrow/Schweber Electronics	(412)963-6807
	Newark	(412)788-4790
	Time Electronics	(614)794-3301

TENNESSEE

Franklin	Richardson Electronics	(615)791-4900
Knoxville	Newark	(615)588-6493

TEXAS

Austin	Arrow/Schweber Electronics	(512)835-4180
	Future Electronics	(512)502-0991
	Hamilton Hallmark	(512)258-8848
	Newark	(512)338-0287
	Time Electronics	(512)346-7346
	Wyle Laboratories	(512)345-8853
Carollton	Arrow/Schweber Electronics	(214)380-6464
Dallas	Future Electronics	(214)437-2437
	Hamilton Hallmark	(214)553-4300
	Richardson Electronics	(214)239-3680
	Time Electronics	(214)644-4644
	Wyle Laboratories	(214)235-9953
Ft. Worth	Allied Electronics	(817)336-5401
Houston	Arrow/Schweber Electronics	(713)530-4700
	Future Electronics	(713)785-1155
	Hamilton Hallmark	(713)781-6100
	Newark	(713)270-4800
	Time Electronics	(713)530-0800
	Wyle Laboratories	(713)879-9953
Richardson	Newark	(214)235-1998

UTAH

Salt Lake City	Arrow/Schweber Electronics	(801)973-6913
	Future Electronics	(801)467-4448
	Hamilton Hallmark	(801)266-2022
	Newark	(801)261-5660
West Valley City	Time Electronics	(801)973-8494
	Wyle Laboratories	(801)974-9953

WASHINGTON

Bellevue	Almac Electronics Corp.	(206)643-9992
	Newark	(206)641-9800
	Richardson Electronics	(206)646-7224
Bothell	Future Electronics	(206)489-3400
Redmond	Hamilton Hallmark	(206)881-6697
	Time Electronics	(206)820-1525
	Wyle Laboratories	(206)881-1150
Spokane	Arrow/Almac Electronics Corp.	(509)924-9500

WISCONSIN

Brookfield	Arrow/Schweber Electronics	(414)792-0150
	Future Electronics	(414)879-0244
Milwaukee	Time Electronics	(708)303-3000
New Berlin	Hamilton Hallmark	(414)797-7844
Wauwatosa	Newark	(414)453-9100

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ALBERTA

Calgary	Electro Sonic Inc.	(403)255-9550
	Future Electronics	(403)250-5550
	Hamilton Hallmark	(800)663-5500
Edmonton	Future Electronics	(403)438-2858
	Hamilton Hallmark	(800)663-5500

BRITISH COLUMBIA

Vancouver	Arrow Electronics	(604)421-2333
	Electro Sonic Inc.	(604)273-2911
	Future Electronics	(604)294-1166
	Hamilton Hallmark	(604)420-4101
	Newark	(800)463-9275

MANITOBA

Winnipeg	Electro Sonic Inc.	(204)783-3105
	Future Electronics	(204)944-1446
	Hamilton Hallmark	(800)663-5500

ONTARIO

Ottawa	Arrow Electronics	(613)226-6903
	Electro Sonic Inc.	(613)728-8333
	Future Electronics	(613)820-8313
	Hamilton/Avnet Electronics	(613)226-1700
Toronto	Arrow Electronics	(416)670-7769
	Electro Sonic Inc.	(416)494-1666
	Future Electronics	(416)612-9200
	Hamilton Hallmark	(905)564-6060
	Newark	(800)463-9275
	Richardson Electronics	(800)348-5530

QUEBEC

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	Future Electronics	(514)694-7710
	Hamilton Hallmark	(514)335-1000
	Newark	(800)463-9275
	Richardson Electronics	(800)348-5530
Quebec City	Future Electronics	(418)877-6666

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CALIFORNIA, Los Angeles	(310)417-8848
CALIFORNIA, Irvine	(714)753-7360
CALIFORNIA, Roseville	(916)922-7152
CALIFORNIA, San Diego	(619)541-2163
CALIFORNIA, Sunnyvale	(408)749-0510
COLORADO, Colorado Springs	(719)599-7497
COLORADO, Denver	(303)337-3434
CONNECTICUT, Wallingford	(203)949-4100
FLORIDA, Maitland	(407)628-2636
FLORIDA, Pompano Beach/ Ft. Lauderdale	(305)351-6040
FLORIDA, Clearwater	(813)538-7750
GEORGIA, Atlanta	(404)729-7100
IDAHO, Boise	(208)323-9413
ILLINOIS, Chicago/ Hoffman Estates	(708)419-2500
INDIANA, Fort Wayne	(219)436-5818
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INDIANA, Kokomo	(317)455-5100
IOWA, Cedar Rapids	(319)378-0383
KANSAS, Kansas City/ Mission	(913)451-8555
MARYLAND, Columbia	(410)381-1570
MASSACHUSETTS, Marlborough	(508)481-8100
MASSACHUSETTS, Woburn	(617)932-9700
MICHIGAN, Detroit	(313)347-6800
MINNESOTA, Minnetonka	(612)932-1500
MISSOURI, St. Louis	(314)275-7380
NEW JERSEY, Fairfield	(201)808-2400
NEW YORK, Fairport	(716)425-4000
NEW YORK, Hauppauge	(516)361-7000
NEW YORK, Poughkeepsie/ Fishkill	(914)896-0511
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